University of Southern Queensland

Faculty of Health, Engineering & Sciences

Dynamic Conductor Ratings: Annealing Properties of Homogenous

Conductors across Varying Climatic Conditions

A dissertation submitted by

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Abstract

Static line ratings are currently utilised by electrical supply authorities to provide a safe and conservative rating for their overhead network. This in turns provides energy security to the customer and longevity for the conductor. Due to current economic environments, energy supply authorities are starting to consider the implementation of dynamic line ratings (DLRs). The dissertation's main objective is to analyse the available methodologies for modelling the heat balance equation (HBE) in order to provide Ergon Energy Corporation Limited (EECL) the means to implement dynamic ratings.

Research has proven that a DLR exploits the available weather parameters and temperature levels in order to increase or decrease the networks ampacity, hence a DLR is typically established by adjusting the convective losses. This has become an area of interest for EECL as they continue to investigate ways to reduce both their capital and operational expenditure, whilst continuing to be an explorative and innovative company.

The initial aim of scrutinising the HBE methodology is to determine which application is most suitable for EECL. This was identified as a critical task as the Australian standard AS/NZS 7000:2010 directs the reader directly to IEC/TR 61597-1995, which is dramatically different to that which is provided by ESAA D(b)5 1988, the currently methodology utilised by EECL. The results of this sensitivity test reiterated that the existing process provided by ESAA D(b)5 is in fact satisfactory as it is more superior to the IEC/TR 61597, hence eliminating EECL from remodelling there ratings process.

The completion of the sensitivity analysis returned results that highlighted specific characteristics which can be used to adjust the ampacity of the network. These components are; ambient temperature; wind speed; and wind approach angle. Such knowledge becomes beneficial as EECL has access to the Bureau of Meteorology's (BOM) historical weather data, for which a statistical analysis can provide a means of predicting the types of weather conditions expected over the duration of the dynamic period.

Associated with DLRs is the inherent risk of conductor annealing and increased conductor sag. Understanding the severity of the risks, it has been identified that the lifespan of the conductor was required to be determined. Calculating this is problematic for EECL as there are minimal records of conductor operating temperatures and high temperature exposures. To overcome this problem, a dynamic conductor ratings model was created. This model stipulates that if the current tensile strength of the conductor is unknown, it is to be sampled and tested. The results of this test will provide an expected tensile strength that can be used to back engineer the residual lifespan, hence allowing for the level of risk in a DLR to be quantified.

The impact of uprating a conductor with respects to DLRs, as identified in the dissertation, has the potential to provide great financial benefits and more flexibility to the network. It also has the potential to place the asset and community at serious risk. The results and outcomes of this dissertation have the potential to assist plant rating engineers, asset managers and network planners in their understanding and application of DLRs, such that they will be able to identify portions of the network which as safe to uprate and portions which may require de-rating. It is also expected that by highlighting the risks involved, it will encourage EECL to begin monitoring the lifespan of the network, hence allowing them to gain a better knowledge of the life expectancy of a network and its available ampacity.

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Glossary

AAAC:	All Aluminium Alloy. This specifies the metallurgical makeup of the overhead conductor.
AAC:	Aluminium Alloy. This specifies the metallurgical makeup of the overhead conductor.
A.E.R:	Australian Energy Regulator. They provide the determination of electrical supply authorities' expenditure.
Annealing:	The effect caused by the overheating of the conductor where the crystallisation of the metal occurs.
AS 7000	Australian Standard 7000:2010 – Overhead line design – Detailed procedures.
Azimuth:	The angle between the north vector and the perpendicular projection of the star down onto the horizon.
BOM:	Bureau of Meteorology.
CAPEX:	Capital expenditure. The expense associated with network upgrades and augmentations.
CBL:	Conductor breaking limit. This specifies the tension at which the conductor is expected to fail.
CCC:	Current carrying capacity. This is the amount of load a conductor can withstand without failure.

Cigré TB601:	Engineering research organisation. Technical Brochure 601: Guide for Thermal Rating Calculations of Overhead Lines.
CSA:	Current state assessment. This is a report which EECL produces. It is used to gather data such as load levels and further load growth.
De-rate:	The process of reducing the CCC of an overhead conductor network.
Distribution:	A form of overhead network. This network is subjected to a source and provides power to the various end users.
DLR:	Dynamic line rating. This is the process of changing the line rating based upon changing conditions.
EECL:	Ergon Energy Corporation limited. The electrical supply authority for regional Queensland.
ESAA D(b)5:	Electrical Supply Authority Association. Guideline D(b)5 -1988 Current Ratings of bare Overhead Line Conductors.
HBE:	Heat balance equation. This the formula used to calculate the CCC of a conductor.
HDBC:	Hard Drawn Bare Copper. This specifies the metallurgical makeup of the overhead conductor.
IEC 61597:	International Eletrotechnology Commission. Standard 61597 – Overhead electrical conductors – calculation methods for stranded bare conductors.
LIDAR:	Is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.
MATLAB:	Matrix Laboratories 2012b. The engineering mathematics program used for computational work.
OPEX:	Operational expenditure. The expense associated with maintaining the network.

ROAMES:	The technology used to map and measure EECL entire overhead network.
SCADA:	Supervisory Control And Data Acquisition. Is a system that operates with coded signals over communication channels so as to provide control of remote equipment
SQL:	Structured Query Language. Is a special-purpose programming language designed for managing data held in a relational database management system.
Static rating:	This is the process of producing a line rating based upon static conditions.
Sub-transmission:	This is the network which is subjected to a source and provides that source to a single other source.
Uprate:	The process of increasing the CCC of the network based upon dynamic conditions.

Nomenclature

Symbol	Description	Units	
AS/NZS 7000:2010 – Loss of Tensile strength			
Α'	Experimentally derived constants for the conductor	dimensionless	
B'	Experimentally derived constants for the conductor	dimensionless	
<i>C'</i>	Experimentally derived constants for the conductor	dimensionless	
D'	Experimentally derived constants for the conductor	dimensionless	
D_O	Diameter of wire prior to drawing	Mm	
D_w	Diameter of drawn wire	Mm	
R	Reduction in cross sectional area during wire drawing	%	
T *	Wire absolute temperature	K	
t	Time duration at temperature	Н	
W	Loss of strength in the partially annealed state	%	
Wa	Loss of strength in the fully annealed state	%	
AS/NZS 7000:2010 – Loss of Tensile strength			
D	Minimum clearance distance	m	
q	Constant which varies from 0.005 to 0.01(normal)	dimensionless	
U	Constant	dimensionless	
V_a	Upper circuit nominal voltage phase to earth value	kV	
V_b	Lower circuit nominal voltage phase to earth value	kV	
θ	Phase angle difference between circuits	deg (°)	
IEC TR 61597:1995 – Heat Balance Equation			
D	Conductor diameter	m	
Ι	Conductor Current	A	
I _{max}	Current Carrying Capacity	А	
K _e	Emissivity coefficient in respect to black body	dimensionless	
Nu	Nusselt number	dimensionless	
P_{conv}	Convection heat loss on the conductor	W	
P_i	Joule heat gain on the conductor	W	
P_{rad}	Radiation heat loss on the conductor	W	
P_{sol}	Solar heat gain by the conductor surface	W	
Re	Reynolds number	dimensionless	

Symbol	Description	Units
R_T	Electrical resistance of the conductor at a temperature T	Ω/m
S	Stefan-Boltzmann constant (5.67×10^{-8})	dimensionless
S _i	Intensity of solar radiation	W/m^2
T_1	Ambient temperature	К
<i>T</i> ₂	Final equilibrium temperature	К
ν	Wind speed	m/s
λ	Thermal conductivity of the air film in contact with the conductor, assumed constant and equal to: 0.02585	W.m ⁻¹ .K ⁻¹
ν	Solar radiation absorption coefficient	dimensionless
ESAA D(b)5 1988 – Heat Balance Equation		
а	Solar absorption coefficient	
Α	Constant dependant on the value of Gr and $(Gr \cdot Pr)$	dimensionless
В	Constant dependant on Reynolds Number	dimensionless
С	Constant dependant on angle	dimensionless
D	Conductor diameter	m
е	Emissivity of conductor	dimensionless
F	Albedo ground reflectance	dimensionless
g	Acceleration of gravity; 9.81	$m \cdot s^{-2}$
Gr	Grashof Number	dimensionless
Ι	Current carrying capacity	А
Idiff	Diffuse solar radiation intensity	$W \cdot m^{-2}$
Idir	Direct solar radiation intensity	$W \cdot m^{-2}$
k	Factor allowing for effective increase in D.C. resistance due to skin effect, hysteresis and eddy current losses	dimensionless
n	Constant dependant on Reynolds Number	dimensionless
Nu	Nusselt number	dimensionless
m	Constant dependant on the value of Gr and $(Gr \cdot Pr)$	dimensionless
Р	Constant dependant on angle	dimensionless
Pr	Prandtl Number	dimensionless
PF	Power loss by forced convection	W
PN	Power loss by natural Convection	W
PR	Power loss by radiation	W
PS	Power gain by solar heat input	W
R_{dc}	Conductor D.C. resistance at 20°C	Ω
R_{e}	Reynolds number	dimensionless
t_a	Ambient temperature	°C
t_c	Conductor maximum operating temperature	°C
t _d	Sky temperature	°C
t_a	Ground temperature	°C
v	Wind speed	m/s
V _f	Viscosity of the Air Film	m^2/s
α	Temperature coefficient of resistance at 20°C	dimensionless
λf	Thermal conductivity of the Air Film	$W/m^2 K^4$
1/2	Angle of attack of the wind relative to conductor axis	deg (°)
$\frac{\psi}{\sigma}$	Stefan-Boltzmann constant: 5.67×10^{-8}	dimensionless
U U		

Symbol	Description	Units		
Cigré TB601 – Heat Balance Equation				
A_1	Constant based upon wind approach angle	dimensionless		
A ₂	Constant dependant on the value of Gr and $(Gr \cdot Pr)$	dimensionless		
В	Constant dependant on Reynolds Number	dimensionless		
D	External diameter of conductor	m		
d	Outer layer wire diameter	m		
F	Albedo ground reflectance	dimensionless		
g	Acceleration of gravity; 9.81	$m \cdot s^{-2}$		
Gr	Grashof Number	dimensionless		
H_s	Solar altitude	dimensionless		
Ι	Load current	А		
I_B	Direct solar radiation intensity	W/m^2		
I _d	Diffuse solar radiation intensity	LW/m^2		
I_T	Global solar radiation	W/m^2		
k_{sk}	Increase in resistance due to skin effect	dimensionless		
m_1	Constant based upon wind approach angle	dimensionless		
m_2	Constant dependant on the value of Gr and $(Gr \cdot Pr)$	dimensionless		
n	Constant dependant on Reynolds Number	dimensionless		
N	Day of the year $(1^{st} \text{ January } = 1)$	dimensionless		
Nu	Nusselt number	dimensionless		
N _S	The clearness ratio	dimensionless		
<i>P_c</i>	Convective cooling	W		
P_i	Corona heating	W		
P_J	Joule heating	W		
P_M	Magnetic heating	W		
P_r	Radiative cooling	W		
P_s	Solar heating	W		
P_w	Evaporative cooling	W		
Pr	Prandtl Number	dimensionless		
P_T	Total heat per unit length	W		
R_{dc}	DC resistance	Ω		
R _e	Reynolds number	dimensionless		
R_S	Conductor roughness	dimensionless		
T_a	Temperature of air film	°C		
T_{av}	Mean temperature	°C		
T_{C}	Conductor core temperature	°C		
T_S	Conductor surface temperature	°C		
V	Wind speed	m/s		
v_f	Kinematic viscosity of the air	m^2/s		
y	The height above sea level	m		
Z	Hour angle of the sun= $15(12$ -Time) in degrees	dimensionless		
α	Temperature coefficient	dimensionless		
α_s	Absorptivity of conductor surface:	dimensionless		
Е	Emissivity of the conductor surface	dimensionless		
λ	Effective radial thermal conductivity	$W/K.m^2$		

Symbol	Description	Units
λ_f	Thermal conductivity of the air	$W/K.m^2$
φ	Latitude	deg (°)
δ_s	declination	deg (°)
η	Angle of the solar beam to the axis of the conductor	deg (°)
γ	Density of air at a given film temperature	kg/m^3
γ_c	Azimuth of the conductor	deg (°)
γs	Azimuth of the sun where	deg (°)
μ_f	Dynamic viscosity of the conductor	$Kg \cdot m^{-1} \cdot s^1$
σ_B	Stefan-Boltzmann constant: 5.67×10^{-8}	dimensionless

Chapter 1

Introduction

1.1 Chapter Overview

The purpose of this chapter is to provide a clear statement of the task and problems of this dissertation; the specific objectives of the research; how the research will benefit the power industry; and furthermore the necessary background information for dynamic ratings of overhead conductors and the electricity network.

1.2 Background

1.2.1 Overhead Conductors

The transmission network is an essential asset of a power utility as it provides a pathway for electricity to be sent from one zone substation to another. The conductors are a metal/alloy compound that allows electricity to flow along it. There are multiple

types of conductors. This dissertation is focused on homogenous conductors (single metal makeup), these conductors are; Hard Drawn Bare Copper (HDBC), All Aluminium Alloy Conductors (AAAC) and Aluminium Alloy Conductors (AAC). Such conductors are available in different sizes. An example of this is the HDBC conductor 19/0.83. This conductor is made up of 19 strands of 0.83inch² (imperial measurement). This can be seen in Figure 1 below. As the transmission line requires a large amount of initial capital (CAPEX). It is important to make sure that the selection criteria is correct for as the transmission design is based upon the type and size of conductor, i.e. pole spacing, type of line equipment, etc.



Figure 1: Hard drawn bare copper (HDBC) conductor 19/0.083 (graphical representation)

1.2.2 Design Parameters

As mention above the correct selection of conductor in vital when constructing a transmission/sub transmission power line. It is at this stage of a project, the type and size of the conductor is selected based upon the required load profile, available CAPEX budget and the location. In addition to this, possible contingency load are taken into consideration. Generally, the load profile is most important, this is due to the conductor annealing if it is under rated. According to the AS/NZS 7000:2010 clause 4.2.5 states that the conductor cumulative annealing damage shall not exceed 15% of the conductor breaking limit (CBL) for it design life. It also states that for copper, aluminium and steel, this annealing temperature will be at 70°, 80° and 200°C respectively. With this knowledge, it is expected that the static steady state heat balance equation is used to determine the available ampacity of a conductor. This dissertation will investigate ways to extract more out of the current transmission/sub transmission network with dynamic

applications of the various steady state heat balance equations supplied by IEC /TR 61597 Overhead Electrical conductors – calculation methods for stranded bare conductors (currently utilised for AS/NZS 7000:2010 Overhead line design – detailed procedures), Cigré Technical Brochure 601 Guide for Thermal Rating Calculations of Overhead Lines and the ESAA D(b)5 Current Rating of Bare Overhead Line Conductors.

1.3 The Need for the Project

Electrical utilities of today are required to uphold and maintain the current network with a cost effective approach. As the Australian Electrical Regulator (AER) is looking to reduce capital budgets to power utilities in response to the consumer demands to reduce the cost of electricity, plant rating engineers and asset management teams are looking to introduce dynamic ampacity ratings on their transmission/sub transmission networks.

There are significant risks with the implementation of dynamic ratings. If the conductor becomes underrated, the risk of annealing becomes imminent, creating both an unreliable and unsafe network. Whist there are physical dangers with such implementations (loss of life), there are also economic ramifications as unplanned outages on transmission lines is generally associated with extremely high customer minute losses. Hence it is both detrimental to both the customers and the utility if the conductor is significantly damaged due to dynamic conditions.

It is prudent that rating engineers have a clear understanding with the impacts of dynamic ratings. Associated with this is the fact that there are multiple ways to determine dynamic ratings. This dissertation has acknowledged that there is a knowledge gap between the suitability of the current Australian standard (AS/NZS 7000:2010) for the heat balance equation, as it has adopted the European Standard (IEC/TR 61597-1995) as opposed to the previous guideline issued by the Electrical Supply Association of Australia (D(b)5 1988). It is the expectation that there results of this dissertation will provide clarity for rating engineers to proceed with dynamic conditions and extract more ampacity out of their network which will reduce their capital expenditure and the unit cost to the consumer.

1.4 Project Objectives

The main objective of the research in this dissertation is to clarify the best dynamic rating model suitable for Ergon Energy Corporation. This project has been made available from the Senior Advanced Analysis Ratings Engineer, Gregory Caldwell, with the expectation that the findings will enable him to implement such ratings with high degree of confidence.

The specific objectives of this dissertation are as follows (the project objectives are also stated in *Project Specifications*, Appendix A):

- 1. Identify, analyse and compare the previous guidelines and current standards for calculating the steady-state conductor ratings.
- Understand how such calculations are used to define the available ampacity of an overhead conductor by analysing the significance of each component in the different heat balance equations.
- 3. Understand how the seasonal weather conditions can affect the ampacity of transmission/sub transmission lines.
- 4. Critically analyse and validate the findings of (1., 2., and 3.) by determine a suitable approach for modelling dynamic conductor ratings.
- 5. Validate the findings of (4.) using real time data gathered from two current case studies within Ergon Energy.
- 6. Create a model to determine the rating of a sub transmission line based upon dynamic conditions.
- Using real data and dynamic conditions use the DLR rating calculator to model (6.)

8. From (7.), analyse the effects on conductor lifespan due to the implementation of dynamic conditions. Identify the industry benefits to Ergon Energy due to uprating/derating an overhead conductors and identify ways in which the gathered real time data can further help to gain better knowledge of dynamic systems.

1.5 Limitations and Restrictions

The following limitations and restrictions apply for the project and dissertation:

- The research and computations are limited to the following types and uses of overhead conductors:
 - Homogenous (single metal makeup)
 - o Transmission/Sub Transmission network
- When referring to equipment from Ergon Energy's network, transmission feeder identification number/name will not be used. Instead the network used in the case studies will be referred to by feeder 'x' and feeder 'y'. The case study in chapter 8 will utilise its feeder details, as this is not sensitive material as this is only a feasibility study, subjected to engineering inspection from an asset ratings engineer.
- When calculating the current carrying capacity of a conductor the computations do not take into consideration that the miscellaneous line equipment, i.e. splices, dead ends and connectors. It is the expectation that such line equipment will actually affect the outcome though it is outside the scope of the dissertation to determine such impacts.

1.6 Overview of the Dissertation

For the purpose of outlining the contents of the dissertation, the following descriptions are for the chapters.

- Chapter 2 Literature Review: The aim is to present all relevant literature for the purpose of establishing DLRs without jeopardising the integrity of the existing network. This chapter provides the essential grounding measures for which the dissertation will be based around.
- Chapter 3 Methodology: This chapter is to identify the process taken to achieve the objectives for this dissertation. It will form the base approach for the outcomes of the literature review, sensitivity analysis, selecting which version of heat balance equation is best and the results of the Dynamic Line Rating Calculator.
- Chapter 4 Weather Parameters for Overhead Conductor Ratings: An understanding of the weather conditions for rural Queensland (QLD) will be paramount for this dissertation. This chapter will provide weighting to the selection of variants for the heat balance equation sensitivity analysis.
- Chapter 5 Sensitivity Analysis Selection of Heat Balance Equation: The literature review revealed that there are multiple ways to utilise the heat balance equation. The aim of this chapter will be to identity through rigorous variations of input parameters, which standard or guideline is best suited for Queensland conditions.

Chapter 6 – Analysis of Real Time Data & Damage Properties: This section contains two case studies which have been provided by EECL. It is the expectation that the modelling of real time data will provide confidence for EECL to consider implementing DLRs. This chapter also contains a damage study which analyses how to define the available life left in a conductor and how to calculate the annealing impacts due to DLRs.

- Chapter 7 Model Dynamic Conductor Ratings: The purpose of the DLR model will be to provide the ability to justify the implementation of DLRs. This is a key objective of the dissertation. Here this chapter will define how the DLR can be calculated and monitored.
- Chapter 8 Industry Application and Justification: Based on available data, the DLR model is to be tested to quantify the industry benefits of a DLR system to energy distribution companies without sacrificing the integrity of the network.
- Chapter 9 Conclusion: To collate the findings of the project and an assessment to the degree of the completion of the dissertations objectives. Additionally also provide avenues for further research into the topic area.

1.7 Chapter Summary

This chapter presents an introduction, background and purpose for the dissertation. Initially identified were the different types of conductors, what types are going to be analysed and the design parameters surrounding the selection on conductor size. It is important to understand exactly how currently, overhead conductors are sized for transmission and sub transmission lines. The key point here is that the current Australian standard utilises the heat balance equation from the European standards to determine such measures. This dissertation looks to investigate whether or not this is the best practice. In addition to this this chapter also highlights that there is an underutilisation of the transmission/sub transmission network based upon the conservative static approach. This hereby clearly distinguishes the fact that there is a need for this project. By the use of dynamic conductor ratings it is expected that the ampacity of the transmission network can be increased. Following this the introductory chapter further explains the objectives and limitations for which for the project and is concluded by an overview of each chapter topic and the end of chapter summary.

Chapter 2

Literature Review

2.1 Chapter Overview

As stated in Chapter 1. The main aim of this dissertation is to develop a dynamic rating model suitable for Ergon Energy Corporation Limited (EECL) by quantifying how much extra ampacity can be utilised without exceeding the mechanical limits of the conductor. This chapter present the appropriate literature for dynamic ratings and mechanical limits.

2.2 Overhead Conductor Ratings

Annealing properties of conductors has been examined by numerous professionals over a lot of years. It is the understanding that the process of annealing is due to overheating the conductor to a point where the tensile strength is reduced so far that the properties separate causing a failure. A review of the current and past industry standards and guidelines identified that conductors ratings can be either static or dynamic. This subsection is to explain the difference between the two.

2.2.1 Static Ratings

The static ratings of an overhead conductor prescribes the maximum load (A) it is able to carry within a defined set of parameters. Static ratings of overhead conductors are generally calculated in a conservative manner. This is done so that the ratings are considered to be safe hence providing longevity of the equipment whilst reducing the chance of failure. Many factors must be considered in establishing safe ratings. Most important is the low-temperature annealing and the loss of strength (Olmsted, 1943).

According to Olmstead, there are 8 factors which create an allowable rating of an overhead conductor. These ratings are;

- 1. The ability of the conductor to withstand the resulting temperature without excessive loss of mechanical strength by annealing.
- The ability of clamps, connectors, and joints on the conductor to withstand the resulting temperature without oxidation of the contact surfaces and local heating in excess of the allowable conductor temperature.
- 3. The adequacy of span clearances to permit the additional sag caused by the conductor temperature associated with the proposed rating.
- 4. The problem of providing short-circuits and overloads protection to operate within the margin between the current rating and destructive overloads.

- 5. The adequacy of substation and terminal equipment to carry the currents for which the transmission conductors may be rated.
- 6. Operating problems of the bulk power system with individual circuit rated to high values.
- 7. The ability of voltage-regulating equipment to compensate for the voltage variation which accompany heavily loaded lines.
- 8. The considerable energy losses resulting from heavy line currents

It is also Olmstead's view that no engineer can't afford to ignore any one parameter until they are satisfied that it does not limit the particular line which they wish to rate. It is for such reasons that engineers refer to the static ratings.

2.2.2 Dynamic Ratings

Dynamic ratings of overhead power lines are associated with real-time data of overhead line temperatures and current loading. There are multiple ways in which dynamic ratings can be approached and safe ratings be maintained. Hydro Tasmania Consulting (2009) provides two types of model for this. They are, whether and sag based. Also suggested in Jupe, Bartlett & Jackson (2011) are current and tension based modelling. These will be discussed in the section 2.5 Dynamic Modelling.

WEATHER BASED

This model suggest that real-time data can be used to retrieve the ambient temperature and line currents of a transmission line, hence by use of the heat balance equation, allow for the available ampacity to be determined in regards to available temperature gain available. The field data required are:

- Wind speed measured by an anemometer
- Wind direction
- Air Temperature
- Solar heat intensity; and
- Conductor parameters

SAG BASED

This model relies on the direct relationship between the conductor temperature and the conductor sag. By using a predetermined relationship between the conductor position, tension and temperature, the heat balance equation, again, can be used to provide the available ampacity and additionally act as safety alert as to limiting the chance of the conductor sagging below statutory height. The field data required are:

- Conductor position and or tension
- Air temperature
- Wind Speed measured by an anemometer
- Wind direction
- Solar heat intensity
- Line current and
- Conductor parameters

2.3 The Heat Balance Equation

Over time, there have been multiple methods of calculating the ampacity of an overhead transmission lines, all are represented by as a form of the heat balance equation (HBE). This equation is the steady-state model for the thermal rating of an overhead conductor and can be defined as the situation where the heat supplied to the conductor is balanced by the heat dissipated (Cigre, 2014). See the heat balance equation below.

$$P_{I} + P_{M} + P_{S} + P_{i} = P_{c} + P_{r} + P_{w}$$
(2.1)¹

where P_I is the power loss due to joule heating [W];

 P_M is the power loss due to magnetic heating [W];

 P_i is the power loss created by corona heating[W];

 P_s is the power loss created by solar heating[W];

P_c is the power increase from convective cooling[W];

 P_r is the power increase due to radiative cooling[W];

 P_w is the power increase created by evaporative cooling[W];

Figure 2 shows how the heat balance equation simulates the power rating of conductor.



Figure 2: Heat Balance Equation

CURRENT HEATING

Current heating is the heating of the conductor due to the effects of load current and includes the Joule, magnetic and skin effects (Cigre, 2014). Joule heating is due to the resistance of the conductor. Magnetic heating is due to the cyclic magnetic flux which is caused by eddy currents, hysteresis and magnetic viscosity. Skin effects related to the increase in conductor resistance as a function of the frequency of alternating current.

¹ Cigre, 2014. TB 601: Guide for thermal rating calculations of overhead lines. Available from: Cigre.
SOLAR HEATING

There are many factors that contribute to the solar heating component, they are diameter of the conductor; inclination to the horizontal, absorptivity, surface of the conductor, the intensities; direct solar radiation; the diffuse sky radiation to a horizontal surface; solar altitude; angle of the solar beam with respect to the axis of the conductor; and the albedo (reflectance) of the surface of the ground beneath the conductor (Cigre, 2014).

CORONA HEATING

Corona heating is only considered significant with high surface voltage gradients in the presence of precipitation and high wind where convective and evaporative cooling is high (Cigre, 2014). It is for this reason, Cigré does not provide information on formulae to calculate this.

CONVECTIVE COOLING

Due to the conductor being under load, the temperature of the conductor will increase and heats the air adjacent to it. As the density of this air decreases, it will cause a rise in the case of natural convection (Cigre, 2014). In addition to this it also takes into consideration of forced convection which is cooling due to wind conditions.

RADIATIVE COOLING

This cooling component is in relation to the radiation losses of the conductor. These are generally quite small.

EVAPORATIVE COOLING

This type of cooling is significant in the presence of a wetted conductor. This is the cooling of the conductor due to the evaporation. This is generally ignored (Cigre, 2014).

In Australia, the concept of this equation has been used since 1965 when the Electricity Supply Association of Australia (ESAA) stipulated it in their guideline, D(b)5, "Current Rating of Bare Overhead Line Conductors". The last published version of this guideline was in 1988. This is the version which will be analysed for this dissertation.

2.3.1 CIGRE Technical Brochure 601: Guide for Thermal Rating Calculations of Overhead Conductors, 2014

In 1992, Cigré released Electra 144, "Mathematical Model for Evaluation of Conductor Temperature in the Steady (or Quasi-Steady) State (Normal Operation)", equation 2.1 above. Since then Cigré released their latest version, Guide for Thermal Rating Calculations of Overhead Lines in 2014. It is also to be noted that the Cigré document breaks down each component of the equation. The equations that follow are as per the technical brochure 601. These equations are specified for both homogenous and non-homogenous conductors where heat gain is equal to heat gain as per equation 2.1:

heat gain = heat loss $P_I + P_M + P_S + P_i = P_c + P_r + P_w$ (2.1)²

P_J	Joule heating
P_M	Magnetic heating
P _i	Corona heating
P_s	Solar heating
P _c	Convective cooling
P_r	Radiative cooling
P_w	Evaporative cooling

² Cigre, 2014. TB 601: Guide for thermal rating calculations of overhead lines. Available from: Cigre.

JOULE HEATING (NON-FERROUS CONDUCTORS)

$$P_{I} = k_{sk} I^{2} R_{dc} [1 + \alpha (T_{av} - 20)] \quad (W)$$
(2.2)

Where

- k_{sk} Usually less than 1.02 (section 3.14 pg 14): Factor k_{sk} allows for the increase in resistance due to skin effect. The value provided is predetermined for non-ferrous conductors.
- *I* Load current (A): This component is the effective current on the conductor.
- R_{dc} Dc resistance (Ω): The dc resistance for the conductor is to be measured at 20°C per unit length. The brochure directs the user to use Annex A (pg 47-48) to gather the parameters of the conductor metal type and to solve for R_{dc} or to obtain manufacture data.
- α Temperature coefficient: this is the resistance per degree Kelvin. The per unit base for this value is 20°C (K^{-1})
- T_{av} Mean temperature (°C): the mean temperature of the conductor can be calculated by eq. 4.3 as prescribed by the Cigré brochure (section 3.4 pg 22).

$$T_C - T_s = \frac{P_T}{4\pi\lambda}$$

(2.3)

Where

 P_T

Total heat per unit length (W)

$$\lambda$$
Effective radial thermal conductivity (W/mK) T_c Conductor core temperature (°C) T_s Conductor surface temperature (°C)

Hence it is assumed that

$$T_{av} = T_S \tag{2.4}$$

MAGNETIC HEATING (NON-FERROUS CONDUCTORS)

This form of heating is generally found in steel core conductors, for non-ferrous conditions (section 3.2 pg 16) (Cigre, 2014). This is outside the scope of the dissertation and can be ignored.

SOLAR HEATING

$$P_s = \alpha_s I_T D \qquad (W) \tag{2.5}$$

- α_s Absorptivity of conductor surface: The value for this can range from 0.23 for bright stranded aluminium conductor to 0.95 for weathered conductor in industrial environments. The recommended value here is 0.5.
 - D External diameter of conductor (m): This is the external diameter of the conductor. This can be found from data spreadsheets from conductor catalogues.
 - I_T Global solar radiation (W/m2): Cigré recommend that a global solar radiation meter be used to calculate this as they are

generally reliable and relatively affordable. If a meter is not going to be used the following equation can be used to calculated the solar radiation as prescribed by Cigré (section 3.3 pg 18).

$$I_T = I_B \left(\sin(\eta) + \frac{\pi}{2} F \sin(H_s) \right) + I_d \left(1 + \frac{\pi}{2} F \right)$$
(2.6)

Where

 I_B Direct solar radiation intensity (W/m²). This can be found using the following formula (4.7) as sea level.

$$I_{B(0)} = N_S \frac{1280 \sin(H_S)}{\sin(H_S) + 0.314}$$
(2.7)

Where

 H_s

N_S The clearness ratio, value 1.0 for standard atmosphere and 0.81.2 for clear skies with decreasing amounts of dust and aerosols.
0.5 is for an industrial atmosphere and less than 0.5 or cloudy or overcast day

If the height of the network is above sea level then the following formula is used to find the direct solar radiation.

$$I_{B(y)} = I_{B(0)} \left[1 + 1.4 \times 10^{-4} y \left(\frac{1367}{I_{B(0)}} - 1 \right) \right]$$
(2.8)

The solar altitude can be calculated using the equation 2.8.

$$H_S = \sin^{-1}(\sin\varphi\sin\delta_s + \cos\varphi\cos\delta_s\cos Z)$$

Where

Latitude φ δ_s Is the declination $\delta_s = 23.3 \sin\left[\frac{2\pi(284+N)}{365}\right]$ (2.9) Day of the year $(1^{st}$ January =1). Note that this is based on the Ν European system and hence in Australia $(1^{st} July = 1)$ Ζ Hour angle of the sun= 15(12-Time) in degrees. Time is given from 0 to 24. I_d The diffuse solar radiation intensity (W/m^2) $I_d = (430.5 - 0.3288I_B)\sin(H_s)$ (2.10)Angle of the solar beam with respect to the axis of the conductor. η

$$\eta = \cos^{-1}[\cos(H_S)\cos(\gamma_S - \gamma_c)] \tag{2.11}$$

- γ_c Azimuth of the conductor
- γ_S Azimuth of the sun where

$$\gamma_S = \sin^{-1} \left[\frac{\cos(\delta_S) \sin(Z)}{\cos(H_S)} \right]$$
(2.12)

F

Albedo groun	d reflectance – reflected solar radiation
0.2	General value
0.05	Water
0.1	Forest
0.15	Urban
0.3	Sand
0.4-0.6	Ice
0.6-0.8	Snow

CORONA HEATING

Cigré fail to provide equations to calculate this as it is expected that steady-state calculations will be based upon average or high ambient conditions where corona will not be present.

CONVECTIVE COOLING

There are two types of cooling, natural and forced. Cigré produce equations for both forms and also establishes that at low wind speed (v < 0.5m/s) that the natural convection method can be used. This will be required in further chapters as the dissertation looks to establish worst case scenarios.

Cigré has also conducted a dimensional analysis and they have found that certain, nondimensional groupers of parameters are useful in calculating convective heat transfer. They are; Nusselt number (Nu); Reynolds number (Re); Grashof number (Gr) and Prandtl number (Pr). For the purpose of the dissertation, the complex calculations used to determine these values will not be used, rather the recommended tables provided by Cigré will be utilised. Therefore the convective heat loss is given by:

$$P_c = \pi \lambda_f (T_s - T_a) N u \tag{W}$$
(2.13)

$$T_S$$
 Temperature of conductor surface (°C)

- T_a Temperature of air film (°C)
- λ_f Thermal conductivity of the air (W/K.m²). Which can be calculated by;

$$\lambda_f = 2.368 \times 10^{-2} + 7.23 \times T_f - 2.763 \times 10^{-8} T_f^2$$
(2.14)

Where

$$T_f = 0.5(T_S + T_a) \tag{2.15}$$

Forced convective cooling

$$Nu_{90} = B(Re)^n (2.16)$$

Where

R_e Reynolds number

$$R_e = V \frac{D}{v_f}$$
(2.17)

Where

VWind speed (m/s)DConductor Diameter (m)

$$v_f$$
 Kinematic viscosity of the air (m²/s) and can be expressed as

$$v_f = \frac{\mu_f}{\gamma} \tag{2.18}$$

Where

 μ_f Dynamic viscosity of the conductor and can have a valid expression up to a $T_f = 300^{\circ}C$

$$\mu_f = \left(17.239 + 4.635 \times 10^{-2} \times T_f - 2.03 \times 10^{-5} \times T_f^2\right) \times 10^{-6}$$
(2.19)

 γ Density of air at a given film temperature (kg/m³)

$$\gamma = \frac{1.293 - 1.525 \times 10^{-4} \times y + 6.379 \times 10^{-9} \times y^2}{+0.00367 \times T_f}$$

y The height above sea level (m)

- BConstant dependent upon the Reynolds number and conductorsurface roughness R_s found in table 1 below
- n Constant dependent upon the Reynolds number and conductor surface roughness R_s found in table 1 below

$$R_{S} = d/[2(D-d)]$$
(2.21)

Where

- *d* Outer layer wire diameter (m)
- D Conductor diameter (m)

Hence from table 1 below the Reynolds number and the constants can be found.

(2.20)

Surface	R	le	В	n	
	from	То			
Stranded all surfaces	10 ²	$2.65 \cdot 10^3$	0.641	0.471	
Stranded $R_S \leq 0.05$	$2.65 \cdot 10^3$	$5 \cdot 10^4$	0.178	0.633	
Stranded $R_S > 0.05$	$2.65 \cdot 10^3$	$5 \cdot 10^4$	0.048	0.800	

Table 1: Constants for calculation of forced convective heat transfer from conductors with steady crossflow of air^3

For transmission lines, it is important to take into consideration the approach angle of the forced convection. The following formula has been determined by Cigré and is listed below:

$$Nu_{\delta} = Nu_{90}[A_1 + B_2(\sin\delta)^{m_1}]$$
(2.22)

Where

$$A_1 = 0.42, B_2 = 0.68$$
 and $m_1 = 1.08$ for $0^\circ < \delta < 24^\circ$

 $A_1=0.42, B_2=0.58$ and $m_1=0.90$ for $24^\circ < \delta < 90^\circ$

Natural convective cooling

$$Nu = A(Gr \cdot Pr)^m \tag{2.23}$$

Where

Gr Grashof number

$$Gr = \frac{D^{3}(T_{s} - T_{a}) \cdot g}{(T_{f} + 273) \cdot v_{f}^{2}}$$
(2.24)

³ Cigre, 2014. TB 601: Guide for thermal rating calculations of overhead lines. Available from: Cigre.

gAcceleration of gravity;
$$9.81m \cdot s^{-2}$$
PrPrandtl number $Pr = 0.715 - 2.5 \cdot 10^{-4} \cdot T_f$ (2.25) A_2 Constant for various ranges of the Rayleigh number $Gr \cdot Pr$ m_2 Constant for various ranges of the Rayleigh number $Gr \cdot Pr$

Hence from the table below, these constants can be found.

Table 2: Constants for calculation of natural convection heat transfer from conductors in air⁴

G _r	$.P_r$	A	m		
from	То				
10 ²	10^{4}	0.850	0.188		
10 ⁴	10 ⁶	0.480	0.250		

RADIATIVE COOLING

Radiative losses are usually a small fraction of the total heat loss, especially in the presence of forced convection, with this understand the formula for radiative cooling is:

$$P_r = \pi D \varepsilon \sigma_B [(T_s + 273)^4 - (T_a + 273)^4] \quad (W)$$
(2.26)

Where

D Conductor diameter (m)

⁴ Cigre, 2014. TB 601: Guide for thermal rating calculations of overhead lines. Available from: Cigre.

ε	Emissivity of the conductor surface. This generally varies from
	0.2-0.3 for new conductors and up to 0.8 to 0.9 for industrial
	weathered conductors

$$\sigma_B$$
 Stefan-Boltzmann constant, 5.6697 × 10⁻⁸ (W.m⁻².K⁻⁴)

```
T<sub>a</sub> Ambient temperature (K)
```

 T_s Surface temperature (K)

EVAPORATIVE COOLING

This element has been ignored as it is not required to calculate the maximum rating of a conductor.

2.3.2 International Electrotechnical Commission IEC TR 61597:1995 Overhead electrical conductors – calculation methods for stranded bare conductors

The International Electrotechnical Commission (IEC) is the standard organisation generally associated with the United Kingdom and Europe. They are a non-profit, non-government standards organisation. In 1995, they released IEC TR 61597. This standard provides information inclusive of ; property of conductors and useful methods of calculation. Section 3 of this standard is dedicated to calculating the current carrying capacity (CCC) of overhead conductors. Here, in section 3.2 (pg 15), it specifies the heat balance equation in a form similar to that which is specified in the Cigré technical brochure 601. The key noticeable omissions are; magnetic heating; corona heating and evaporative cooling, all of which Cigré, 2014, recommends is not necessary. Therefore the equation takes the form below:

heat gain =	heat loss	
$P_j + P_{sol} = P_j$	$P_{rad} + P_{conv}$	(2.27)5
Where		
P_j	is the heat generated by the Joule effect	
P _{sol}	is the solar heat gain by the conductor surface	
P _{conv}	Is the convection heat loss	

The IEC standard, also specifies some different formula, more simplified methods, to calculate the components. These are now explained.

Is the heat loss by radiation on the conductor

JOULE EFFECT

 P_{rad}

Power losses due to the heat increase known as Joule Effect.

$$P_j = R_T I^2 \qquad (W) \tag{2.28}$$

Where

Electrical resistance of the conductor at a temperature $T(\Omega/m)$ R_T

Conductor Current (A) Ι

SOLAR HEAT GAIN

$$P_{sol} = \gamma D S_i \tag{2.29}$$

⁵International Electrotechnical Commission, 1995. *IEC TR 61597: 1995: Overhead electrical conductors*

⁻ Calculation methods for stranded bare conductors. Available from: IEC.

γ	Solar radiation absorption coefficient
D	Conductor diameter (m)
S _i	Intensity of solar radiation (W/m ²)

RADIATED HEAT LOSS

$$P_{rad} = s\pi D K_3 (T_2^4 - T_1^4) \tag{2.30}$$

Where

S	Stefan-	Boltzmann constant (5.67×10^{-8})					
D	Condu	ctor diameter (m)					
K _e	Emissivity coefficient in respect to black body						
Т	Tempe	rature (K)					
	T_1	ambient temperature (K)					
	T_2	final equilibrium temperature (K)					

CONVECTION HEAT LOSS

Only the forced convection heat loss is taken into account. IEC have ignored the natural convection equations.

$$P_{conv} = \lambda N u (T_2 - T_1) \pi \tag{2.31}$$

Where

 λ Thermal conductivity of the air film in contact with the conductor, assumed constant and equal to: 0.02585 (W.m⁻¹.K⁻¹)

Nu	Nusselt number where:	
Nu = 0.65Re	$e^{0.2} + 0.23 Re^{0.61}$	(2.32)
Re	Reynolds number where:	
<i>Re</i> = 1.644 >	$(10^9 v D[(T_1 + 0.5(T_2 - T_1))]^{-1.78})$	(2.33)
v	is the wind speed (m/s)	
D	is the conductor diameter (m)	
Т	is the temperature (K)	
	T_1 ambient temperature (K)	
	T_2 final equilibrium temperature (K)	

From the heat balance equation the CCC can be represented in terms of I_{max} (A).

$$I_{max} = \left[\frac{P_{rad} + P_{conv} - P_{sol}}{R_T}\right]^{\frac{1}{2}}$$
(2.34)

2.3.3 Australian Standard AS/NZS 7000:2010 Overhead Line Design

This standard identifies that it has used the same equations as prescribed in the European Standard IEC TR 61597:1995, "Overhead electrical conductors – Calculation methods for stranded bare conductors", to calculate the static line rating . The equation from IEC TR 61597 is an alteration to that of the Cigré equation from technical brochure 601 as it omits the magnetic heating, corona heating and evaporative cooling. Details of this methodology are found previously in section 2.3.2.

2.3.4 The Electricity Supply Association of Australia D(b)5 1988 Current Rating of Bare Overhead Conductors

This guideline produced by the Electricity Supply Association of Australia (ESAA), is the current model used in Ergon Energy. This model was based upon the research paper "The Thermal Rating of Overhead Line Conductors Part 1. The Steady-State Thermal model", completed by V. T. Morgan (1982). Similar to the IEEE standard, this guideline produces the heat balance equation with the CCC the subject. This model, is different to the others found in the current standards. It uses different formulae to calculate the components of the equation that are required. It also takes into consideration the reflected solar radiation and the possibility that it can change due to the environment for which the conductor is located. The equation stipulated in the guideline is as follows;

$$I = \sqrt{\frac{PR + PF - PS}{kR_{dc} [1 + \alpha(t_c - 20)]}}$$
 Amps for wind conditions (2.35)⁶
or
$$I = \sqrt{\frac{PR + PN - PS}{kR_{dc} [1 + \alpha(t_c - 20)]}}$$
 Amps for still are conditions (2.36)⁴

PS	Power gain by solar heat input
PF	Power loss by forced convection
PN	Power loss by natural Convection
PR	Power loss by radiation
k	Factor allowing for effective increase in D.C. resistance due to
	skin effect, hysteresis and eddy current losses
R _{dc}	Conductor D.C. resistance at 20°C
α	Temperature coefficient of resistance at 20°C

⁶ The Electricity Supply Association of Australia, 1988. *ESAA D(b)5: Current Rating of Bare Overhead Line Conductors*. Available from: Sai Global.

 T_c Conductor maximum operating temperature

POWER GAIN BY SOLAR HEAT INPUT

$$PS = aD\left[Idir\left(1 + \frac{\pi}{2}F\right) + \frac{\pi}{2}Idiff(1+F)\}\right]$$
(W) (2.37)

Where

а	Solar absor	rbtion coefficient
	0.5 for rura	al weathered conductor
	0.85 for inc	dustrial weathered conductor
D	Diameter o	of conductor (m)
Idir	Direct sola	r radiation intensity at 1000 $W \cdot m^{-2}$
Idiff	Diffuse sol	ar radiation intensity at $100 W \cdot m^{-2}$
F	Albedo gro	ound reflectance – reflected solar radiation
	0.2	General value
	0.05	Water
	0.1	Forest
	0.15	Urban
	0.3	Sand
	0.4-0.6	Ice
	0.6-0.9	Snow

POWER LOSS BY FORCED CONVECTION

$$PF = \pi \lambda_f (t_c - t_a) B(R_e)^n [0.42 + C(\sin \psi)^P]$$
 (W) (2.38)

 λ_f Thermal conductivity of the Air Film (W/m² K⁴)

$$\lambda_f = 2.42 \times 10^{-2} + 7.2 \times 10^{-5} \frac{(t_c + t_a)}{2}$$
(2.39)

$$t_c$$
 Conductor maximum operating temperature (°C)

 t_a Ambient temperature (below are recommended values) (°C) 35°C summer noon 10°C winter night

$$B \& n$$
Constant dependant on Reynolds NumberIf $R_e \le 2650: B = 0.641, n = 0.471$ $R_e > 2650: B = 0.048 n = 0.800$

R_e Reynolds Number

$$R_e = \frac{vD}{v_f} \tag{2.40}$$

v Transverse wind velocity (m/s)

D Conductor diameter (m)

 v_f Viscosity of the Air Film (m²/s)

$$v_f = 1.32 \times 10^{-5} + 9.5 \times 10^{-8} \frac{(t_c + t_a)}{2}$$
(2.41)

C & P Constant dependant on angle
If
$$0^{\circ} \le \psi \le 24^{\circ}$$
: C = 0.68, P = 1.08
 $24^{\circ} \le \psi \le 90^{\circ}$: C = 0.58, P = 0.90

 ψ Angle of attack of the wind relative to conductor axis

POWER LOSS BY NATURAL CONVECTION

$$PF = \pi \lambda_f (t_c - t_a) N u \qquad (W) \tag{2.42}$$

Where

$$\lambda_f$$
 thermal conductivity of the Air Film (W/m² K⁴)

$$\lambda_f = 2.42 \times 10^{-2} + 7.2 \times 10^{-5} \frac{(t_c + t_a)}{2}$$
(2.43)
$$t_s \qquad \text{Conductor maximum operating temperature}(^{\circ}\text{C})$$

 t_c Conductor maximum operating temperature(°C)

 t_a Ambient temperature (below are recommended values) (°C) 35°C summer noon 10°C winter night

Nu Nusselt Number

$$Nu = A(Gr \cdot Pr)^m \tag{2.44}$$

A& mConstant dependant on the value of
$$Gr$$
 and $(Gr \cdot Pr)$ If $(Gr \cdot Pr) \leq 10^4$: $A = 0.850, m = 0.188$ $(Gr \cdot Pr) \geq 10^4$: $A = 0.480, m = 0.250$

Gr Grashof Number

$$Gr = \frac{D^3 g(t_c - t_a)}{\left[\frac{(t_c - t_a)}{2} + 273\right] v_f^2}$$
(2.45)

g Acceleration of gravity; $9.81m \cdot s^{-2}$

$$Pr = 0.715 - 2.5 \times 10^{-4} \frac{(t_c + t_a)}{2}$$
(2.46)

POWER LOSS BY RADIATION

$$PR = \pi D\sigma e \left[(t_c + 273)^4 - \frac{1}{2} (t_g + 273)^4 - \frac{1}{2} (t_d + 273)^4 \right] \qquad (W)$$
(2.47)

$$\sigma$$
Stefan-Boltzmann constant: 5.67×10^{-8} e Emissivity of conductor
 0.5 for rural weathered conductor
 0.85 for industrial weathered conductor t_g Ground temperature (°C)
 $t_a + 5°C$ for summer noon conditions
 $t_a - 5°C$ for winter night conditions t_d Sky temperature (°C)

$$T_d = 0.0552(t_a + 273)^{1.5} - 273 \tag{2.48}$$

2.3.5 Summary of the Heat Balance Equations

The heat balance equation can take many different forms, and can be represented with the CCC as the subject. The purpose of digesting the equations is to establish he differences between the methodologies as to how to calculate the CCC of the conductor and to establish what equation would best be suited to Australian, in specific QLD, conditions. The key noticeable factor here is the current Australian Standard refers directly to the IEC standard without providing limitations of the equation and that fact that the methodology used in IEC TR 61597 may not be suited for outback Australian conditions. Despite the fact that all variations in the heat balance equation equate to a 10% difference in output (International Electrotechnical Commission, 1995), the question in regards to which equation is suitable for Australia still remains.

A key noticeable factor between guideline D(b)5 and IEC TR 61597 is the addition of the albedo value for ground reflectance. This value is not used in the IEC TR 61597 standard. This is of great interest for this dissertation and it will be investigated as to the significance of its value. Also noticed is the reduction in general constants for the guideline D(b)5. Again, indicating that this specific guideline will produce a more accurate result for Australian conditions as to that of the IEC standard.

It is also to be noted that the Cigré, TB601, 2014, prescribes a further, more in depth version of the heat balance equation with respects to the ESAA D(b)5. The key addition here is that TB601 factors in the location of the conductor on the earth as to calculate the azimuth of the line and the impact of the earth's rotations through the seasons which affect the solar intensity. These aspects are to be analysed in the sensitivity analysis as to understand their significance.

2.4 Mechanical Limits

Thermal ratings for transmission lines are carried out in a manner which sees the calculations for CCC based upon mechanical limitations. Such limitations consist of; annealing properties; conductor sag and strain tension (length of span). The

requirement to consider these parameters are mandatory as when subjected to increasing loads, conductors and/or tension fittings may exhibit at some level, permanent deformation. If the load is increased even further, failure of the conductor and/or tension fittings will occur at their failure limit (Standards Australia, 2010). See the figure 3 below for the mechanical limit states of conductor design.



Figure 3: Limit states of conductor design⁷

Different types of overhead conductor have different attributes. This section of the literacy review will look to identify the key components of annealing, conductor sag and construction design which will limit the ability to implement dynamic conductor ratings.

2.4.1 Annealing Properties

Conductors exposed to overheating exhibit a reduction in tensile strength due to the chemical reaction in the metallic bonds of the material which hardens the metal whilst reducing the tensile strength. This process is known as annealing, it is cumulative and irreversible (V.T, 1979). For this reason, line ratings are regulated by maximum

⁷ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

temperatures allowable in power lines assuming that weather parameters are given under worst conditions (Kim & Morcos, 2013). The implementation of dynamic ratings would change the way CCC is established. The Australian standard, AS/NZS 7000:2010 states in section 4.2.5 that the cumulative annealing damage shall be determined by summing the loss of tensile strength for temperatures arising from the steady state, short time and short-circuit thermal ratings and associated durations for the design life of the overhead conductors. It also continues to state that the permissible conductor cumulative annealing damage shall not exceed 15% of the conductor breaking load (CBL) for the design life of the conductor.

Appendix BB of AS/NZS 7000:2010 provides the equation for which the annealing damage from elevated temperature operations can be calculated. The equations produced (V.T, 1996) show how to calculate the percentage loss of tensile strength due to high temperature operations.

$$W = W_a \left[1 - e^{-e^{\left[A' + \frac{B'}{T_*} \ln(t) + \frac{C'}{T_*} + D' \ln\left(\frac{R}{80}\right)\right]}} \right]$$
(2.50)⁸

$$R = 100 \left[1 - \left(\frac{D_W}{Do}\right)^2 \right]$$
(2.51)

- *W* Loss of strength in the partially annealed state (% of ultimate tensile strength in the tempered state)
- W_a Loss of strength in the fully annealed state (% of ultimate tensile strength in the tempered state)
- *A'*, *B'* Experimentally derived constants for the conductor

⁸ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

C' and DT *Wire absolute temperature (K)tTime duration at temperature T* (hours)RReduction in cross sectional area during wire drawing (%) D_o Diameter of wire prior to drawing (mm) – usually 9.5mm for aluminium D_w Diameter of drawn wire i.e. strand diameter (mm)

See (V.T, 1996) for appropriate values of A', B', C' and D as AS/NZS 7000:2010 provides general average values which are not appropriate for all scenarios.

2.4.2 Thermal Limits

As mentioned previously in section 2.2.2, there are multiple ways to implement dynamic ratings. In all cases the thermal limits are imperative. This is made clear in the AS/NZS 7000:2010 Appendix BB "Conductor Annealing and Operating temperatures". This appendix denotes that there is an allowable loss of 3% of the original tensile strength after 1000 hours of exposure to the maximum temperature limit for normal operation. Section 4.2.5 of the AS/NZS 7000:2010 also states that the thermal limits for calculating the cumulative annealing damage for copper, aluminium and steel conductors shall be considered at 70°, 80° and 200° respectively. These are significant measures that need to be taken into consideration when developing dynamic ratings. Also to be noted here is that the AS:7000:2010 only provides reference to aluminium conductors. It has been stated in the Energy Networks Australia C(b)1-2006 "Guidelines for design and maintenance of overhead distribution and transmission lines" in Appendix D, which was previously used prior to AS/NZS 7000:2010, that copper has similar annealing properties to aluminium which are not as well documented

as those for aluminium, but is has less loss of strength for the same temperature. This indicates that if the annealing properties of aluminium are used for HDBC, then a conservative measure is being used and due diligence is acted upon. It is important to make this note as the case study to follow will be based upon a HDBC sub-transmission line.

2.4.3 Tensile Strength

The following figures 4, 5 & 6 are provided from AS/NZS 7000:2010 for the loss of tensile strength due to temperature over time. They are derived from standard IEC 276. From these plots it is quite clear that damage can occur over a substantial period of time due to dynamic load increases.

For the implementation of dynamic models, these plots can be used to indicate if; there is any available ampacity on the line; the existing sub transmission lines have been exposed to excessive damage and furthermore to provide an appropriate forecast for possible maintenance.



Figure 4: Percentage of original tensile strength of alloy 1350 vs ageing time⁹

⁹ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures*. 1st ed. Available from: Standards Australia.



Figure 6: Percentage of original tensile strength of alloy 6201 vs ageing time¹¹

¹⁰ Standards Australia, 2010. AS/NZS 7000:2010: Overhead line design - Detailed procedures. 1st ed. Available from: Standards Australia.

¹¹ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

2.4.4 Conductor Clearances

The increase in conductor temperature due to the increase in CCC will see the physical properties of the conductor change as such that the vertical and horizontal sag will change. Section 4.2.12 of AS/NZS 7000:2010 states that the vertical sag is a function of the conductor tension, conductor equivalent mass, span length and shall be determined in accordance to the maximum operating temperature of the overhead line to ensure that the required electrical clearances are maintained. These clearances are for the distance between the top circuit and lower circuit on the same pole, between the circuit and an underpass circuit and between the overhead conductor (circuit) and ground.

Figure 7 below shows how dynamic conditions can affect the clearances between two circuits. The equation specified in the standard is as follows. Note in figure 7, equation 3.3 actually applies to equation 2.34 of the dissertation.

$$U = \sqrt{V_a^2 + V_b^2 - 2V_a V_b \cos\theta}$$
(2.52)¹²

Where

$$V_a$$
Upper circuit nominal voltage phase to earth value (kV) V_b Lower circuit nominal voltage phase to earth value (kV) θ Phase angle difference between circuits (degrees)

At any point in the span (other than supports) the minimum distance required is:

For
$$U \le 11kV$$
 $D = 0.38m$

For
$$U > 11kV$$
 $D = 0.38 + q(U - 11)$ (2.53)

¹² Standards Australia, 2010. AS/NZS 7000:2010: Overhead line design - Detailed procedures. 1st ed. Available from: Standards Australia.



q

Constant which varies from 0.005 to 0.01(normal)



Figure 7: Conductor separation - influence of load current attached on same structure (Fig 3.7 AS/NZS 7000:2010)¹³

Table 3 on the following page applies to designs between the circuit and an underpass circuit cross and are unattached (Figure 8).

 ¹³ Standards Australia, 2010. AS/NZS 7000:2010: Overhead line design - Detailed procedures. 1st ed.
 Available from: Standards Australia.

				UPPER CIRCUIT								
			U ≤ 500 kV U > 330 kV Bare	U ≤ 330 kV U > 275 kV Bare	U ≤ 275 kV U >132 kV Bare	U ≤ 132 kV U > 66 kV Bare	U ≤ 66 kV U > 33 kV Bare	U ≤ 33 kV U > 1000 V Bare or covered	U ≤ 33 kV U > 1000 V Insulated	U < 1000 V Bare, covered and insulated	Other cables (Conductive)	Other cables (Non- conductive)
	$330 \text{ kV} \le 500 \text{ kV}$	No wind	5.2									
	Bare	Wind	3.6									
	$275 \text{ kV} \le U \le 330 \text{ kV}$	No wind	5.2	3.8								
	Bare	Wind	3.6	2.6								
L	$132 \text{ kV} \le U \le 275 \text{ kV}$	No wind	5.2	3.8	2.8							
0	Bare	Wind	3.6	2.6	2.2							
w	$66 \text{ kV} \le U \le 132 \text{ kV}$	No wind	5.2	3.8	2.8	2.4						
E	Bare	Wind	3.6	2.6	2.2	1.5						
R	$33 \text{ kV} \le U \le 66 \text{ kV}$	No wind	5.2	3.8	2.8	2.4	1.8					
	Bare	Wind	3.6	2.6	2.2	1.5	0.8					
С	$1000 V \le U \le 33 kV$	No wind	5.2	3.8	2.8	2.4	1.8	1.2				
I	Bare or covered	Wind	3.6	2.6	2.2	1.5	0.8	0.5				
R	1000 V < U ≤33 kV	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6			
С	Insulated	Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4			
U	$U \le 1000 V$	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6		
I	Bare, covered and insulated	Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4		
т	Other cables	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6	0.6	0.4
	(Conductive)	Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4	0.4	0.2
	Other cables	No wind	5.2	3.8	2.8	2.4	1.8	1.2	0.6	0.6	0.4	0.4
	(Non conductive)	Wind	3.6	2.6	2.2	1.5	0.8	0.5	0.4	0.4	0.2	0.2

Table 3: Minimum vertical separation for unattached crossings (m)¹⁴

NOTES:

1 The above clearances may need to be increased due to local factors.

2 The clearances in this table may need to be increased to account for safe approach distances required for construction, operation and maintenances and for blowout on large spans.

3 The above clearances are based on the upper circuit being at maximum conductor temperature and the lower circuit at ambient temperature.

4 These clearances apply to altitudes up to 1000 m. Correction factors at higher altitudes are contained in AS 2650.

5 The 'wind' condition corresponds to serviceable load conditions.

¹⁴ Standards Australia, 2010. AS/NZS 7000:2010: Overhead line design - Detailed procedures. 1st ed. Available from: Standards Australia.



Figure 8: Unattached crossing¹⁵

And the values required for distance to the ground are as follows.

	Distance to ground in any direction (m)				
Nominal System Voltage U	Over the carriageway of roads	Over land other than the carriageways of roads	Over land which due to its steepness or swampiness is not traversable by vehicles more than 3m in height		
$1000V < U \le 33kV$	6.7	5.5	4.5		
$33kV < U \le 132kV$	6.7	6.7	5.5		
$132kV < U \le 275kV$	7.5	7.5	6.0		
$275kV < U \leq 330kV$	8.0	8.0	6.7		

Table 4: Minimum clearance from ground, lines other than insulated service l	ines ¹	6
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¹⁵ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

¹⁶ Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

$330kV < U \leq 400kV$	9.0	9.0	7.5
$400kV < U \leq 500kV$	9.0	9.0	7.5

2.5 Dynamic Modelling

There are multiple ways to model dynamic conductor ratings. Such models are generally specific and refer to certain constraints on the transmission line. This dissertation will be looking to provide a clear methodology for Ergon Energy to utilise when implementing dynamic conductor ratings. To do this various methods will be reviewed and analysed with respects to Ergon Energy's network. Those methodologies are: sag, temperature, weather, tension and current. Also to be investigated is the possibility of implementing an annealing based model which would involve a collaboration of the weather, temperature sag and tension based models.

2.5.1 Weather Based Modelling

Weather-based dynamic line ratings (DLR) is most suited to transmission lines that pass through flat open spaces with limited bearing changes and sheltering (Black, et al., 2010). This form of modelling takes into consideration the weather parameters for which the transmission line is exposed to and the parameters of the overhead conductor. Hydro Tasmania (2009) provide to following as base to model dynamic conditions via weather based modelling.

- Wind speed measured by an anemometer
- Wind direction
- Air Temperature
- Solar heat intensity; and
- Conductor parameters

To accurately run a model based upon this system. A study of the weather conditions will be required. This would include seasonal mapping of wind speeds, wind direction

and air temperatures along with load levels of the transmission line. To do this, line monitoring equipment may be required. It is the view of Northern Ireland Electric that line monitoring equipment should be used every 4-5 km (Black, et al., 2010). In Ergon Energy's situation this may not be affordable as the networks can be as long as 200kms. To combat this Ergon have established weather data from the Bureau of Meteorology. This has allowed for regional weather maps to be created.

2.5.2 Sag Based Modelling

Sag based methodologies can be used for any situation. In QLD there are statutory height regulations for overhead conductors, these heights can't be breached as it is a mandatory requirement to be above them at all times. This is to ensure the conductors are at a safe height. These heights vary for various voltages and are provided in table 4 in section 2.4.4. There are ways to monitor such clearances. Currently Ergon Energy is using their, ROAMES technology which uses GPS tracking aircraft to fly over the network and with laser technology (LIDAR) to establish how high each span is tracking. This data is then collaborated and a model of the sub-transmission network is created. This is considered to be very accurate and accountable. Based on the measurement of the overhead line conductor sag the absolute clearance of the overhead can be quantified (Jupe, et al., 2011). There are numerous ways to monitor conductor sag. Some of these methods are (Black & Chisholm, 2013):

- Continuous Inclination Monitoring This type of modelling includes conductor mounted instrument pages that read out tilt, line current and cameras mounted on the tower.
- LIDAR Conditioning Surveys
 This method uses laser mapping which is done with a fly-by approach. This is
 the current methodology applied by Ergon Energy.

2.5.3 Temperature Based Modelling

This is a common approach to dynamic modelling as the temperature of the conductor is directly related to the annealing of the conductor and imminently its failure.

Temperature based technologies monitor the operating temperature of the overhead line conductor. This can be compared to the maximum operating temperature (Jupe, et al., 2011). Some of the equipment that can be used to do this are (Jupe, et al., 2011)& (Black & Chisholm, 2013):

- Overhead conductor temperature line clamps
- Fibre wire tapped to the exterior of the conductor
- Fibre optic cable incorporated within conductor

Currently EECL is investigating the possibility of utilising line meters for this which can be connected to the SCADA system to allow remote engineering. Such meters are connected to the line and use a thermocouple to monitor the temperature.

2.5.4 Tension Based Modelling

Tension-base techniques can be used to monitor the tension of the overhead conductors via loading cells or strain gauges. (Jupe, et al., 2011). This is also an approach that Hydro Tasmania uses as to maintain their clearances. This process is complicated by the presence of wind, which has the dual effect of cooling the line as well as adding the conductor tension (Hydro-Electric Corporation, 2009).

2.5.5 Current Based Modelling

Current based modelling generally uses a pre-emptive approach as an estimate value for the environmental conditions are applied (Jupe, et al., 2011). Dynamic models can be calculated using real-time weather data along with a known conductor size to calculate the maximum available ampacity based on the current rating of the line equipment. (Jupe, et al., 2011). This can be done with various equipment, some of these are. Line mounted C.Ts and substation relays. This is a narrow approach to dynamic ratings.

2.6 Knowledge Gap

With the literature review complete, a knowledge gap was identified and the justification for the project was solidified.

Extensive research found that there are a large number of sources relating to DLRs. The research also provided results for different methodologies of how to implement DLRs. This topic has been thoroughly researched by many academics and professionals. This information provided the realisation that, DLRs are implemented for specific reasons, i.e. to maintain clearances, manage peak load of wind farms, etc. What the literature failed to return are suitable models on applying dynamic ratings based on the annealing characteristics of a conductor over the lifespan of the conductor for Australian conditions. Quantifying the lifespan of a conductor is an area which EECL has not able to achieve. It is expected that this dissertation provide the satisfactory knowledge for them to utilise, to create a conductor lifespan register.

The initial question for the dissertation, "which version of the heat balance equation is best suited for Australian conditions?" will also be answered. This in turn will be bridging another knowledge gap as the heat balance equation stated in current Australian Standard AS/NZS 7000:2010 may be inadequate for Ergon Energy as it is a complete adoption of the IEC TR 61597 British and European Standards which is subject to a complete different environment as to that of rural QLD.

2.7 Chapter Summary

It is intended that this chapter present the relevant information obtained from a diverse range of sources to establish the single resource location which can be referred to as required. The completion of the literature review has gathered the required knowledge on; the heat balance equation; methodologies of dynamic modelling; and mechanical limitations associated with dynamic conductor ratings. The literature review has allowed for successful completion of objectives (1) and (4) which has enabled the completion of the remaining objectives. The literature review is a pivotal section of this dissertation proven by the above reasons.

Chapter 3

Methodology

3.1 Chapter Overview

Methodology is the process which outlines the undertaken principles and philosophies used to successfully achieve the project objectives outlined in section 1.4. This chapter aims to outline the methodology used to contextualise the arrangement of the dissertation whilst providing a preview of the content. The main tasks which were required to successfully complete the project were:

- 1. Research
- 2. Sensitivity Analysis
- 3. Case Study Analysis
- 4. Dynamic Conductor Rating Calculator
- 5. Quantification of results

These tasks are lightly discussed in the following sections. The descriptions are brief and non-exhaustive. The full details for each of these can be found in their corresponding chapters.

3.2 Research

The purpose of reviewing the literature was to extract as much knowledge of the current methodologies and processes for calculating CCC such that a clear understanding of conductor ratings was formed. This information is located in the literature review and can be found in chapter 2. In summary, the research was conducted for two reasons; firstly, to provide clarification as to whether the current Australian Standard (AS 7000:2010) provides a sufficient methodology as to calculate the ratings of overhead conductors, compared to that of the previous guidelines provided by the Electricity Supply Association of Australia D(b)5; secondly, to pursue the possibility of implementing dynamic ratings. To gain an appreciation of the literature, the following fields were researched:

- How overhead conductors are rated and why they are deployed;
- Principles of conductor thermal models;
- Differences between the multiple models provided by respectable sources in particular the difference between AS7000:2012 and D(b)5;
- Limitations due to mechanical properties within the overhead construction;
- How dynamic ratings of overhead conductors are being used;
- How EECL can possibly implement dynamic ratings with a sound level of confidence.

In summary the research undertaken, was successful as it has provided a clear understanding of the heat balance models and has provided clarity for the ongoing investigations in the project. There are a few key points worthy of identifying and are as follows:

• EECL's current philosophy for calculating their overhead conductor ratings with ESAA D(b)5 is considered to be satisfactory, and their position in questioning the plausibility of the IEC 61597 standard (for which the AS 7000 is based upon) is justifiable. The research shows that the two are very different and to thoughtlessly accept the change in methodology would be a failure to undertake due diligence.
- The dissertation objective to provide clarity as to which standard/guideline is best for EECL to base its conductor ratings on, requires further investigation of additional methodologies as the IEC 61597 stipulates that the process it provides may not be suitable in all cases and it refers readers to the CIGRÉ technical brochure 601. The benefit of conducting further research into these calculations provides a stronger, more analytical understanding of heat transfer theory. As a result, the three models were examined and broken down for the sensitivity analysis.
- There are many ways in which EECL can look at implementing dynamic conductor ratings. Apprehension lies where the literature highlights the limitations for doing so. These limitations will continue to be taken into consideration where dynamic recommendations are made.

3.3 Sensitivity Analysis

Upon the completion of the literature review, the required knowledge was obtained to enable a sensitivity analysis of the differing heat balance equations. Firstly, the purpose of undertaking such analyses is to understand how each component, in comparison to its corresponding variants, affects the available CCC of a conductor. To quantify the differences, the formulas were modelled as to produce a percentage variation due to change and identify the impact to the CCC. The tested parameters were:

- Wind speed
- Wind angle
- Ambient temperature
- Direct solar radiation
- Absorptivity
- Emissivity

These parameters were chosen as they are well documented in the ESAA D(b)5, and allow for a point of reference to justify the findings.

As the methodology between the formulas are different, so to were the available variables. The IEC 61597 does not provide the ability to add both the albedo, (reflected

solar radiation factor) and wind approach angle. These two components were also tested as to justify the reason for requiring them.

Secondly, the analysis aims to provide guidance into the significance of each equation variable, resulting in a grading from 'most sensitive' to 'least sensitive'. By assessing the impact of each variable, (objective (2) (refer to section 1.4.)), construction of a DLR can be modelled (objective (4)). The variables analysed were:

- Allowable conductor temperature
- Wind speed
- Conductor diameter
- Wind Angle
- Emissivity
- Absorptivity
- Direct solar radiation
- Albedo

3.4 Case Study Analysis

Currently EECL is collecting data on both current (A) and temperature (°C) for overhead networks of interest, considering both distribution and sub-transmission. The meters used for this are supplied by Horseman Navigator. The meters have the ability to measure at 15 minute average interval whilst also having the ability to record the peak current in that time, unfortunately no peak temperature can be recorded. EECL also has access to weather data from the Bureau of Meteorology. Having being able to extract the data, case studies can be analysed as to compare results into providing which HBE is more superior (objective(5)).

From the data gathered, it has been found that there has are moments where the temperature of the conductor has exceeded that of design rating. The time of interest was at summer peak loading, whilst the weather analysis returned data which indicates the wind would be running at 90° to the conductor. This instance and others are tested to further quantify the dangers of dynamic ratings and the importance of understanding the HBE theory.

3.5 Dynamic Conductor Rating Calculator

The outcomes of the literature review, sensitivity analysis and case studies, have provided the relevant knowledge to enable a DLR to be modelled. The process required to produce a dynamic rating is to have a methodology of its own, and should be well understood upon commencement. The model is broken up into two stages, Firstly, acquiring the date for; the seasonal requirements; load requirements and mechanical limits. Following this, the second stage is to ensure that the network has the ability to be dynamically rated and if so, the proposed rating does not jeopardise the asset.

The analysis is a critical stage in which at can determine if it is worth implementing a dynamic rating. The points of interested for seasonal requirements are:

- Winter or summer
- Historical data and forecasted data for;
- Maximum ambient temperatures and occurrence
- Average wind speed and approach angle
- Occurrence of 0m/s wind speed
- Ground surface type

The load requirements are:

- Existing and forecasted data for;
- Contingency loading
- Peak loads at peak temperature times
- Peak loads, maximum demand (MD) and time

For the mechanical limits, the points of interest are:

- Network route
- Pole top configuration
- Additional circuits below
- Pole tope equipment
- Condition of conductor

3.6 Quantification of Results

Asset management involvement is critical when deciding to uprate an overhead conductor. Whilst the concept of uprating a power line may be theoretically easy to implement, practically past experience has indicated otherwise. For any reason to implement a dynamic rating, expenditure is considered. This stage of the report looks to highlight the benefit of DLRs and provide an outlook into the cost saving available to EECL. Ultimately the concept of implementing DLRs is to eliminate expensive operations such as; high voltage remote generation and sub-transmission line upgrades. It is the expectation that by quantifying the benefit to EECL with dollar values, that the project will enable a willingness to invest further time and resources into such applications.

3.7 Chapter Summary

This chapter has provided clarification of the processes, techniques and methodologies employed to successfully complete the objectives of the report. By categorising the project into the broad tasks of: research; sensitivity analysis; case study analysis; dynamic conductor rating calculator; and quantification of results, the corresponding project objectives have been achieved.

Task	Relevant Chapters	Objectives Achieved
Research	4. Literature Review	(1) (4)
Sensitivity Analysis	 Sensitivity Analysis – Selection of HBE 	(2) (3)
Case Study Analysis	6. Case Study Analysis	(5) (8)
DLR Calculator	7. DLR Calculator	(4)
Quantification of	8. DLR Justification and	(6) (7)
Results	Quantification	

Table 5: Connection between project methodology, dissertation and objectives

Chapter 4

Weather Parameters for Overhead Conductor Ratings

4.1 Chapter Overview

A key component in providing DLRs is the manipulation of static weather parameters. A general static rating of an overhead conductor looks at a standardised condition for both summer and winter. The main objective of the project is to be able to produce DLRs. To do this, it is imperative that a weather analysis of the network in question be undertaken prior to implementation.

With EECLs access to the BOM database, the opportunity to be able to collected data and study weather patterns across the entire state is made possible. This chapter focuses on interpreting the results as to enable future applications of DLRs. In addition to this the chapter also aims to highlight the dangers of conductors producing annealing from to poor selection of weather parameters for adjustment.

4.2 Appropriate Selection of weather parameters

From the literature review, it has been determined that weather parameters play a major role in the rating of overhead conductors. Such parameters, if changed, can give the perception that an overhead conductor can carry more load without degradation. Whilst this is correct, there is also an element of danger presented due to an incorrect adjustment of such parameters, hence the restrictions placed by standards Australia for reduction in tensile strength and breaking limits.

There are multiple methodologies for applying conductor ratings from weather parameter adjustments. Some of these methods are (Cigre, 2006):

- Ambient adjusted
- Continually ambient adjusted
- Seasonal
- Real time

This project will look at implementing both the ambient adjusted and seasonal methodologies. With the implementation of such parameters, it is recommended that continuous monitoring of real time data be provided to ensure the conductor has limited exposure to dangerous temperatures.

In addition to this the dissertation will investigate the weather patterns that QLD is exposed to. The purpose of this is to gain a better understanding of the types of wind conditions that will be present across the state throughout the different seasons.

4.2.1 The Ambient - Adjusted Process with Seasonal Requirements

The ambient temperature is pivotal in providing a dynamic conductor rating. It is possible to implement a dynamic rating based upon adjusting the ambient temperature in the HBE. This will provide scope to uprate and de-rate the network based on whether the ambient temperature is high or low. In the summer EECL utilise a ambient temperature factor of 35° C, as stipulated in the ESAA D(b)5. This is acceptable and plausible. The ambient – adjusted process allows the ambient temperature to be

changed as per the location of the transmission network, with a known maximum temperature based on forecasted values, as the ambient temperature change affects conductor temperature in a one-one relationship (Cigre, 2006). This process would also be acceptable for use in EECL as the weather conditions vary differently across the state of QLD. Figure 9 below shows how the difference in ambient temperature affects the CCC. Note this is based from the ESAA D(b)5, EECL current practice.



Figure 9: Change in CCC due to Change in Ambient Temperature (ESAA D(b)5)

Whilst this will allow for a dynamic rating as such, there are also some hazards that can be found with this process. They consist of:

- Less conservative
- Requires wind conditions to be relatively steady and known
- Increase risk of annealing

It is for such reasons that a dynamic rating based on the ambient – adjusted process requires a seasonal analysis to be undertaken in conjunction with the ambient temperature study.

It is understood that seasonal wind conditions can be statistically analysed. High temperature summer conditions are often associated with highly variable wind directions and wind speeds, whilst on the contrary; cold winter conditions are often associated with laminar and directional winds (Cigre, 2006). This may not be the case always, though with access to historical weather data, it is possible to gain a understanding of the regional patters and regain confidence.

To put this concept into practice, EECL have completed a thorough analysis of the weather conditions across the state, based upon 10 years of historical data, made available from the BOM. As a result they have been able to determine a series of wind conditions for regional areas. Figure 10 below shows this. As you can see, the majority of the transmission network is located in the 'Eastern & Coastal' region and in the 'Northern and Southern Central Tablelands'. This gives a fair indication as to the conditions that the network will be exposed to.

	Summer						
	Day		Evening		Night		
Normal	Dec-Mar,		Dec-Mar		Dec-Mar		
	09:00-17:00		17:00-22:00		22:00-09:00		
	(9am - 5pm)		(5pm to 10pm)		(10pm - 9am)		
Region	Wind	Ambient	Wind	Ambient	Wind	Ambient	
Region	(m/sec)	°C	(m/sec)	°C	(m/sec)	°C	
Far North	0.8	38	0.4	34	0.2	30	
Eastern & Coastal	1.3	35	0.8	31	0.3	27	
Eastern & Coastal - Mackay	1.9	33	1.5	27	1.2	27	
Eastern & Coastal - Special	1.7	33	1.3	27	0.4	27	
Central Tablelands - Toowoomba	1.8	33	1.8	27	1.8	21	
Central Tablelands - North	1.3	37	0.7	34	0.2	29	
Central Tablelands - South	1.3	37	0.7	34	0.2	29	
Western	1.7	42	1.4	40	1.4	36	
Western - Special	1.5	41	0.8	37	0.3	32	
	Winter						
	D	ay	Evening		Night		
Normal	Jun	-Aug	Jun-Aug		Jun-Aug		
	09:00	-17:00	17:00-22:00		22:00-09:00		
	(9am	- 5pm)	(5pm to 10pm)		(10pm - 9am)		
Far North	0.8	38	0.4	34	0.2	30	
Eastern & Coastal	1.3	35	0.8	31	0.3	27	
Region	Wind	Ambient	Wind	Ambient	Wind	Ambient	
Region	(m/sec)	°C	(m/sec)	°C	(m/sec)	°C	
Eastern & Coastal - Mackay	1.9	33	1.5	27	1.2	27	

Table 6: Ergon Climate Zones - Weather Conditions¹⁷

¹⁷ Data Supplied by EECL

Eastern & Coastal - Special	1.7	33	1.3	27	0.4	27
Central Tablelands - North	1.3	37	0.7	34	0.2	29
Central Tablelands - South	1.3	37	0.7	34	0.2	29
Western	1.7	42	1.4	40	1.4	36
Western - Special	1.5	41	0.8	37	0.3	32



Figure 10: Ergon Energy Transmission Network and Regional Weather Conditions¹⁸

Whilst the completed analysis is useful, it may not be enough to regain complete confidence as there are transmission networks in EECL that are longer than 150km. With a transmission line this long, Cigré warn of conditions where the wind speeds and directions can't be accurately measured due to nature of the transmission line corridor. Some of the conditions which EECL will be required to consider are; wind shadowing due to mountainous terrain; wind shadowing due to industrial buildings; and summer foliage. Such effects may not be able to be detected from open terrain meteorological observations, which often reflect higher wind speed. If sections of lines are not clear, it may be a requirement that weather stations with real time measuring capabilities and engineering access be installed.

¹⁸ Data Supplied by EECL via Google Earth

4.3 Wind Conditions and Wind Patterns across Queensland

As prescribed in the previous section 4.2.1. There is an inherent inability to prescribe a dynamic rating based on ambient temperature if the wind conditions are unknown. This section of the report helps to define and understand the wind conditions and patterns exposed to QLD and their impact on the conductor CCC, as to gain extra variance in the DLR. This detail has been made available by the BOM for EECL.

4.3.1 Synoptic Scale Influences on Wind

QLD is exposed to multiple large scale wind influences. This ranges from the wind generated by; tropical cyclones and depressions; the Australian monsoon; south east trade winds; easterly trough; and the east coast lows. Descriptions and impacts of these wind systems are defined below.

TROPICAL CYCLONES AND DEPRESSIONS

An intense low-pressure system, such systems generate wind in excess of 90km/hr and wind gusts of up to 280km/hr. Such winds are not of concern for this dissertation as in times of exposure, EECL shut down their assets as to mitigate risks and help maintain public safety. Tropical depressions also produce high wind speeds and wind gusts. These winds are often associated with cyclonic conditions and will also be omitted from this study.

THE AUSTRALIAN MONSOON

According to the BOM, northern Australia is exposed the monsoon weather season. This is generally between October and April. This system is characterised by the northwesterly monsoonal flow. If the monsoon is active, norther QLD is exposed to broad cloud cover with sustained moderated fresh to north westerly winds. Sustained wind conditions may be an area of interest for delivering dynamic ratings.

THE SOUTHEAST TRADE WINDS

These winds affect much of the northern parts of eastern QLD, though they are strongest in the winter months when then monsoon is in the northern hemisphere. They generally blow east to southeast. They are present all year round as they are part of the general circulation of the atmosphere.

With the known direction of these winds is gives confidence that most transmission networks running in a north south direction will get good wind coverage. It is the speed of the wind that is still a concern and will still require a weather forecast and or historical data analysis.

EASTERLY TROUGH

Also known as the 'inland trough' or 'dry trough', are dominate in the summer months. The trough is located in the inland side of the Great Dividing Range, forming a boundary between the moist sea air and the dry rural air. This trough is present through central QLD and down through central northern New South Wales (NSW). The presence of the trough is most common in the summer months and they last from a few days to a week and a time.

This type of wind condition pattern tends to travel in a north south manner. EECL has various large (>150km) networks which are within the range of this trough. At these times of exposure, an analysis is required to determine the effects of such conditions.

EAST COAST LOWS

These lows generally only occur a few times a year and are most common in the autumn and winter months. They are generally located in southern QLD and NSW. Associated with them are strong gusty winds and heavy rain.

For the southern part of the network, such wind conditions may provide the ability to uprate the transmission network significantly. Whilst there are only limited exposures of these lows, the winter months will be cooler which will further add confidence in the dynamic model.

4.3.2 Meso-scale Influences on Wind

Meso-scale influences refer the different types of wind conditions where are create by the topography and orography of the terrain. There are multiple types of influence though the conditions which may impact our rating are; sea breeze and land breeze; and westerly gales.

SEA BREEZE AND LAND BREEZE

Typically, sea breezes start after sunrise and reach a maximum strength in the early afternoon, then diminish after sunset. Likewise land breezes are generated at night and usually are light and reach maximum speeds at sunrise, they then rapidly diminish. These breezes are generated by the difference between the land temperature and the sea temperatures.

The most prominent sea breezes are located in the tropics and can penetrate from 50km up to 150km inland. In the middle latitudes (30° to 55° degrees latitude) may only penetrate from 15km to 50km. The exposure of such conditions are generally in the summer months, this is because the inland temperature needs to be significantly greater than that the sea temperature. In addition to this, an overcast or cloudy day will seriously diminish the effect of the breeze for the same reasons.

EECL can utilise this data as they have a lot of transmission network along the east coast of QLD. Again, an analysis is still required as the condition is present in the summer months and the ambient temperatures will be greater.

WESTERLY GALES

Such conditions are prominent in the southern part of QLD. These are generally experienced in the winter and early spring. The cause of this condition is due to a low in northern NSW cause a change in pressure gradients. When these winds are generated they are generally very cold and can last up to multiple days.

Due to the already present cooler ambient conditions, westerly gales can provide more confidence in uprating the network throughout the winter and early spring months.

4.4 Analysing Weather Conditions

4.4.1 Wind Conditions

The severe effect of calm wind conditions cause doubt in the ability to implement DLRs. When the conductor is exposed to such conditions, the risk of exceeding the maximum operating temperature of the line is imminent. With this in mind, placing a dynamic loading condition when the conductor is exposed to season high levels of zero wind would be a failure to apply due diligence. To overcome this, EECL has conducted series of studies for the occurrence of wind speeds over a 24 hr period for both summer and winter. The example provided in Figure 11, shows the result for Toowoomba through summer.



TOOWOOMBA AIRPORT Summer Wind Frequency Distribution

Figure 11: Distribution of Wind Frequency - Toowoomba Summer¹⁹

¹⁹ Data Supplied by EECL – Network Ratings

From Figure 11 it can be seen that for Toowoomba, through summer, the wind conditions for noon show that the wind speed is generally greater than 1m/s, and more importantly, the non-occurrence of zero wind. As this is when the ambient temperature is generally at its highest, this gives confidence that the rating of the conductor is satisfactory. Also from the figure it can be seen that the occurrence of zero wind speed is highest between 4:00am and 8:00am. This is generally when the temperature is lowest; hence the difference between the air temperature and the ground temperature is least, causing the reduction in convection.

These calculations have been based on the 5^{th} percentile wind speeds indicating that there is a 5% chance that actual wind speeds will at this velocity or lower, hence there is 95% chance of the wind speeds being greater than what's indicated. It is for such reasons that EECL has not modelled the occurrence of wind conditions greater than 2m/s as their static ratings are based upon; still conditions; 1m/s convection and 2m/s convection.

To be able to use this data for dynamic conditions, individual analysis may be required as often the required time of the dynamic rating is outside the summer or winter months, hence; lower load profiles; less lost customer minutes; most acceptable times for seasonal rural requirements such as cotton gins; etc.

4.4.2 Temperature Conditions

As a dynamic rating is dependent on the ambient temperature along with the wind conditions, a correlating temperature analysis has been conducted which shows how the wind speeds are affected by the ambient temperature. Unlike the wind conditions, the ambient temperature has been calculated based upon the 95th percentile conditions, hence indicating that only 5% of the time the temperature will be greater than the values modelled. This analysis will allow to for greater versatility in the dynamic condition. Figure 12 shows this.



TOOWOOMBA AIRPORT Summer 95th Temperature & 5th Wind Speed



Similar to analysing wind conditions, the correlation between the wind and ambient temperature is required. With such studies comes the ability to identify if there is in fact an inherent dangerous dynamic condition. This could be signified by a case which shows both high ambient temperatures and low winds.

4.5 Chapter Summary

It is the expectation that this chapter has outlined how important weather conditions are when implementing DLRs. The following list outlines the outcomes from this chapter:

- Queensland is exposed various weather conditions across that state, this is due to synoptic influences such as; depressions; monsoon; south east trade winds; easterly troughs; and east coast lows. Following this, meso-scale influences such as; sea breeze and land breeze; and westerly gales.
- There are multiple ways to model the weather conditions. They consist of; ambient – adjusted; continually ambient adjusted; seasonal; and real time.

²⁰ Data Supplied by EECL – Network Ratings

From these methodologies, it has been identified that the most suitable method is a combination of, ambient adjusted with seasonal requirements.

• EECL has already studied summer and winter weather condition across the state. This data has provided a grounding of how to model the occurrence of zero wind speed based on the 5th percentile wind speeds and the 95th percentile temperature conditions.

As a result of this, objective (3) (refer to section 1.4) has been achieved. This chapter now provides enough scope for EECL to conduct further weather analysis. It also enables the ability to provide an emphasis on the coinciding parameters of the HBE which are to be studied in the following chapter – sensitivity analysis.

Chapter 5

Sensitivity Analysis – Selection of the Heat Balance Equation

5.1 Chapter Overview

Primarily this chapter is to determine if the current methodology used by EECL is appropriate. As previously stated there are multiple ways to produce and CCC of a conductor through various HBE methods. This chapter look at the variables that decide the CCC and how they affect the rating.

Secondly this chapter will determine the amount of variation provide by the different factors across the different models. And analysis will provide which method is superior and how they vary in each component of the HBE.

Ultimately this chapter is to provide the base for the DLR calculator which will drive the possibility of implementing dynamic conditions.

5.2 Variation in Heat Balance Equation Models

The variations of the different HBEs have been studied. This section is to identify how each equation differs from each other and the impact to the CCC if a condition is manipulated. To do this the formulae has been represented in the form of a flow chart. This allows for a clear visualisation of differing components and methodologies for how the HBEs change. The flow charts have been entered and explained as follows.

5.2.1 Cigré TB601 Model

The following flow charts depict the process to utilise this methodology. These series of flow charts show the complexity to which this HBE is subjected to. Figure 13 shows the general process. Each of the power components have been broken down across Figure 14 to Figure 16. From these figures it can be seen that the process of calculating the solar heat gain and the convective heat loss are very complex. With the provision for the extra variables, it is expected that a very accurate calculation will be produced. Verification of this is tested in section 5.3.



Figure 13: Cigré TB601 - HBE general process



Figure 14: Cigré TB601 - Solar heat gain methodology



Figure 15: Cigré TB601 - Radiative heat loss methodology



Figure 16: Cigré TB601 - Convective heat loss methodology

5.2.2 IEC 61597 Model

The following flow charts depict the process to utilise this methodology. These series of flow charts show the simplicity to which this HBE is subjected to as opposed to its counterparts in Cigré and ESAA. Figure 17 shows the general process. Each of the power components have been broken down across Figure 18 to Figure 20. From these figures it can be seen that the process of calculating the solar heat gain and the convective heat loss simplified with the reduction in variables. It is expected that the reduction in variables will create a more inaccurate model and increase the risk of annealing to the conductor. These results are verified in section 5.3.



Figure 17: IEC - HBE general process



Figure 18: IEC 61597 - Solar heat gain methodology



Figure 19: IEC 61597 - Radiative heat loss methodology



Figure 20: IEC 61597 - Convective heat loss methodology

5.2.3 ESAA D(b)5 Model

The following flow charts depict the process to utilise this methodology. These series of flow charts show a similar complexity in respects to the Cigré model. They both have the ability to adjust each component of the HBE. Figure 17 shows the general process. Each of the power components have been broken down across Figure 22 to Figure 24. It is expected that this model will provide similar result to the Cigré model. These results are verified in section 5.3.



Figure 21: ESAA D(b)5 - HBE general process



Figure 22: ESAA D(b)5 - Solar heat gain methodology



Figure 23: ESAA D(b)5 - Radiative heat loss methodology



Figure 24: ESAA D(b)5 - Convective heat loss methodology

5.2.4 HBE Model Variations

From the flow charts above, it is evident that the models will produce different results. To gain an understanding as to why this may occur, the differences between the equations have been identified and analysed. Table 7 below shows an overview of the differences.

	IEC TR 61597-1995	Cigré TB601	ESAA D(b)5
Joule Heating	X	\checkmark	✓
Solar Heating	Х	\checkmark	Х
Convective Cooling	X	\checkmark	Х
Radiated Cooling	\checkmark	\checkmark	Х

Table 7: Difference Between the HBEs

At this stage of the dissertation, the assumption has been made that Cigré provide the best model to calculate CCC as takes into consideration the most variables. This was further tested an modelled and it was found that the ESAA provided a little less CCC, though the results were very close. This data is found in section 6.4. This chapter looks to further discuss the testing to prove such assumptions.

5.2.4.1 Joule Heating

The IEC methodology for calculating joule heating differs from the others as it does not take into consideration the mean temperature of the conductor nor does it consider the resistance due to skin effect. This omission makes the equation less valid and weakens it ability to de-rate the conductor due to harsh conditions.

5.2.4.2 Solar Heating

Cigré has developed are far more sensitive equation compared to both the ESAA and the IEC. They have managed to take into consideration; the location of the conductor on the earth; the azimuth of the conductor; and the time of day. ESAA may have less variables than Cigré though it is still more sensitive than the IEC. Instead of using the global positioning of the conductor to calculate the direct solar and diffused radiation, ESAA provide a set of values suitable for Australian conditions. IEC, on the other had suggested that a meter be used to calculation the solar radiation intensity, whilst providing a indicative value, if the data can't be sourced. Another key point that suggests the model for IEC is least superior is that they (IEC) don't take into consideration the reflected solar radiation.

5.2.4.3 Convection Cooling

The IEC have again provided a least sensitive methodology for calculating the convection cooling. The methodology provided in the Cigré and ESAA, is very complex. In comparison, the IEC utilise; a differing set of constants that change the Reynolds number; a single set of parameters to calculate the Nusselt number; and no alternate methodology for natural/forced convection. It is alarming to notice that there is a major inability to make significant adjustments in the convective heat loss component of the HBE. ESAA provide a very similar method to Cigré though they are slightly different. This difference is surrounded around the formula used to calculate the effects of the wind approach angle. The effects of this have been analysed in section 5.4.

5.2.4.4 Radiative Cooling

The formula provide by the ESAA is different to that of the Cigré and IEC. The key indicator here is that Cigré and IEC utilise the ambient temperature and conductor temperature, whilst the ESAA take the conductor, air and ground temperatures. The air and ground temperatures are calculated from the ambient temperature. This methodology is slightly more complex and provides little change to the CCC.

5.3 Selection of Varying Conditions

In regards to the HBEs, a selection of varying parameters has been identified as it is believed such components may provide the most scope for introducing DLRs. These components will be discussed and subjected to further testing in the following section 5.4.

5.3.1 Ambient Temperature

Current methodologies see conductors rated based on ambient temperatures of 35°C for summer noon conditions and 10°C for winter night (The Electricity Supply Association of Australia, 1988). This methodology is also adopted by overhead conductor supply companies such as Olex. This leaves scope for the temperature to be adjusted as it is subjected to seasonal change and forecasted conditions. This analysis will analyse a range of conditions for both day and night.

5.3.2 Solar Radiation Intensity

The ESAA stipulates that the recommend value for direct solar radiation intensity is 1000 W/m^2 and 100 W/m^2 for diffuse solar radiation, whilst the IEC provides an indicative value of 900 W/m^2 as a total solar radiation exposure. The Cigré TB601 prescribes a method of calculating this value based upon the location of the conductor on the earth with respects to the angle of the sun. The variation in such values is required to be analysed due to the size of the state of QLD.

Another aspect of the solar radiation is that of the albedo (reflected solar radiation). ESAA prescribes the following values for the coefficient based on the types of surface subjected to the conductor. As mentioned IEC have chosen to omit this from there standard. The values range from 0 to 1 and are defined by Table 8.

Ground Coverage	ESAA D(b)5	Cigré TB601
Water	0.05	0.05
Forest	0.1	0.1
Urban Areas	0.15	0.15
Soil, Grass and Crops	0.2	0.2
Sand	0.3	0.3
Ice	0.4-0.6	0.4-0.6

Table 8: Albedo Conditions

Snow	0.6-0.9	0.6-0.8
	0.0 0.9	

5.3.3 Absorptivity and Emissivity

Absorptivity and emissivity is associated with the condition of the conductor. The coefficients change due to the type of environment the conductor is exposed to. In general it is lowest when the conductor is first installed though can be at its worst within two years if exposed to highly polluted industrial conditions. The concepts are the same across all variations of the HBE. For rural weathered conductors the coefficient is set of 0.5 whilst for industrial weathered the coefficient is set from 0.85 to 0.9.

5.3.4 Air Movement

This is the wind conditions subjected to the conductor, both the wind direction and the wind speed. For a static rating the wind direction is set for transverse conditions where the approach angle is 90° to the conductor. When the approach angle is 0°, the wind direction is parallel. ESAA show that the wind speed ratings are based on 3 conditions, still air, 1m/s and 2m/s. As for the IEC 61597, their approach is that of 1m/s. The IEC does not take into consideration natural convection where calm conditions are present. It is for such reasons this is a significant part of the study. In addition to this, Cigré do not provide any static ratings, only a methodology to calculate such ratings.

5.3.5 Conductor Operating Temperature

There are multiple reasons for applying this condition. There may be pre-existing sag issues with a network where if the conductor is overheated above a particular temperature, the clearance to ground is encroached or there could be metallurgical constraints. It could also be that the network was only designed to a particular reduced temperature due to the design standards present at that time. These factors have to be considered in dynamic ratings and the impact of these will be analysed.

Ultimately this dissertation is looking at metallurgical constraints such as annealing. It is acknowledged that the design of EECLs network is at a reduction of such temperature limits. Though for the purpose of uprating a line, it is expected that remedial work may be required.

5.4 Percentage Change in Current Carrying Capacity Due to Varying Conditions

With the parameters identified for analysis, MATLAB code has been constructed which will analyse the percentage change in CCC due to differing conditions. This section does not reflect the actual change in CCC, rather provide the percentage difference as to be able to compare each varying conditions against each other. It aims to obtain how the different models react.

It is important to make known that the IEC 61597 fail to prescribe a value for rural/industrial condition for the solar absorption and emissivity coefficients, a single condition of 0.5 for general use is prescribed. This may be acceptable in European conditions though not for heavy industrial area which EECL's network is often exposed to. As a result the tests below will only show the general condition, hence highlighting the impact of omitting such variances.

The conductor chosen to for testing is, All Aluminium Conductor, 37 strands at 3.00mm diameter, commonly referred to as 'Saturn' (AAC 37/3.00 Saturn). This conductor is a midrange conductor and was chosen as to show a greater variance in CCC, rather than that of a smaller conductor like AAC 7/3.00 Libra.

The MATLAB code for these studies can be found in Appendix D.

5.4.1 Ambient Temperature

The following results are based on a test that was conducted which saw a \pm 15°C temperature change based on 35°C for summer noon and 15°C for winter night. The results for this test yielded the following:

	Rural	Rural	Industrial	Industrial
t_a	Weathered	Weathered	Weathered	Weathered
	Summer Noon	Winter Night	Summer Noon	Winter Night
ESAA D(b)5	≈ 48%	≈ 22%	≈ 54%	≈ 22%
IEC 61597	≈ 45%	≈ 37%		-
Cigré TB601	≈ 53%	≈ 26%	≈ 63%	≈ 26%

 Table 9: % Change in CCC due to change in ambient temperature





Figure 25: ESAA D(b)5 - Percentage Change in CCC - Ambient temperature



% Variation in CCC as per Variation in Ambient Temperature - IEC 61597

Figure 26: IEC 61597 - Percentage Change in CCC - Ambient temperature



Figure 27: Cigré TB 601 - Percentage Change in CCC - Ambient temperature

5.4.2 Direct Solar Radiation

The results are based on a test that was conducted which saw a range from 700 W/m to 1300W/m summer noon and winter night. As expected there is no change at night due to no direct radiation available. The results for this found the variation percentage is relatively small though for industrial weathered conductors, the additional impact is noticeable. The test yielded the following:

Rural Rural Industrial Industrial Weathered Weathered Weathered Weathered Idir Winter Night Summer Noon Winter Night Summer Noon ESAA D(b)5 ≈ 7% $\approx 0\%$ ≈ 12% ≈ 0% IEC 61597 ≈ 5% $\approx 0\%$ ---Cigré TB601 ≈ 8% $\approx 0\%$ ≈ 19% $\approx 0\%$

Table 10: % Change in CCC due to change in diect solar radiation





Figure 28: ESAA D(b)5 - Percentage Change in CCC - Direct solar radiation



Figure 29: IEC 61597 - Percentage Change in CCC - Direct solar radiation



Figure 30: Cigré TB 601 - Percentage Change in CCC - Direct solar radiation
5.4.3 Absorptivity

The results are based on a test that was conducted which saw a range from 0.5 to 0.8 summer noon and winter night. As expected there is no change at night due to no direct radiation available. The results for this found the variation percentage is relatively small though for rural weathered conductors, the additional impact is noticeable. The test yielded the following:

	Rural	Rural Rural		Industrial
а	Weathered	Weathered	Weathered	Weathered
	Summer Noon	Winter Night	Summer Noon	Winter Night
ESAA D(b)5	≈ 8%	$\approx 0\%$	$\approx 7\%$	$\approx 0\%$
IEC 61597	≈ 5%	$\approx 0\%$		-
Cigré TB601	≈ 8%	$\approx 0\%$	≈ 19%	$\approx 0\%$

Table 11: % Change in CCC due to change in Absorptivity



Figure 31: ESAA D(b)5 - Percentage Change in CCC - Absorptivity



Figure 32: IEC 61597 - Percentage Change in CCC - Absorptivity



% Variation in CCC as per Variation in Absorptivity - Cigre TB 601

Figure 33: Cigré TB601 - Percentage Change in CCC - Absorptivity

5.4.4 Emissivity

The results are based on a test that was conducted which saw a range from 0.5 to 0.8 summer noon and winter night. Again the results yielded a small variation in percentage., the additional impact is noticeable. The test yielded the following:

	Rural	Rural	Industrial	Industrial
е	Weathered	Weathered	Weathered	Weathered
	Summer Noon	Winter Night	Summer Noon	Winter Night
ESAA D(b)5	≈ 5%	$\approx 4\%$	≈ 6%	$\approx 4\%$
IEC 61597	≈ 4.5%	≈ 4%		-
Cigré TB601	≈ 5%	$\approx 4\%$	≈ 6%	$\approx 0\%$

Table 12: % Change in CCC due to change in Emissivity





Figure 34: ESAA D(b)5 - Percentage Change in CCC - Emissivity



Figure 35: IEC 61597 - Percentage Change in CCC - Emissivity



% Variation in CCC as per Variation in Emissivity - Cigre TB 601

Figure 36: Cigré TB601 - Percentage Change in CCC - Emissivity

5.4.5 Wind Speed

This test that was carried out with a wind speed range of 0.25 m/s to 6 m/s summer noon and winter night. With a nominal wind speed of 2 m/s the results returned proved that there is room for scope in dynamic ratings. The most significant finding is that the condition of the conductor does not hinder the ability to get an output change along with either day or night time conditions. The results are as follows:

	Rural	Rural	Industrial	Industrial
ν	Weathered	Weathered	Weathered	Weathered
	Summer Noon	Winter Night	Summer Noon	Winter Night
ESAA D(b)5	≈ 90%	≈ 60%	≈ 92%	≈ 55%
IEC 61597	≈ 75%	≈ 65%		-
Cigré TB601	≈ 90%	≈ 75%	≈ 90%	≈ 70%

Table 13: % Change in CCC due to change in Wind Speed



% Variation in CCC as per Variation in Wind Speed - ESAA D(b)5



Figure 37: ESAA D(b)5 - Percentage Change in CCC – Wind Speed



Figure 38: IEC 61597 - Percentage Change in CCC – Wind Speed



% Variation in CCC as per Variation in Wind Speed - Cigre TB 601

Figure 39: Cigré TB 601 - Percentage Change in CCC – Wind Speed

5.4.6 Wind Approach Angle

This analysis was conductor between wind approach angles of 0° to 90° for both summer noon and winter night. The outcome was unique. As a static rating is based on a 90° approach angle, the rating of the conductor can be significantly reduced if that angle is reduced. This is again significant information required when applying a dynamic rating. In addition to this there are no results for the IEC 61597, The methodology provided does not include scope to change the wind angle. The results yielded are:

Table 14: % Change in CCC due to change in Wind approach angle

	Rural	Rural	Industrial	Industrial
ψ	Weathered	Weathered	Weathered	Weathered
	Summer Noon	Winter Night	Summer Noon	Winter Night
ESAA D(b)5	≈ 90%	≈ 60%	≈ 92%	≈ 55%
IEC 61597	≈ 75%	≈ 65%		-
Cigré TB601	≈ 90%	≈ 75%	≈ 90%	≈ 70%



Figure 40: ESAA D(b)5 - Percentage Change in CCC – Wind Approach Angle



Figure 41: Cigré TB 601 - Percentage Change in CCC – Wind Approach Angle

5.5 Characteristics of Cigré TB 601 – Change in Latitude

The complex calculation provided by Cigré for solar radiation takes into consideration the latitude, time of day and days of the year. This was tested in MATLAB as to gain a better understanding of its impact when calculating the CCC.

The test was conducted across the period of a year with 1 degree increments is latitude from southern QLD, Stanthorpe region, through to northern QLD, cairns region. This was chosen as it is covers the extent of EECL sub-transmission network.

The results of this test show that there is extra capacity in the winter months, the closer the network is to the equator. The change is quite minor and its significance is further reduced by the fact that the southern regions are cooler through the winter

The results of this test can be seen below in Figure 42.



Figure 42: Cigré TB601 - Change in CCC due to global location

5.6 Dynamic Conditions Analysis

Having conducted that study to analysis individual components of the HBE, a further study was conducted to see how such variations compare to one another. This was completed with the Cigré methodology as it provided to be the best equation due to its sensitivity.

The purpose for this study was to further develop scope into selecting only a limited amount of conditions to monitor for the implementation of dynamic ratings. The variables analysed are:

- Reflected solar radiation
- Absorptivity and emissivity
- Wind approach angle
- Wind speed
- Ambient temperature

Reflected solar radiation was chosen as to gain an understanding into its impact on line ratings. Absorptivity and emissivity are going to be analysed as one entity as they are subjected to the condition on the overhead conductor. Wind approach angle and wind speed have been analysed as they have an inherent ability to significantly change the rating and ambient temperature as the summer noon and winter night ratings are not valid year round.

The results of this analysis were examined only to find fairly expected results. That is that the reflected solar radiation has a limited consequence when applied to dynamic situations, as too does the absorptivity and emissivity. These factors are still required to produce a DLR though. Likewise for the wind conditions and ambient temperature, their influence is significant and can clearly provide the opportunity to uprate or de-rate depending on the conditions.

These can be seen in Figure 43 and Figure 44.



Figure 43: Cigré TB 601 – HBE variable comparison (3D analysis)

The purpose of producing a 3D analysis is to gain a visual understand of the differences. This plot clearly displays the wind conditions and ambient temperature's ability to alter the conductor rating. Further understanding into reflected solar radiation and absorptivity and emissivity was found in Figure 44, where it can be seen that they have a very limited impact.



Figure 44: Cigré TB 601 – HBE variable comparison (2D)

From the results of these tests, wind speed, wind approach angle, and ambient temperature have been selected for use as to provide dynamic ratings. With this methodology, further test were conducted to see the plausibility of changing wind angle and speeds. Figure 45 shows this.



Figure 45: Cigré TB 601 – HBE wind speed v wind angle (2D)

The current static rating only applies a 0, 1 and 2 m/s loading on the conductor and an approach angle of 90°. As you can see from the plot above, there are a lot of other combinations which can affect the ratings. It also clarifies the importance of monitoring wind conditions as if there is large periods of low wind speeds and 0° approach angles, the chance of receiving annealing damage is immediately increased. This concept is looked at closely in chapter 6.

5.7 Section of HBE

From the test conducted it has identified that the HBE provided by ESAA D(b) 5 is in fact adequate to provide the CCC for EECL. The difference between this methodology and that of the Cigré TB 601 is very minor. The main contributor to this, being the consideration of the conductor's location (latitude), hence this has little effect on the CCC. The Cigré methodology would be best suited for a small conductor network or to that of a substation busbars, as to fully utilise its capacity.

With convection cooling being a major factor in a DLR, the methodology provided by IEC is rendered the lease preferred option when calculating the CCC due to its still parameters for; calculating the Reynolds number; a single set of parameters to calculate the Nusselt number; and no alternate methodology for natural convection.

5.8 Chapter Summary

This Chapter has presented the results found from the sensitivity analysis of the three different HBE methodologies. From these results the following conclusions can be made.

• The methodology provided in the IEC 61597 provides the least amount of flexibility in adjusting the parameters of the HBE. Subsequently affecting its ability to provide accurate predictions of CCC.

- The methodology provided by Cigré TB 601 has minor differences to the ESAA D(b)5, in that it takes into consideration the location of the conductor on the earth (latitude).
- The results from the Cigré TB 601 are very similar to that of the ESAA D(b)5, suggesting that the current methodology used by EECL is satisfactory.
- DLRs are possible based upon dynamic adjustments of the following parameters; wind approach angle; wind speed; ambient temperature. All other parameters are to be static and selected based upon the location of the conductor and the conditions it is exposed to.

The completion of the sensitivity analysis, has enabled objective (2, 3 & 4) (refer to section 1.4) to be completed. This has resulted in the selection of the HBE required for use in EECL being the ESAA D(b)5.

Chapter 6

Analysis of Real Time Data & Damaged Properties

6.1 Chapter Overview

To gain a high level of confidence in the accuracy of the CCC provided by the HBEs, are a priority for this dissertation. To achieve this, 2 case studies have been conducted which test the accuracy of the predicted CCC and to prove that there is either extra or a reduction in ampacity on the network. This has been done with the use of real time data, which has been made available by EECL.

To complete this task, all three HBEs have been used and tested against sampled weather conditions, conductor temperatures and load levels. The cases span across both the distribution and sub-transmission networks. Due to the location of these feeders being sensitive corporate information, the feeders will not be referred to by name or location.

Furthermore it is hopeful that that this analysis will provide further clarity and weight to justify the correct selection of HBE for EECL

6.2 Real Time Weather Data

As stated, EECL has access to historic weather data the BOM. This information can be extracted from the EECL database via a SQL Query. From the query, the following is accessible; weather station number; date time; air temperature; wind direction; and wind speed (m/s). The report has found that there are some instances where the full date time data has missing entries. Whilst this is problematic, the actual date is still provided allowing the data can be modelled. This issue is present with the days required to analyse in the first case study. The data is extracted in the form of .csv file which can be converted to an .xls file and entered into MATLAB.

6.3 Real Time Load and Conductor Temperature Data

Currently EECL is using a 'SMART Navigator LM' (by Horstmann GmbH), overhead fault circuit indicator to monitor line current and temperature. This device pictured below in Figure 46 has remote communications which allows it to connect to the EECL SCADA system. To measure the line temperature, a thermo-couple is inserted into the device. The measured data can is extracted at a sample rate of 1 minute. This data can be exported to an .xls file allowing it to be imported directly to MATLAB.



Figure 46: Line Current and Temperature Meter²¹

²¹ Source: EECL by Greg Caldwell

6.4 Case 1: Feeder 'x' - Maximum Conductor Operating Temperature Breach

On January 27, 2015, the conductor (AAC 7/0.134" Fly) of feeder 'x' was exposed to operating temperatures of approximately 70°C. This is above the maximum allowable temperature for the network, 50°C. Data was gathered from 26 - 28 Jan 2015. The data returned average peak loads and temperatures of approximately 230A and 60°C respectively, with the exception of the 27th Jan at 230A and 70°C. See Figure 47 for the load and temperature profiles.



Figure 47: Feeder "x" Temperature and Current - Real Time

From Figure 47, it can be seen how the peak load on the Jan 27 produces a maximum conductor temp of almost 70°C, yet on Jan 28 the similar peak loads produce conductor temperatures of about 60°C.

To get an understanding of why this occurred, the wind conditions were analysed and it was found that the wind conditions were at a worst case scenario for Jan 27 during times of peak load conditions. The data in Figure 48 shows that there was a significant period of no wind at around sample 10 followed by wind with 0° approach angle around

sample 20. It is estimated that this is the approximate time when the feeder experiences high conductor temperatures.

From this data it is evident that the loads will produce an increase in Conductor temperature. It also proves that the dynamic conditions can be either beneficial or detrimental.



Figure 48: Wind Condition - Feeder "x" 27 Jan 2015 to 28 Jan 2015

With an understanding of how the temperature breach occurred. The following data was entered into the HBEs and tested to see if the predicted CCC correlates to the actual CCC.

This data was modelled and the results can be seen in Figure 49.



Figure 49: Feeder "x" CCC based on Dynamic Conditions

This figure clearly identifies that the CCC can be estimated from the HBEs, in particular the methodology provided by Cigré and ESAA. Again we know that the temperature breach occurred around sample 20-22. This plot shows a significant reduction around that time where the HBEs provided the following CCC:

Table 15: Estimted CCC from HBEs for case 1

	Measured CCC	Approximate CCC	% error $\left[1 - \frac{Measured CCC}{Approx CCC}\right] \cdot 100$
Cigré TB601	230A	255A	9.8%
ESAA D(B)5	230A	235A	2.1%
IEC TR 61597	230A	470A	51.1%

As the real time data in Figure 47 indicates that this occurs with peak loads of approximately 230A, it can be said that the ESAA methodology provides a very close estimation. Typically, a 5% error is considered acceptable by EECL. The alarming fact here is that the IEC methodology produces a very inaccurate result. This is expected, due to the inability to adjust the various convection components.

6.5 Case 2: Extra Capacity in the Network

Recently, EECL has conducted a survey of a backup sub-transmission network in southern QLD. This was completed so that the sub-transmission line could be uprated, allowing for the primary network to be isolated for major redevelopment, hence eliminating the need to construct a new power line. Whilst this reduced EECL capital expenditure for securing power to the region, it also significantly increased the risk of damaging the smaller backup sub-transmission line.

The contingency was implemented with regular monitoring. The original meters used to monitor the line were a set and forget meter with no remote access. This became a problem as the contingency arrangement was required to run through the late spring months where some harsh weather conditions became present. For the dates surrounding the 22/10/2014 to the 28/10/2014 there was a predicted heat wave which arose to initial concerns of annealing damage. As there was no remote access to monitor the conductor's temperature, a risk was taken to continue with the contingency and analyse the results after.

Since then, EECL as conducted their own analysis which shows that the network was not exposed to any damage. It is believed that this outcome was due to better than normal wind conditions and additional conservative measures in a static rating.

Figure 50 on the following page shows that on the 27-10-2014, the peak afternoon temperature was approximately 41 to 42°C. The static rating is generally calculated on an ambient temperature of 35°C, hence according to the static rating, the load will be too high and annealing damage will be present. However, this was not the case as the conductor never exceeded the minimum design temperature of 50°C. This case study highlights the fact that EECL's network has extra capacity available.



Figure 50: 33kV Feeder 'y' - Extra capacity above static rating²²

²² Source: Gregory Caldwell – EECL

6.6 Conductor Damage Properties

The implementation of DLRs, introduces addition risk of conductor damage. As stated in section 2.4 of the literature review, there is an allowable loss of 3% of the original tensile strength after 1000 hours of exposure to the maximum temperature limit for normal operation, whilst the permissible conductor cumulative annealing damage shall not exceed 15% of the CBL over the life of the conductor. With this restriction, it becomes increasingly hard to define what limit of risk is allowed in the DLR calculation, as to achieve the desired CCC, where there are no records kept of high operating temperatures and no reduction in tensile strength studies completed after fault conditions and lightning exposure. To alleviate this problem, EECL has begun sampling sections of the network to determine the integrity of the conductor. The tests performed consist of:

- Visual examination for deterioration, flaking, corrosion, scaling and heat damage
- Dimensional measurement of each assembled conductor and individual strands
- Determination of breaking load and tensile strength
- Metallographic examination of selected regions of interest

From these test, a tensile strength can be determined. Figure 51 below shows how the reduction in tensile strength for AAC 37/3.00 Saturn conductor is produced due to different operating temperatures. The annealing curves provide in appendix BB of AS 7000 show an average loss of tensile strength as per the conductor material, it does not take into consideration the sizing of the strands and the average operating temperature range. As it can be seen from Figure 51, there is very little (<1%) reduction in tensile strength of this conductor at 80°C over 10000 hours exposure.



Figure 51: Reduction in tensile strength from 50 to 80° C at 0 to 10000 hours for AAC 37/3.00 Saturn Conductor

From this information, the damage found in case study 1, indicates that the annealing would have been minimal and subsequently having little impact on the life of the conductor. By using this information EECL can determine if the life of the conductor will be significantly diminished.

6.7 Chapter Summary

The purpose of this chapter was to justify the results found from the sensitivity analysis by conducting case studies into dynamic arrangements. In addition to this the conductor damage properties were examined as to calculate the mechanical dangers inherited by moments of high conductor temperatures. The results of these studies produced the following:

- Prolonged exposure to harsh wind conditions and high ambient temperatures can significantly increase the possibility of high conductor operating temperatures.
- Based on the condition of the network, there is a very real expectation that there is extra capacity available. To be able to utilise this, the conductor will require monitoring via devices which have remote engineer access.
- EECL has the ability to calculate the extent of the pre-existing damage to their network via external testing and sampling. This test allows for a % tensile strength test to be undertaken resulting in an indication of how much life the conductor has as the conductor is not allowed to be below 15% of the CBL. This will prove to be a critical task for most DLRs.

The completion of this chapter has enabled objective (5, & parts of 8) (refer to section 1.4) to be completed.

Chapter 7

Model – Dynamic Conductor Ratings

7.1 Chapter Overview

A DLR is only available if there the appropriate data has been gathered, analysed and understood. This chapter aims to identify the essential data required to produce a DLR whilst providing rating engineers with additional confidence.

The model created can be found in the form of a flow chart in Appendix B. The model is structured with 5 major components, they are:

- General conditions
- Analysis of conductor rating parameters
- Identification of problematic issues and rectification
- Production of DLR

• Implementation of DLR and continual monitoring

The 5 stages have been broken down as to provide clarity for each part of the process.

7.2 General conditions

This is the initial part of the dynamic rating process. It is at this stage the location of the network is identified along with the duration of the dynamic requirements. The correct information gathered here allows for an appropriate selection of data, for that which is required for the analysis.

7.2.1 Network Location

EECL has a very extensive network with both short and long, industrial and rural, distribution/sub-transmission lines. It is for this reason that a general understanding of the network and the terrain it is subject to is required. Furthermore this reinforces, that which is highlighted in chapter 4, as the effectiveness of the weather conditions are generally determined by the terrain surrounding the conductor. The following information is required for gathering.

7.2.1.1 Physical location

A map of the entire network in question is to be ascertained. EECL has this information available as the entire network is graphically superimposed on top of a map of QLD via google maps.

7.2.1.2 Orientation

This the direction for which the network is built, i.e. north to south, east to west, etc. It is important at this stage to document any change in direction for the network as this will be crucial for the wind conditions analysis. If the network is subjected to a 45°-90° bends, the effect of convective cooling could be significantly diminished across that section of the network, creating annealing hotspots.

7.2.1.3 Different terrain

There are situations where the terrain will changed from the start and finish locations. The type of information required here are; network on top of a hill; bottom of a valley; open plain; forest; etc.

7.2.1.4 Ground type

This data is required to provide the albedo (reflected solar radiation). It may also be possible that the type of ground surface exposed to the network could change tough. This data may also be able to help identify weak points (reduction in tensile strength) in the network.

7.2.2 Duration & Purpose– Dynamic Rating

The duration of the dynamic rating is critical. There are multiple reasons for which a dynamic rating may be required. The time of the required rating is pivotal when collecting the essential data for the second stage of the dynamic model, such that there may be times when the dynamic condition is not available due to the seasonal influence of the weather conditions. The information required for gathering here is:

7.2.2.1 Proposed Start and Finish Times

The dynamic rating may be required for a short, medium or long time. Short-time conditions may be that of a few hours to a couple of weeks. Medium-time scenarios may consist of a couple of weeks to a month. Long-time duration periods may range from a 2-3 months (season) or even as great as a year.

7.2.2.2 Purpose for Dynamic Conditions

Such information is required to identify the type of scenario the dynamic conditions are required for. If the dynamic ratings are required for network contingency situations, they will generally result in an increase in load. The requirement may be a result of a large customer producing unexpected load growth coming online, resulting in the static rating being breached during a season condition (summer/winter).

7.3 Analysis of Conductor Rating Parameters

As the flow chart indicates, there are three major components which require analysing; seasonal weather conditions; load requirements; and mechanical limits. By collecting this data it is expected that a DLR will be able to be produced.

7.3.1 Weather Conditions

As established, the weather conditions are pivotal in gaining extra CCC from the network. Utilising the data which was gathered to determine the duration and purpose of the DLR, it should already be identified which season/seasons the DLR is required for.

With this identified, a study of at least 5yrs historical data, where available, and a short/long range forecast is to be carried out. With the historical data, the intention is to

identify the wind conditions, wind speed and wind direction, and the maximum ambient temperature.

In the instance where the wind speeds and wind approach angle are both identified to be poor, serious consideration should be taken into abandoning the dynamic condition and a possible derating of the network should be made known to both the, network ratings engineers and regional asset managers. This information may provide enough scope to upgrade the network as it is at a possible peak capacity. Likewise if the information gathered is shown to be positive and provides scope for increased CCC, the DLR process should proceed.

7.3.1.1 Wind Speed

The analysis of the historical data should consider the frequency of zero wind (<0.5m/s) and low wind conditions (<2m/s). This is to be done using the 5th percentile wind conditions. This will allow for 95% of the wind speed to be greater than that measured (statistical prediction). The purpose of this task is to understand where the wind speeds trend lowest. With this information, it is be used in conjunction with the load analysis to help determine breaches of conductor operating temperature. The forecast data, when available, should be used to solidify the results found for the historical data analysis. It is understood that this may not always be available where the analysis is being carried out months prior to implementation.

If the results of this analysis show that there is a high occurrence of zero and low wind conditions between the hours of 10:00 to 16:00, then it is to be documented that there is an increased risk of annealing for such times. Furthermore, additional research into the daily low profiles will be required to identify when the daily peak loads occur and how serious the poor wind speeds are.

7.3.1.2 Wind Direction

Using the same data source as the wind speed, the wind direction is also required to be analysed. The purpose of this study is to identify what types of wind conditions are present for the time of the DLR. As mentioned in chapter 4, there are specific types of wind conditions experienced across QLD for different seasons, e.g. south east trade winds, these winds are generally from the south east and are present near coastal regions. From this analysis it should be identified what are the typical wind directions for the region of interest and should be compared with the orientation of the network.

If the results of this analysis show that the wind approach angle is generally less than 24° to the conductor, then this too requires documentation as the risk of annealing is again increased. Following the same process as for poor wind speed conditions, additional research into the daily load profiles will be required to identify when the daily peak loads occur and how serious the poor wind approach angles are.

7.3.1.3 Ambient Temperature

The sensitivity analysis shows that the ambient temperature has substantial impact on the CCC of the network. Again the historical data is required to analysis the peak temperatures across the period of the DLR and the time of day which it occurs. This significance of the results is to be tested in the same manner as the wind conditions. The forecast data is to be tested against the historical data and analysed to see the impact on the proposed CCC.

7.3.2 Load Requirements

The purpose of this investigation is to determine a load profile for the proposed DLR period. This will enable the engineer to determine the peak loads across the duration, hence providing the how much extra ampacity is available in the network. It will also enable the engineer to identify peak times of annealing risks and where possible, the required information for protection engineers to ensure that the network will trip on load. Protection relays for remote rural feeders/sub-transmission lines are often subjected to low pick-ups and a significant increase in load may bring peak loads inside the 80% loading margin.

7.3.2.1 Load Profile

To determine the peak load profile, the engineer will be required to gather the historical data from current state assessment (CSA). This will provide the peak loads for both the summer and winter periods. Generally this is when the peak periods of load occur. Following this, the peak loads for the period of the DLR should also be collated.

Similarly the forecasted peak loads should also be gathered. This can be calculated from the forecasted percentage load growth which is made available from the CSA.

The flow chart asks if the DLR is for contingency loads. The intension of this is to determine if there are additional loads added to the network, e.g. Network tied, or if the dynamic condition is required as the static rating is becoming too low for seasonal loads. If the rating is for a contingency operation, both existing load profiles are to be gathered and added to create a new peak profile. The same process should be followed as provided above for calculating the load profile for the DLR.

Once the profiles are developed they are to be analysed to determine the times of peak load. This information may be required for the weather analysis if the conditions are too poor.

After this research is complete, a simple 'sanity' check of the data should be conducted. It is possible at this stage to know if the required rating is far too great for the conductor to handle. If this is the case the DLR should be abandoned as the risk annealing is too high. Otherwise, proceed with the DLR.

7.3.3 Mechanical Limits

The entire process of creating a DLR is to limit the impact of the mechanical limitations for the network in question. This is increasingly harder to manage than the electrical properties. As stated by the limitations of the project (refer to section 1.5), this study does not take into consideration of the make-up of the miscellaneous line equipment, i.e. dead ends, line connectors, etc.

The purpose for this part of the process is to collate the data surrounding the conductor material and the type of construction the network is exposed to.

7.3.3.1 Pole Top Configuration

The intention here is to identify if there are any stages of the network which are considered to be dangerous if a DLR is implemented. The pole top configuration may become dangerous if the increase in conductor temperature produces too much additional sag, hence the encroachment of clearances is present. As the literature states, there are many types of clearances to take into considerations, refer to section 2.4.4 for further details of these.

A type of configuration that may become dangerous is that of the 'wishbone' configuration, along with other configurations where phases are below one another. Such construction types can become dangerous if they are not equally balanced. The danger becomes inherent if the above phase sags more than the bottom producing a reduction is clearance. Examples of such constructions can be seen in Figure 52.



Figure 52: Possible Dangerous Configurations due to DLRs²³

If the configuration is considered to be dangerous, it is to be documented and research into the design parameters, such as max operating temperatures should be ascertained. Furthermore, the load profiles of each phase might also be required as to calculate the sag on each phase. Each phase is required to be tested as the network is regularly transposed (rotated) as to neutralise inductive/capacitive loading across phases, hence each phase is required to be analysed against each other.

²³ Sourced by EECL – Greg Caldwell

7.3.3.2 Additional Circuits

It is common for urban sub-transmission circuits to share poles with other distribution circuits. This may also become a problem when implementation a DLR, as for the same reasons as a configuration becoming dangerous, clearances. The possibility of coming inside such clearances is progressively increased when the temperature is increased. If this situation is present, document it and complete the same process of analysing the sag, 'between phases', except analysing the clearance between networks.

7.3.3.3 Statutory Clearances

This is looking at the clearance between the ground and the conductor. By law, it is mandatory that distribution companies maintain the appropriate clearance. This information has been sampled by the ROAMES technology which EECL uses to map the entire network. Where the conductor is at risk of encroachment or already encroached the DLR shall not proceed and corrective action should take place.

7.3.3.4 Condition of Conductor

The most significant part of the mechanical limits study is the gain an understanding of the condition of the conductor. As the conductor is overheated, the irreversible process of annealing takes form. With the vast majority of EECLs remote rural network being old (>30yrs), its condition has become unknown.

The key importance for this part of the process is to determine that tensile strength of the conductor. Section 6.6 shows the processes in place to gain an understanding of the mechanical integrity of the network.

Where it is known that the conductor is old and/or has a lack of damage records, resources such as sampling and testing, is recommended. Dependant of the result, the DLR should either produce a rating which either uprates or de-rates the network.

7.4 Identification of Problematic Issues and Rectification

It is the expectation that there will be recommendations from the studies conducted in the previous part of the DLR process. Where a problem has been identified, this section aims to provide the means to possibly resolve issue. Any issue that requires rectification should be made known to the rating engineers, and the associated area asset officer, along with possible remedial action. Where economically viable, the network should be upgraded and the problems resolved. Each case should be documented and kept as records as to enhance the knowledge base of EECL and the engineer.

7.5 Production of Dynamic Line Rating

The sensitivity and case studies have proven that the methodology provided by the ESAA D(b)5 is sufficient for EECL to continue using. With this in mind the rating engineers have already created a spreadsheet which allows for the dynamic parameters to be adjusted as per the present conditions. Understanding this, the results of the above studies can be collated and a DLR can be calculated.

The values used should be that which produces the maximum CCC for the conditions present. With this value, the CCC can be mapped and the result can be compared to the load profile as to see if the revised CCC is greater than the load profile.

For the possibility where the DLR is less than the load profile, the DLR will not be available. If this is the case it may be possible for network operations to adjust load profiles further, by means of additional load shifting. If this is possible the DLR can be compared again, though is unsuccessful, the DLR will not be available.

In the event where the DLR reduces the current capacity of the network, notification to the appropriate groups shall be issued.

7.6 Implementation of DLR and Continual Monitoring

It is understood that the risk of overheating the conductor is still a possibility. This is the case with both a static and dynamic rating, the difference being the risk has increased with an uprated dynamic condition. It is with this knowledge; the implementation of a DLR should also coincide with the installing of meters with remote engineering access. The meters provide to capability to monitor the condition via SCADA can and provide alarms to operations when the condition becomes unstable, i.e. breach of max operating temperature. This also creates a knowledge base for EECL to draw on and to model to continue to gain a better understanding of dynamic ratings.

Upon issuing the DLR for implementation, network operations should have a contingency switching plan in place that allows for the existing network arrangement to be reinstated if the conductor reaches a dangerous operating temperature. It is also understood that a DLR should only be implemented with a high level of confidence that this situation won't occur, whilst understandably knowing that it can.

7.7 Chapter Summary

It has been the intention that his chapter provide the capabilities for a ratings engineer to undertake a substantial study which can possibly result in a DLR. It is also the intent of this chapter to provide the necessary steps to build a foundation for which EECL can continue to grow confidence in the dynamic ratings sector.

If the engineer is to follow this process it is expected that task will return the following information for the network in question:

- A thorough understanding of the terrain, orientation and location of the network
- The duration and period for the DLR

- A study of subjective; seasonal conditions; load requirements; and mechanical limits
- Any remedial work which may be required to be completed prior to implementation
- A proposed DLR with an action plan for unstable conditions
- And further monitoring capabilities for a continually growing knowledge base

The completion of this model has enabled objective (5) (refer to section 1.4) to be completed. This has resulted in an adequate process to enable a DLR to be calculated with confidence.

Chapter 8

Industry Application and Justification

8.1 Chapter Overview

The purpose of this chapter is to produce a sample DLR following the process which has been provided in chapter 7. Confirming that a DLR can be produced is a main objective this chapter though it is also intended to provide clarity into the associated impacts, such as; possible tensile strength reduction. Finally this chapter aims to highlight the industry benefits and dangers associated with a DLR, as to justify the implementation of such scenarios.

8.2 Dynamic Application

The feeder selected for analysis is the 33kV Rywung Feeder out of Chinchilla Town Substation (MC007). The reason for selecting this feeder is that it is currently underrated to supply both its primary load (33/11kV Rywung Substation) (MC017) and its secondary load (33/11kV Miles Substation) (MC008). The network is arranged so that a feeder tie is required to be closed if it is to supply MC008, hence only supplying
load to MC017. This restriction is due to the risk of annealing being too high based upon the current static rating process. The schematics of this network are made available in Appendix C.

It is to be noted that this is a feasibility study and is still subjected to a ratings engineer approval.

8.2.1 Limitations of the Study

For the purpose of this study there are a couple of limitation is place. Due to the current economic environment, it is outside EECL scope to provide a sample of the network for this study. As this study is purely a feasibility study, this is understandable. The forecasted weather conditions and duration will not be available as there are no specific times for application applied to this study. If this study was to be conducted for the actual purpose of implementation, then it would be recommended that the above be made available.

8.2.2 Collation of Data

Following the process form chapter 7 the following data has been found for analysis.

8.2.2.1 Network Location

The network in question spans between Chinchilla and Miles. This network travels in a general east to west direction. The specifics of the network are described as follows;

- Conductor type: 7/2.00 HDBC
- Length approx. 45km
- Orientation: approx. 17km SEE to NNW, 28km E to W
- Subjected to multiple altitudes ranging from 304-373m above sea level
- Terrain: Clear plains 0-29km, channel between trees 29-50kms

- Ground conditions: grass and crops Albedo 0.2
- Weather Zone: Central Tablelands South

8.2.2.2 Analysis of Conductor Rating Parameters

From the seasonal conditions, load requirements and mechanical limits, the following has been found.

• Seasonal Conditions: From the data collected by EECL, following has been found.

Table 16: 33kV Rywung Feeder - DLR weather conditions

	Summer	Winter
zero wind condition high	18:00 to 07:00	18:00 to 09:00
zero wind condition low	08:00 to 17:00	10:00 to 17:00
ambient temperature max	~ 37°C	~ 23°C
ambient temperature max & zero wind low	~ 30°C	~ 23°C
ambient temperature max & zero wind high	~25°C	~12°C
5 th percentile max wind	1.5m/s	1.4m/s
wind approach angle	~37.5°	~33°

• Load requirements: From the data collected by EECL, following has been found.

	Sun	nmer	Winter		
	MC008	MC017	MC008	MC017	
maximum demand	195A	10A	175A	5A	
growth rate	4.0 %	1.5 %	4.0 %	1.5 %	

Table 17: 33kV Rywung - DLR load conditions

- Mechanical limitations: From the data collected by EECL, following has been found.
 - Pole Top configuration standard no danger
 - Additional circuits no
 - \circ Condition of Conductor sound

8.2.3 DLR Results

To be able to select the appropriate conductor temperature for the DLR analysis, a study was done on the percentage reduction in tensile strength. To do this, it has been estimated that 33kV Rywung Feeder would be required to run at contingency levels, at a worst case of 1 week per year. As the conductor is old HDBC and EECL has a priority to replace HDBC when appropriate, it has also been estimated that the conductor only has approximately 10 years life left. From this, a risk factor of 1% to 7% for operating at high temperatures has been applied to the total exposure hours.

From these assumptions the following hours of exposure were graphed against the annealing damage for operating temperatures of 50°C to 80°C. Figure 53 shows how the percentage of high exposure reduces the tensile strength of the conductor.

To calculate the results, an annealing test was conducted with the max temperature of the line a t 80°C as to test the limits of the DLR.



Figure 53: 33kV Rywung Feeder - Exposure to annealing damage

From this data a profile can be produced for the DLR. There are two profiles created for this example, summer and winter. The results indicate that the dynamic rating of the conductor is greater in the summer months as the wind conditions are a lot better. As the location of the network is in a dry regional area, the temperature in winter is still high whilst the wind speeds and wind approach angles are less severe, hence has a reduced effect.

The results of the study are:

	DLR Test						
	Day		Evening		Night		
33kV Rywung Feeder	Jan-Mar 2015,		Jan-Mar 2015,		Jan-Mar 2015,		
	09:00-17:00		17:00-22:00		22:00-09:00		
	(9am - 5pm)		(5pm to 10pm)		(10pm - 9am)		
	Summer						
	Static	Dynamic	Static	Dynamic	Static	Dynamic	
	172	275	166	277	140	232	
	Winter						
	Static	Dynamic	Static	Dynamic	Static	Dynamic	
	182	320	171	72	159	290	
	Static	Dynamic	Static	Dynamic	Static	Dynamic	
	N/A	257	N/A	67	N/A	259	

Table 18: Results for DLR analysis

It was alarming to see the average ratings for autumn and winter evening so low, though for the location, the wind studies show that the evenings and nights are regularly subjected to calm wind. This reduces the effect of the cooling. The impact of this issue is reduced as the night loads are significantly less than the day.

To calculate the dynamic ratings, sampled data was used and tested against the HBE from the ESAA D(b)5. From this the dynamic ratings were broken up into their time zones: Day; Evening; and Night, and the mean was taken. The dynamic CCC of the network can be seen in Figure 54 to Figure 56. The plots show sampled data for summer, autumn and winter for 2015. Additional data across multiple years was analysed also analysed though each year was sampled individually, hence for reference only one set of summer autumn and winter seasons were displayed,

Also to be noted is the DRL for the autumn months were additionally analysed to see if an intermediate rating would be beneficial. This proved a worthy cause though as dynamic rating was worst midseason. This indicates that sampling and analysing autumn and spring months are required. Whilst this may be of concern, it should also be reiterated that the load is typically less these times of the year.



Figure 54: Summer Dynamic CCC for 33kv Rywung Feeder



Figure 55: Autumn Dynamic CCC for 33kv Rywung Feeder



Figure 56: Winter Dynamic CCC for 33kv Rywung Feeder

From this study, it is evident that the sub-transmission line can be uprated and de-rated.

The results do prove that this contingency DLR is feasible, though it is recommended further work be done to calculate the current state of the network to properly determine the risks associated with this network.

8.3 Industry Benefits

It is the expectation from customers, that electricity supply authorities provide a secure network. That is, customer minutes (outages) are kept to a minimum. This often comes at a very expensive price as aging assets deteriorate and load growth is continually on the rise. This section of the projects shows that possible benefits of utilising a DLR.

From the analysis of 33kV Rywung Feeder, it was found that dynamic rating would eliminate the need for H.V. Generation to supply Miles Substation MC008, in the event of an unplanned outage on MC008's primary incoming feeder. The expenditure below have been made available by the regional asset management (RAM) team form EECL, as to the expected traditional cost of catering for a planned outage.

• H.V. Generation

To cater for Miles Substation, the following would be required; 3 Generation sets; contingency substation design showing the arrangements for the temporary connections to the substation, along with earth grid studies and the required electrical schematics; protection relay studies and settings; and general associated installation and monitoring cost.

Cost: approx. \$300 000 for 1 week.

• 33kV Rywung Feeder Redevelopment

This process would see the following take place; Sub-transmission line design to be completed; procurement of all equipment; contingency plans for 33kV Rywung Substation MC017 supply; reclaim the original network; inspect current state of the power poles and replace where necessary; run new network; and commissioning.

Cost: approx. \$1M per 5kms (given the project experiences no major issues).

Total cost: approx. \$9.5 M

• Implementation of a DLR

This process consists of; producing a DLR; protection relay setting reviews; procurement of meters; operations to create control measures for high temperature situation.

Cost: approx. \$10 000 - \$20 000

This analysis shows a significant cost benefits to supply authorities, hence validating the importance of investigating such ratings. Overall benefits of the DLR are:

- Reduction in H.V. Generation
- Prolonging the replacement of overhead conductors due to annual load growth
- Reduction in customer minutes unplanned outages
- Greater access to the network providing more flexibility for operations to switch portions of the network in and out.

Along with benefits, risks are also associated with DLRs. Some of these risks are as follows:

- Possible reduction in the lifespan of the conductor due to annealing
- Increased risk of failure due to an incorrect DLR

- Increased chance of breaching statutory clearances due to increase conductor sag, along with other associated clearances.
- Possible loss of life to a pedestrian from a fallen power line due to a poor DLR.

The risk shown, highlight the reasons why static ratings are chosen to rate the network. They are very conservative and they enable a long lifespan for the conductor. Such risks should always be taken into consideration when implementing a DLR.

8.4 Chapter Summary

The purpose of this chapter was to show that a DLR could be implemented and a cost saving could be achieved. It is believed that this has been achieved. This chapter also highlights that the risks with failing to apply due diligence to a dynamic ratings are also severe. As engineers have a moral obligation to complete their work to best of their ability with the appropriate sources, it has been shown that a DLR can be produced without sacrificing ones integrity.

The completion of this chapter has enabled objective (8) (refer to section 1.4) to be completed

Chapter 9

Conclusion and Further Work

9.1 Conclusion

The main objective of the project presented in this dissertation was to determine if current HBE methodology utilised by EECL (ESAA D(b)5) is in fact sufficient as it is different to that which is prescribed in the current Australian Standard (AS/NZS 7000:2010), when calculating a DLR. It was revealed that the methodology utilised by EECL is in fact satisfactory. That is, the methodology recommended by the Australian Standards does not cater for the various weather conditions which can be exploited, in an effort to uprate or de-rate the network. Additionally it was established that a dynamic line rating can be produced by adjusting the following parameters; wind speed; wind approach angle; ambient temperature; and maximum operating temperature.

The dissertation established that the implementation of a DLR would cause the overhead conductors to inherit additional risk with respects to a reduction in lifespan. It was also established that EECL currently have no analytical approach suitable to determine the current state of the conductor let alone provide a way to determine such a reduction. To overcome this, the dissertation, prescribes a process which determines the

risk of annealing, by utilising the standards for the mechanical limits such as % tensile strength reduction. This was achieved by initially sampling the network and having tensile strength test completed which in turn provide the current % loss in tensile strength. With the conductor's condition found, the technique of applying a % exposure to high temperature operation to the annealing damage curve, provides the predicted % loss of tensile strength hence the risk of failure for the application.

Having completed the main objective, there was a range of other objectives designed to enhance the knowledge of how conductors are rated. These include; establish to most appropriate HBE for EECL; create a model/process which will confirm if a DLR is available for any particular network; and devise a means for calculating the reduction in lifespan of a conductor if it is exposed to high temperature operations.

The influence of DLRs on the overhead network, as identified in the dissertation, may provide great benefit to electricity supply authorities. Such benefits consist of: network flexibility; additional security; and a reduction in capital and operational expenditure. Likewise there are also negative influences factors including: risk of additional loss of tensile strength; risk of conductor failure; risk of breaching conductor sag limits; and loss of life due to a fallen power line. Understanding the conditions for which the network is exposed has proven to be the single most pivotal piece of information the dissertation has returned.

Overall it believed that the dissertation provides a satisfactory, repeatable process which will enhance the electricity supply authorities the confidence to explore the opportunities of surrounding the implemental of DLRs.

9.2 Further Work

Due to time constraints, it was not possible to investigate all avenues identified at the commencement of the project. As such, these ideas become sources of further work. A list is presented below. The first concept involves a simple continuation of the current work completed whilst the other provides enough scope to become a project in its own right.

1. Model the unsteady state thermal model of a network.

In Cigré TB601, a formula is provided to analyse the unsteady state of the conductor temperature. This will be extremely beneficial in providing additional means of modelling the expected temperature rise in a conductor due to dynamic conditions. In addition to this the ability of forecasting conditions and provide immediate available CCC would become present. This task is relevant based on the research provided in the literature review.

2. Miscellaneous line equipment - electrical

It was established in the literature review that the miscellaneous line equipment will play a significant role in determining a DLR. As these components are subjected to the same currents as that of the power line, they too are also subjected to annealing damage. To what extent, this project has not identified. It would a very interesting topic to review and analyse and is of interest to the author of the dissertation.

3. Mechanical Stresses

Along with the electrical components which subject a conductor to damage, there are also mechanical stress due to wind loading and strain tensions. Such loadings affect the lifespan of the network. This would prove to further establish the effect of high temperature operation with respects to increased surface areas, causing a decreased diameter, being exposed to harsh wind conditions and excessive vibration. Using this information to understand where the mechanical hardening occurs, i.e. near the cross arm tie or the middle of the span is an area of interest.

References

Abbott, S., Abdelkader, S., Bryans, L. & Flynn, D., 2010. *Experimental validation and Comparison of IEEE and CIGRE dynamic line models*. Universities Power Engineering Conference (UPCE), 45th International.

Berjozkina, S., Sauhats, A., Bargels, V. & Vanzovichs, E., 2012. Detecting the Capacity reserve in an Overhead Line. *World Academy of Science, Engineering and Technology*, 1(61), p. 380.

Black, ", Colandairaj, J., Connor, S. & O'Sullivan, B., 2010. Equipment and methodology for the planning and implementatinof dynamic line ratings on overhead transmission circuits. *Modern Electric Power Systems (MEPS), 2010 Proceeding of the International Symposium*, pp. 1-6.

Black, C. & Chisholm, W., 2013. Key Consideration for the Selection of Dynamic Thermal Line Rating Systmes. *Power Delivery, IEEE Transactions on*, PP(99), p. 1.

Cigre, 2006. TB 299: Guide for Selection of Weather Parameters for Bare Overhead Conductor Ratings. Available from: Cigre.

Cigre, 2014. *TB 601: Guide for thermal rating calculations of overhead lines*. Available from: Cigre.

Hydro-Electric Corporation, 2009. *Dynamic Transmission Line Rating Technology Review*, Cambridge: Hydro Tasmania Consulting.

International Electrotechnical Commission, 1995. *IEC TR 61597: 1995: Overhead electrical conductors - Calculation methods for stranded bare conductors*. Available from: IEC.

Jupe, S., Bartlett, M. & Jackson, K., 2011. *Dynamic Thermal Ratings: The State of the Art.* 21st International Conference on Electricity Distribution, Cigre.

Kim, S. & Morcos, M., 2013. An Application of Dynamic Thermal Line Rating Control Systems to Up-Rate the Ampacity of Overhead Transmission Lines. *Power Delivery, IEEE Transactions on*, 28(2), pp. 1231-1232.

Krontiris, T., Wasserrab, A. & Balzer, G., 2010. *Weather-Based loading of overhead lines - Consideration of conductor's heat capacity*. Modern Electrical Power Systems (MPES), 2010 Proceedings of the International Symposium.

Olmsted, L. M., 1943. Safe Raqtings of Overhead Line Conductors. *American Institute* of Electrical Engineers, Transactions of the, 62(12), pp. 845-853.

Powerlink, 2009. TNSP Operational Line Ratings, Brisbane: Powerlink.

Siler, M., Heckenbergerova, J., Musilek, P. & Rodway, J., 2013. *Sensitivity analysis of conductor current-temperature calculations*. Electrical and Computer Engineering (CCECE), 26th Annual IEEE Canadian Conference.

Standards Australia, 2010. *AS/NZS 7000:2010: Overhead line design - Detailed procedures.* 1st ed. Available from: Standards Australia.

Stapleton, G., Miller, T., Pearce, D. & Castillo, M., 2012. *EEP202 Thermal Ratings and Heat Transfer*. Brisbane: Queenland University of Technology.

Staszewski, L. & Rebizant, W., 2010. *The difference between IEEE and Cigre heat balance concepts for line ampacity considerations*. Modern Electric Power Systems (MEPS), Proceedings of the Internation Symposium, pp. 1-4.

The Electricity Supply Association of Australia, 1988. ESAA D(b)5: Current Rating of Bare Overhead Line Conductors. Available from: Sai Global.

V.T., M., 1991. *Thermal Behaviour of Electrical Conductors*. 621.31 ed. Brisbane: Research Studies Press & John Wiley and Sons.

V.T, M., 1979. The Loss of tensile Stength of Hard-Drawn Conductors by Annealing in Service. *Power Apparatus and Systems, IEEE Transactions on*, PAS-98(3), pp. 700-709.

V.T, M., 1996. Effect of elevated temperature operation on the tensile strength of overhead conductors. *Power Delivery, IEEE Transactions*, 11(1), pp. 345-352.

Appendix A

Project Specification

University of Southern Queensland

FACTULTY OF ENGINEERING AND SURVEYING

ENG4111 Research Project PROJECT SPECIFICATION

FOR: Ryan Patrick MURPHY

- TOPIC: DYNAMIC CONDUCTOR RATINGS: ANNEALING PROPERTIES OF HOMOGENOUS CONDUCTORS ACROSS VARING CLIMATIC CONDITIONS
- SUPERVISOR:Andreas Helwig, Lecturer, USQGreg Caldwell, Senior Advanced Analysis Ratings Engineer,
Ergon Energy

PROJECT AIM: To graphically analyse and develop dynamic conductor ratings for

Ergon Energy's sub transmission network

PROGRAMME: (Issue A, 15 March 2015)

- 1. Identify, analyse and compare the previous guidelines and current standards for calculating the steady-state and unsteady-state conductor ratings.
- 2. Conduct a sensitivity analysis, whereby each component of the heat equation is modelled to enable an analysis of the effects of changing weather conditions.
- 3. Identify and research an suitable approach for modelling dynamic conductor ratings.
- 4. Create a model to determine the rating of a sub transmission line with assumed dynamic conditions.
- 5. Validate the findings of (4.) using real time data gathered from two current case studies within Ergon Energy.

- 6. Analyse the effects on conductor lifespan due to the implementation of dynamic conditions.
- 7. Construct an academic dissertation, identifying the best suited methodology for Ergon Energy to implement dynamic conductor ratings.

As time permits:

Further investigate operational and mechanical issues, e.g. conductor sag, with the implementation of dynamic ratings

Appendix B

Dynamic Line Rating Model











Appendix C

Operation Schematics – 33kV Rywung Feeder Network

The following screen shots are taken from:

2142-02: Operating Schematic - Subtransmission 33kV Line Diagram - Dalby Chinchilla

2142-03: Operating Schematic - Subtransmission 33kV Line Diagram - Dalby Chinchilla



Figure 57: Operating Schematic 2142-02 - 33kV Rywung Feeder



Figure 58: Operating Schematic 2142-03 - 33kV Rywung Feeder

Appendix D

MATLAB Script – Sensitivity Analysis

IEC TR 61597

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Absorptivity IEC
% Created by
% Ryan Murphy
8 22/05/2015
           ----- set up program -----
clear all;
close all;
clc;
8----- Conditions -----
\ AAC (37/3.00) – Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                 ____General Parameters
k=1.015;
                   % Effective Resistance - supplied as 1.015
            RT=0.11*10^-3;
Power gain by solar heat input
for xx=1:1:13
   a=0.475+(xx*0.025); % Solar absorption coefficient
                    % 0.5 for rural weathered conductor
                   % 0.85 for industrial weathered conductor
   D=21*10^-3;
                   % Diameter of conductor AAC 37/3.00 Saturn
   Si=900;
                    % Solar intensity
   %%% Solar heating %%%
   PS=a*D*Si;
                   Power loss by forced convection
   t2=348.15; % Max operating temperature (75 celcius)
                   % General Ambient Temperature (35 celcius)
   t1=308.15;
                    % Thermal conductivity of Air Film
   lambda=0.02585;
   v=1;
                   %Wind speed 'For Loop'
                   % Reynolds Number
      Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                    % Nusselt Number
      Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
      angle=90;
                  % wind approach angle
                   % Constants C and P
      C=0.58;
                   % Constant
      P=0.9;
                  % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
              _____Power loss by radiation
8
   o=5.67*10^-8; % Stefan-Boltzmann constant
e=0.6; % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ia(:,xx) = sqrt((PR+PF-PS)/RT);
   a=a-0.65;
   aa(:, xx) =a;
end
```

```
_Power gain by solar heat input___
for xx=1:1:13
   a=0.475+(xx*0.025); % Solar absorption coefficient
    D=21*10^-3;
                       % Diameter of conductor AAC 37/3.00 Saturn
                       % Solar intensity
   Si=900;
    %%% Solar heating %%%
    PS=0;
                       Power loss by forced convection
   t2=348.15;
                       % Max operating temperature (75 celcius)
                       % General Ambient Temperature (10 celcius)
    t1=283.15;
                       % Thermal conductivity of Air Film
   lambda=0.02585;
   v=1;
                       %Wind speed 'For Loop'
                       % Reynolds Number
        Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                       % Nusselt Number
       Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
                      % wind approach angle
        angle=90;
                       % Constants C and P
       C=0.58;
                       % Constant
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
                     Power loss by radiation
8
                  % Stefan-Boltzmann constant
   o=5.67*10^-8;
    e=0.6;
                      % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/RT);
    a=a-0.65;
   bb(:,xx)=a;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
plot(p1,p2)
set(gca, 'xlim',[-0.15 0.15]);
legend([p1 p2],{'Noon','Night'},'Fontsize',12)
title('% Variation in CCC as per Variation in Absorptivity - IEC
61597', 'Fontsize',14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Emissivity IEC
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
8----
     ----- Conditions -----
\ AAC (37/3.00) – Saturn, summer noon conditions,2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                  General Parameters
                   % Effective Resistance - supplied as 1.015
k=1.015;
RT=0.11*10^-3;
                   % Conductor resistance
_____Power gain by solar heat input
a=0.5;
                   % Solar absorption coefficient
D=21*10^-3;
                   % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                   % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                Power loss by forced convection
               % Max operating temperature (75 celcius)
+2=348.15:
t1=308.15;
                   % General Ambient Temperature (35 celcius)
                   % Thermal conductivity of Air Film
lambda=0.02585;
                %Wind speed 'For Loop'
v=1;
                % Reynolds Number
Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                % Nusselt Number
Nu = (0.65 * Re^{0.2}) + (0.23 * Re^{0.61});
angle=90; % wind approach angle
                % Constants C and P
C=0.58;
                % Constant
P=0.9;
                % Constant
%%% Forced Convection %%%
PF=pi*lambda*Nu*(t2-t1);
                   Power loss by radiation
0=5.67*10^-8;
               % Stefan-Boltzmann constant
for xx=1:1:13
   e=0.475+(xx*0.025);
                      % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
  Ia(:,xx)=sqrt((PR+PF-PS)/RT);
   e=e-0.65;
   aa(:,xx)=e;
end
_____Power gain by solar heat input
8
a=0.5;
                   % Solar absorption coefficient
D=21*10^-3;
                   % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                   % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                Power loss by forced convection
t2=348.15; % Max operating temperature (75 celcius)
t1=283.15;
                   % General Ambient Temperature (10 celcius)
```

```
% Thermal conductivity of Air Film
lambda=0.02585;
                    %Wind speed 'For Loop'
v=1;
                    % Reynolds Number
Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                    % Nusselt Number
Nu = (0.65 * Re^{0.2}) + (0.23 * Re^{0.61});
angle=90;
                    % wind approach angle
                   % Constants C and P
C=0.58;
                   % Constant
P=0.9;
                    % Constant
%%% Forced Convection %%%
PF=pi*lambda*Nu*(t2-t1);
                      Power loss by radiation
o=5.67*10^-8;
                    % Stefan-Boltzmann constant
for xx=1:1:13
    e=0.475+(xx*0.025);
                           % emissivity of conductor
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
    Ib(:,xx)=sqrt((PR+PF-PS)/RT);
    e=e-0.65;
   bb(:,xx)=e;
 end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
plot(p1,p2)
set(gca, 'xlim',[-0.15,0.15]);
legend([p1 p2], {'Noon', 'Night'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Emissivity - IEC
61597', 'Fontsize',14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

MATLAB Script – Sensitivity Analysis

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Direct Solar Radiation Intensity IEC
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
     ----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                  General Parameters
                   % Effective Resistance - supplied as 1.015
k=1.015;
RT=0.11*10^-3;
k=1.015;
                   % Conductor resistance
_____Power gain by solar heat input
a=U.5; % Solar absorption coefficient
D=21*10^-3; % Diameters
                   % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
      Si=650+(xx*50); % Direct solar radiation intensity at A.m.^-2
   PS=a*D*Si;
                    Power loss by forced convection
   t2=348.15;
                    % Max operating temperature (75 celcius)
                    % General Ambient Temperature (35 celcius)
   t1=308.15;
                    % Thermal conductivity of Air Film
   lambda=0.02585;
                    %Wind speed 'For Loop'
   v=1:
                    % Reynolds Number
      Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                    % Nusselt Number
      Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
      angle=90;
                   % wind approach angle
                    % Constants C and P
      C=0.58;
                    % Constant
                   % Constant
      P=0.9;
   %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
               _____Power loss by radiation
8
               % Stefan-Boltzmann constant
% emissivity of conductor
   o=5.67*10^-8;
   e=0.6;
   %%% Radiated Loss %%%
  PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
  Ia(:,xx)=sqrt((PR+PF-PS)/RT);
   aa(:,xx)=Si;
end
_____Power gain by solar heat input
8
a=0.5;
                    % Solar absorption coefficient
                    % 0.5 for rural weathered conductor
                    % 0.85 for industrial weathered conductor
D=21*10^-3;
                    % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
```

```
Si=650+(xx*50); % Direct solar radiation intensity at A.m.^-2
    %%% Solar heating %%%
   PS=0;
                     __Power loss by forced convection
   t2=348.15;
                       % Max operating temperature (75 celcius)
                      % General Ambient Temperature (10 celcius)
   t1=283.15;
                      % Thermal conductivity of Air Film
   lambda=0.02585;
                      %Wind speed 'For Loop'
   v=1:
                      % Reynolds Number
       Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                      % Nusselt Number
       Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
       angle=90;
                      % wind approach angle
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
                    __Power loss by radiation
0
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
   e=0.6;
                      % emissivity of conductor
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/RT);
   bb(:,xx)=Si;
 end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
plot(p1,p2)
set(gca, 'xlim',[700 1300]);
legend([p1 p2], {'Noon', 'Night'}, 'Fontsize', 12)
title('% Variation in CCC as per Direct Solar Radiation Intensity - IEC
61597', 'Fontsize',14);
xlabel('Direct Solar Radiation Intensity (W/m^2) - 100% nominal CCC at
1000(W/m^2)', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Ambient Temperature IEC
% Created by
% Ryan Murphy
% 22/05/2015
%----- set up program ------
clear all:
close all;
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions,2m/s wind conditions,
\% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
```

```
% ESAA Formula
%----- Define Parameters -----
                ____General Parameters
k=1.015:
             % Ellectic ....
% Conductor resistance
                    % Effective Resistance - supplied as 1.015
RT=0.11*10^-3;
Power gain by solar heat input
8
a=0.5;
                     % Solar absorption coefficient
                    % 0.5 for rural weathered conductor
                    % 0.85 for industrial weathered conductor
D=21*10^-3;
                    % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                    % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                 Power loss by forced convection
           % Max operating temperature (75 celcius)
+2=348.15:
for xx=1:1:7
      t1=288.15+(xx*5);
                    % Thermal conductivity of Air Film
       lambda=0.02585;
       %Wind speed 'For Loop'
       v=1;
                    % Reynolds Number
       Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                    % Nusselt Number
      Nu = (0.65 * Re^{0.2}) + (0.23 * Re^{0.61});
      angle=90;
                   % wind approach angle
                    % Constants C and P
      C=0.58;
                    % Constant
                   % Constant
      P=0.9;
   %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
              Power loss by radiation
8
               % Stefan-Boltzmann constant
   o=5.67*10^-8;
   e=0.6;
                    % emissivity of conductor
   %%% Radiated Loss %%%
  PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ia(:,xx) = sqrt((PR+PF-PS)/RT);
   aa(:,xx)=t1-308.15;
end
____Power gain by solar heat input_
8
a=0;
                  % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                    % 0.85 for industrial weathered conductor
D=21*10^-3;
                    % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                    % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                 Power loss by forced convection
               % Max operating temperature (75 celcius)
t2=348.15;
for xx=1:1:7
      t1=288.15+(xx*5);
                    % Thermal conductivity of Air Film
       lambda=0.02585;
       %Wind speed 'For Loop'
       v=1;
                    % Reynolds Number
       Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                    % Nusselt Number
      Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
       angle=90;
                    % wind approach angle
                     % Constants C and P
```

```
C=0.58;
                      % Constant
       P=0.9;
                      % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
                     _Power loss by radiation_
8
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
   e=0.6;
                      % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/RT);
   bb(:,xx)=t1-308.15;
end
Ia=Ia./Ia(4)*100;
Ib=Ib./Ib(4)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
plot(p1,p2)
set(gca, 'xlim',[-15 15]);
legend([p1 p2],{'Summer Noon','Winter Night'},'Fontsize',12)
title('% Variation in CCC as per Variation in Ambient Temperature - IEC
61597', 'Fontsize', 14);
xlabel('Temperature based on 308.15^{\circ}K Noon and 288^{\circ}K
Night', 'Fontsize', 14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```
```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Wind Speed IEC
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                  General Parameters
                   % Effective Resistance - supplied as 1.015
k=1.015;
RT=0.11*10^-3;
k=1.015;
                  % Conductor resistance
_____Power gain by solar heat input
                   % Solar absorption coefficient
a=0.5;
                   % 0.5 for rural weathered conductor
                   % 0.85 for industrial weathered conductor
D=21*10^-3;
                   % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                   % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                Power loss by forced convection
t2=348.15;
                  % Max operating temperature (75 celcius)
t1=308.15;
                   % General Ambient Temperature (35 celcius)
                   % Thermal conductivity of Air Film
lambda=0.02585;
%Wind speed 'For Loop'
for xx=1:1:24;
      v=xx*0.25;
                   % Reynolds Number
      Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                   % Nusselt Number
      Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
      angle=90;
                  % wind approach angle
                  % Constants C and P
              % Constant
      C=0.58;
      P=0.9;
                  % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*Nu*(t2-t1);
                 Power loss by radiation
               % Stefan-Boltzmann constant
   o=5.67*10^-8;
   e=0.6;
                  % emissivity of conductor
   %%% Radiated Loss %%%
  PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
  Ia(:,xx)=sqrt((PR+PF-PS)/RT);
   aa(:,xx)=v;
end
Power gain by solar heat input
8
a=0:
                % Solar absorption coefficient
                   % 0.5 for rural weathered conductor
                   % 0.85 for industrial weathered conductor
D=21*10^-3;
                   % Diameter of conductor AAC 37/3.00 Saturn
```

```
Si=900;
                        % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
                   Power loss by forced convection_
t2=348.15;
                       % Max operating temperature (75 celcius)
                        % General Ambient Temperature (10 celcius)
t1=283.15;
                       % Thermal conductivity of Air Film
lambda=0.02585;
%Wind speed 'For Loop'
for xx=1:1:24;
        v=xx*0.25;
                       % Reynolds Number
        Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                       % Nusselt Number
        Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
        angle=90;
                       % wind approach angle
                       % Constants C and P
       C=0.58;
                       % Constant
        P=0.9;
                       % Constant
    %%% Forced Convection %%%
    PF=pi*lambda*Nu*(t2-t1);
                      Power loss by radiation
8
    o=5.67*10^-8;
                     % Stefan-Boltzmann constant
    e=0.6;
                       % emissivity of conductor
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/RT);
   bb(:,xx)=v;
end
Ia=Ia./Ia(8)*100;
Ib=Ib./Ib(8)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
plot(p1,p2)
set(gca, 'xlim',[0.25 6]);
legend([p1 p2], {'Noon', 'Night'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Wind Speed - IEC
61597', 'Fontsize',14);
xlabel('V (m/s) - 100% nominal CCC at 2m/s', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

ESAA D(b)5

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Absorptivity ESAA
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all:
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions,2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                  ____General Parameters
             % Effective Resistance - supplied as 1.015
% Conductor resistance
k=1.015;
Rdc=0.11*10^-3;
                    % Temperature coefficient
alpha=0.00403;
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
      a=0.475+(xx*0.025); % Solar absorption coefficient
       D=21*10^-3; % Diameter of conductor AAC 37/3.00 Saturn
       Idir=1000;
                        % Direct solar radiation intensity at A.m.^-2
       Idiff=100;
                         % Diffuse solar radiation intensity at A.m.^-2
       F=0.2;
                         % Albedo ground reflectance-reflected radiation
                         % 0.2 General value
       %%% Solar heating %%%
       PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                         Power loss by forced convection
       tc=75;
                            % Max operating temperature
       ta=35;
                            % General Ambient Temperature
                            % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                             % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
                             % Wind speed
       v=1:
                             % Reynolds Number
       Re=v*D/vf;
                            % D is the diameter of conductor
                            % Constants B and n
       if Re<=2650
                            % Conditions for B & n
          B=0.641;
                            % Constant
          n=0.471;
                            % Constant
       end
       if Re>2650
          B=0.048;
                            % Constant
          n=0.8;
                            % Constant
       end
       angle=90;
                            % wind approach angle
                            % Constants C and P
       if angle<=24
          C = 0 68:
                            % Constant
          P=1.08;
                            % Constant
       else
          C=0.58;
          P=0.9;
       end
       %%% Forced Convection %%%
```

```
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                            Power loss by radiation
       o=5.67*10^-8;
                         % Stefan-Boltzmann constant
       e=0.5;
                          % emissivity of conductor
       tg=ta+5;
                          % ground temperature
                          % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65:
       aa(:,xx)=a;
end
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025); % Solar absorption coefficient
       D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
       Idir=1000;
                          % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                          % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          % 0.2 General value
       %%% Solar heating %%%
       PS=0;
                          Power loss by forced convection
       tc=75;
                             % Max operating temperature
                              % General Ambient Temperature
       ta=10;
                              % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                              % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1;
                              % Wind speed
                              % Reynolds Number
       Re=v*D/vf;
                              % D is the diameter of conductor
                              % Constants B and n
       if Re<=2650
                             % Conditions for B & n
          B=0.641;
                             % Constant
           n=0.471;
                             % Constant
       end
       if Re>2650
           B=0.048;
                             % Constant
                             % Constant
           n=0.8;
       end
       angle=90;
                             % wind approach angle
                             % Constants C and P
       if angle<=24
                             % Constant
          C=0.68;
           P=1.08;
                            % Constant
       else
           C=0.58;
           P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                            Power loss by radiation
       o=5.67*10^-8;
                          % Stefan-Boltzmann constant
       e=0.5;
                          % emissivity of conductor
       tg=ta-5;
                          % ground temperature
                      % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                        % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity------
       Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65;
       bb(:,xx) = a;
```

```
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025); % Solar absorption coefficient
       D=21*10^-3; % Diameter of conductor AAC 37/3.00 Saturn
       Idir=1000;
                          % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                          % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                          % Albedo ground reflectance-reflected radiation
                           % 0.2 General value
       %%% Solar heating %%%
       PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                          Power loss by forced convection
       t_{c=75}:
                              % Max operating temperature
       ta=35;
                              % General Ambient Temperature
                              % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
                              % Wind speed
       v=1:
                              % Reynolds Number
       Re=v*D/vf;
                              % D is the diameter of conductor
                              % Constants B and n
       if Re<=2650
                              % Conditions for B & n
           B=0 641:
                              % Constant
           n=0.471;
                              % Constant
       end
       if Re>2650
          B=0.048;
                              % Constant
           n=0.8;
                              % Constant
       end
       angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
           C=0.68;
                             % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9:
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));

    *
    FOWER 1055 S, 2000

    o=5.67*10^-8;
    % Stefan-Boltzmann constant

    c=0.85;
    % emissivity of conductor

                            Power loss by radiation
                          % ground temperature
       tg=ta+5;
                      % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                         % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65;
       cc(:,xx)=a;
end
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025); % Solar absorption coefficient
       D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
       Idir=1000;
                          % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                          % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          % 0.2 General value
       %%% Solar heating %%%
       PS=0:
                          Power loss by forced convection
       tc=75;
                           % Max operating temperature
                              % General Ambient Temperature
       ta=10;
```

```
% Thermal conductivity of Air Film
        lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                                % Viscosity of the Air Film
        vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
        v=1;
                                % Wind speed
                                % Reynolds Number
        Re=v*D/vf;
                                % D is the diameter of conductor
                                % Constants B and n
        if Re<=2650
                                % Conditions for B & n
            B=0.641;
                                % Constant
            n=0.471;
                                % Constant
        end
        if Re>2650
           B=0.048;
                                % Constant
           n=0.8;
                                % Constant
        end
                                % wind approach angle
        angle=90;
                                % Constants C and P
        if angle<=24
           C=0.68;
                                % Constant
            P=1.08;
                                % Constant
        else
            C=0.58;
            P=0.9;
        end
        %%% Forced Convection %%%
        PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                              Power loss by radiation_
        o=5.67*10^-8;
                            Stefan-Boltzmann constant
        e=0.85;
                            % emissivity of conductor
        tg=ta-5;
                            % ground temperature
                        % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273;
                                          % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity-----
        Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        a=a-0.65;
        dd(:,xx) = a;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim', [-0.15, 0.15]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer','Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Absorptivity - ESAA
D(b)5','Fontsize',14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Wind approach angle
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
     ----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                   General Parameters
k=1.015;
                    % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
____Power gain by solar heat input
a=0.5;
                     % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                     % Albedo ground reflectance-reflected radiation
                                  General value
                     8 0.2
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                 Power loss by forced convection
tc=75;
                     % Max operating temperature
ta=35;
                     % General Ambient Temperature
                     % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
                     % Wind speed
v=1;
                     % Reynolds Number
Re=v*D/vf;
                     % D is the diameter of conductor
                     % Constants B and n
if Re<=2650
                     % Conditions for B & n
   B=0.641;
                     % Constant
   n=0.471;
                     % Constant
end
if Re>2650
   B=0.048;
                    % Constant
   n=0.8;
                     % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5);% wind approach angle
   % Constants C and P
       if angle<=24
          C=0.68;
                            % Constant
          P=1.08;
                            % Constant
       else
          C=0.58;
          P=0.9;
       end
   % if wind angle between 0-24 C=0.68, P=1.08
   % if wind angle between 24-90 C=0.58, P=0.9
```

```
%%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
8
                    ____Power loss by radiation_
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
    e=0.5;
                       % emissivity of conductor
   tg=ta+5;
                       % ground temperature
                       % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4) - ((0.5*(tq+273)^4)) - ((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=angle;
end
____Power gain by solar heat input
8
a=0:
                       % Solar absorption coefficient set for 0 for night
                       % conditions
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
                       % Direct solar radiation intensity at W.m^-2
Idir=1000;
Idiff=100;
                       % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                       % Albedo ground reflectance-reflected radiation
                                      General value
                       8 0.2
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                   Power loss by forced convection
tc=75;
                      % Max operating temperature
ta=10;
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                       % Wind speed
                       % Revnolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
                       % Constants B and n
if Re<=2650
                       % Conditions for B & n
   B=0.641:
                       % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                      % Constant
   n=0.8;
                       % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5); % wind approach angle
    % Constants C and P
       if angle<=24
           C=0.68;
                              % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0 9:
       end
    % if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                     __Power loss by radiation_
8
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
   e=0.5;
                      % emissivity of conductor
                       % ground temperature
   tg=ta-5;
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
   -----Current Carrying Capacity------Current Carrying Capacity------
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
```

```
bb(:,xx) = angle;
end
 Power gain by solar heat input
8
a=0.85;
                      % Solar absorption coefficient
D=21*10^{-3};
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                      % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                      % Albedo ground reflectance-reflected radiation
                      8 0.2
                                     General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                  Power loss by forced convection
tc=75;
                      % Max operating temperature
ta=35;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1:
                      % Wind speed
                      % Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                      % Conditions for B & n
   B=0.641;
                      % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                      % Constant
   n=0.8;
                      % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5);% wind approach angle
    % Constants C and P
       if angle<=24
           C=0.68;
                             % Constant
           P=1.08;
                            % Constant
       else
           C=0.58;
           P=0.9;
       end
   \% if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                 _____Power loss by radiation
8
   o=5.67*10^-8;
                 % Steran Borton
% emissivity of conductor
                      % Stefan-Boltzmann constant
   e=0.85;
   tg=ta+5;
                      % ground temperature
                      % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity----
   Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   cc(:,xx) = angle;
 end
___Power gain by solar heat input
8
a=0;
                      % Solar absorption coefficient set for 0 for night
                      % conditions
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                      % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                      % Albedo ground reflectance-reflected radiation
                      8 0.2
                                     General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
```

```
Power loss by forced convection
tc=75;
                        % Max operating temperature
ta=10;
                        % General Ambient Temperature
                        % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                         % Viscosity of the Air Film
vf = (1.32 \times 10^{-5}) + ((9.5 \times 10^{-8}) \times ((tc+ta)/2));
v=1;
                        % Wind speed
                        % Reynolds Number
Re=v*D/vf;
                        % D is the diameter of conductor
                        % Constants B and n
if Re<=2650
                        % Conditions for B & n
    B=0.641;
                        % Constant
                        % Constant
    n=0.471;
end
if Re>2650
                        % Constant
   B=0.048;
    n=0.8;
                        % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
        angle=-5+(xx*5);% wind approach angle
    % Constants C and P
        if angle<=24
                                % Constant
            C=0.68;
            P=1.08;
                                 % Constant
        else
            C=0.58;
            P=0.9;
        end
    \% if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                       Power loss by radiation
8
    o=5.67*10^-8;
                        % Stefan-Boltzmann constant
    e=0.85;
                         % emissivity of conductor
    tg=ta-5;
                        % ground temperature
                        % Sky temperature
    td=(0.0552*((ta+273)^{1.5}))-273;
                                       % given formula
    %%% Radiated Loss %%%
    PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
    Id(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
    dd(:,xx)=angle;
end
Ia=Ia./Ia(19)*100;
Ib=Ib./Ib(19)*100;
Ic=Ic./Ic(19)*100;
Id=Id./Id(19)*100;
figure (1)
hold on
pl=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[0 90]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Approach Angle - ESAA
D(b)5', 'Fontsize',14);
xlabel('Angle (Degrees) - 100% nominal CCC at 90 Degrees', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Wind Speed ESAA
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                    General Parameters
k=1.015;
                     % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                     % Temperature coefficient
____Power gain by solar heat input
a=0.5;
                     % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                     % Albedo ground reflectance-reflected radiation
                                   General value
                      8 0.2
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                 Power loss by forced convection
tc=75;
                     % Max operating temperature
ta=35;
                     % General Ambient Temperature
                      \% Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                     % Reynolds Number
                     % D is the diameter of conductor
       Re=v*D/vf;
                     % Constants B and n
                   % Conditions for B & n
% Constant
       if Re<=2650
          B=0.641;
                    % Constant
          n=0.471;
       end
       if Re>2650
          B=0.048; % Constant
                     % Constant
          n=0.8;
       end
       angle=90;
                     % wind approach angle
                     % Constants C and P
       C=0.58;
                     % Constant
       P=0.9;
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                  ____Power loss by radiation
   o=5.67*10^-8; % Stefan-Boltzmann constant
e=0.5; % emissivity of conductor
   tg=ta+5;
                     % ground temperature
```

```
% Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       -----Current Carrying Capacity-----Current Carrying Capacity------
8----
   Ia(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=v;
 end
Power gain by solar heat input
8
a=0;
                      % Solar absorption coefficient set for 0 for night
                      % conditions
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                      % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
                      % Albedo ground reflectance-reflected radiation
F=0.2:
                      % 0.2
                                    General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
          _____Power loss by forced convection
t_{c} = 7.5:
                      % Max operating temperature
ta=10;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf = (1.32 \times 10^{-5}) + ((9.5 \times 10^{-8}) \times ((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                      % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650
                     % Conditions for B & n
          B=0.641; % Constant
           n=0.471;
                     % Constant
       end
       if Re>2650
          B=0.048; % Constant
           n=0.8;
                    % Constant
       end
       angle=90;
                             % wind approach angle
                      % Constants C and P
       C=0.58:
                      % Constant
       P=0.9;
                      % Constant
                      \% if wind angle between 0-24 C=0.68, P=1.08
                      \% if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
   o=5.67*10^-8;
                     % Stefan-Boltzmann constant
   e=0.5;
                      % emissivity of conductor
                      % ground temperature
   t_{\alpha}=t_{a}-5;
                      % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   bb(:,xx)=v;
 end
_____Power gain by solar heat input
8
                      % Solar absorption coefficient
a=0.85;
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                      % Albedo ground reflectance-reflected radiation
                                     General value
                      8 0.2
```

```
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                  Power loss by forced convection
t = 7.5:
                      % Max operating temperature
ta=35;
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda=(2.42*10^-2)+((7.2*10^-5)*((tc+ta)/2));
                       % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                       % Reynolds Number
       Re=v*D/vf:
                      % D is the diameter of conductor
                       % Constants B and n
                      % Conditions for B & n
       if Re<=2650
           B=0.641;
                      % Constant
           n=0.471;
                      % Constant
       end
       if Re>2650
           B=0.048;
                      % Constant
           n=0.8;
                      % Constant
       end
                      % wind approach angle
       angle=90;
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                    ____Power loss by radiation_
8
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
   e=0.85;
                       % emissivity of conductor
   tq=ta+5;
                       % ground temperature
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   cc(:,xx)=v;
end
Power gain by solar heat input
8
a=0;
                      % Solar absorption coefficient set for 0 for night
                      % conditions
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                      % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
                       % Albedo ground reflectance-reflected radiation
F=0.2;
                       8 0.2
                                      General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                   Power loss by forced convection
t.c=75;
                       % Max operating temperature
ta=10;
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda=(2.42*10^-2)+((7.2*10^-5)*((tc+ta)/2));
                       % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                       % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650
                     % Conditions for B & n
           B=0.641;
                      % Constant
           n=0.471;
                      % Constant
       end
```

```
if Re>2650
           B=0.048;
                       % Constant
           n=0.8;
                       % Constant
        end
        angle=90;
                                % wind approach angle
                        \% Constants C and P
        C=0.58;
                        % Constant
        P=0.9;
                       % Constant
                       \% if wind angle between 0-24 C=0.68, P=1.08
                        % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                          Power loss by radiation
    o=5.67*10^-8;
                        % Stefan-Boltzmann constant
    e=0.85;
                        % emissivity of conductor
    tg=ta-5;
                        % ground temperature
                        % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273;
                                      % given formula
    %%% Radiated Loss %%%
    PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
    Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
    dd(:,xx)=v;
end
Ia=Ia./Ia(8)*100;
Ib=Ib./Ib(8)*100;
Ic=Ic./Ic(8)*100;
Id=Id./Id(8)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[0.25 6]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Wind Speed - ESAA
D(b)5', 'Fontsize',14);
xlabel('V (m/s) - 100% nominal CCC at 2m/s', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Emissivity ESAA
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
clf;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
8----- Define Parameters -----
2
          _____General Parameters
k=1.015;
                    % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
_____Power gain by solar heat input
a=0.5;
                    % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^{-3};
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                    % Direct solar radiation intensity at W.m^-2
Idiff=100;
                    % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                     % Albedo ground reflectance-reflected radiation
                     % 0.2
                                   General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
2
                Power loss by forced convection
tc=75;
                    % Max operating temperature
ta=35;
                     % General Ambient Temperature
                     % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                     % Wind speed
                     % Reynolds Number
Re=v*D/vf;
                     % D is the diameter of conductor
                     % Constants B and n
if Re<=2650
                     % Conditions for B & n
   B=0.641;
                     % Constant
   n=0.471;
                     % Constant
end
if Re>2650
   B=0.048;
                    % Constant
   n=0.8;
                     % Constant
end
                    % wind approach angle
angle=90;
                    % Constants C and P
if angle<=24
                     % Constant
   C=0.68;
   P=1.08;
                     % Constant
else
   C=0.58;
   P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
```

```
Power loss by radiation
o=5.67*10^-8; % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                              % emissivity of conductor
                              \% ground temperature
       tg=ta+5;
                              % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tq+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       e=e-0.65;
       aa(:,xx)=e;
end
__Power gain by solar heat input_
8
a=0:
                    % Solar absorption coefficient
                      % 0.5 for rural weathered conductor
                      \% 0.85 for industrial weathered conductor
                      % Diameter of conductor AAC 37/3.00 Saturn
D=21*10^-3;
                      % Direct solar radiation intensity at W.m^-2
Idir=1000;
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                      % Albedo ground reflectance-reflected radiation
                                General value
                      802
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                  Power loss by forced convection
tc=75;
                     % Max operating temperature
                      % General Ambient Temperature
t.a=10;
                      % Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
                      % Wind speed
v=1;
                      % Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                      % Conditions for B & n
   B=0.641;
                      % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                     % Constant
                      % Constant
   n=0.8;
end
angle=90;
                      % wind approach angle
                      % Constants C and P
if angle<=24
   C=0.68;
                     % Constant
   P=1.08;
                      % Constant
else
   C=0.58;
   P=0 9:
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                     Power loss by radiation
0=5.67*10^-8;
                % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                             % emissivity of conductor
                              % ground temperature
       tq=ta-5;
                              % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
```

```
e=e-0.65;
       bb(:,xx)=e;
end
8
         Power gain by solar heat input
a=0.85:
                      % Solar absorption coefficient
                      \% 0.5 for rural weathered conductor
                      % 0.85 for industrial weathered conductor
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
                      % Direct solar radiation intensity at W.m^-2
Idir=1000;
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                      % Albedo ground reflectance-reflected radiation
                                    General value
                      8 0.2
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                  Power loss by forced convection
tc=75;
                     % Max operating temperature
ta=35;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                      % Wind speed
                      % Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                     % Conditions for B & n
   B=0.641;
                     % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                    % Constant
   n=0.8;
                      % Constant
end
angle=90;
                      % wind approach angle
                      % Constants C and P
if angle<=24
   C=0.68;
                     % Constant
   P=1.08;
                     % Constant
else
   C=0.58;
   P=0.9:
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                    Power loss by radiation
°______
o=5.67*10^-8; %
                 % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                             % emissivity of conductor
       tg=ta+5;
                             % ground temperature
                             % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity------
       Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       e=e-0.65;
       cc(:,xx)=e;
end
Power gain by solar heat input
8
                      % Solar absorption coefficient
a=0;
                      % 0.5 for rural weathered conductor
                      % 0.85 for industrial weathered conductor
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
```

```
F=0.2;
                        % Albedo ground reflectance-reflected radiation
                        8 0.2
                                        General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                   Power loss by forced convection
tc=75;
                        % Max operating temperature
ta=10;
                        % General Ambient Temperature
                        % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                        % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
                        % Wind speed
v=1;
                        % Reynolds Number
Re=v*D/vf;
                        % D is the diameter of conductor
                        % Constants B and n
if Re<=2650
                        % Conditions for B & n
   B=0.641;
                        % Constant
    n=0.471;
                        % Constant
end
if Re>2650
                        % Constant
   B=0.048;
   n=0.8;
                        % Constant
end
                        % wind approach angle
angle=90;
                        % Constants C and P
if angle<=24
   C=0.68;
                        % Constant
    P=1.08;
                       % Constant
else
    C=0.58;
    P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                      Power loss by radiation
o=5.67*10^-8;
                    % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
        e=0.475+(xx*0.025);
                                % emissivity of conductor
        tg=ta-5;
                                % ground temperature
                                % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273;
                                         % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity------
        Id(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        e=e-0.65;
        dd(:,xx)=e;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim', [-0.15, 0.15]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Emissivity - ESAA
D(b)5', 'Fontsize',14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC','Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Ambient Temperature ESAA
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                   General Parameters
k=1.015;
                     % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
____Power gain by solar heat input
a=0.5;
                     % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                     % Albedo ground reflectance-reflected radiation
                                  General value
                     8 0.2
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
       _____Power loss by forced convection
t = 70:
                     % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta=15+(xx*5);
                     % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1;
                     %Wind speed
                     % Reynolds Number
       Re=v*D/vf;
                     % D is the diameter of conductor
                    % Constants B and n
                  % Conditions for B & n
% Constant
       if Re<=2650
          B=0.641;
                    % Constant
          n=0.471;
       end
       if Re>2650
          B=0.048; % Constant
                     % Constant
          n=0.8;
       end
       angle=90;
                    % wind approach angle
                     % Constants C and P
       C=0.58;
                     % Constant
       P=0.9;
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                       Power loss by radiation
   o=5.67*10^-8; % Stefan-Boltzmann constant
e=0.5; % emissivity of conductor
   tg=ta+5;
                     % ground temperature
```

```
% Sky temperature
   td=(0.0552*((ta+273)^1.5))-273;
                                  % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       -----Current Carrying Capacity------
   Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=ta-35;
end
Power gain by solar heat input
8
a=0:
                    % Solar absorption coefficient
                      % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^{-3}:
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     % Direct solar radiation intensity at W.m^-2
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
                     % Albedo ground reflectance-reflected radiation
F=0.2;
                      8 0.2
                                    General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
     Power loss by forced convection
8
t_{c}=70:
                    % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta = -5 + (xx + 5);
                      % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1;
                     %Wind speed
                     % Reynolds Number
       Re=v*D/vf;
                     % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650 % Conditions for B & n
B=0.641; % Constant
</pre>
          n=0.471;
                     % Constant
       end
       if Re>2650
          B=0.048; % Constant
          n=0.8;
                    % Constant
       end
       angle=90;
                    % wind approach angle
                     % Constants C and P
       C=0.58;
                    % Constant
       P=0.9;
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
                 % Stefan-Boltzmann constant
   o=5.67*10^-8;
   e=0.5;
                     % emissivity of conductor
   tg=ta-5;
                     % ground temperature
                      % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
   %-----Current Carrying Capacity------
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   bb(:,xx) = ta - 15;
end
8
            Power gain by solar heat input
a=0.85:
                     % Solar absorption coefficient
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                     \% Direct solar radiation intensity at W.m^-2
Idiff=100;
                     % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                     % Albedo ground reflectance-reflected radiation
                     8 0.2
                              General value
%%% Solar heating %%%
```

```
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
         _____Power loss by forced convection
tc=70;
                      % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta=15+(xx*5);
                       % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1:
                       %Wind speed
                       % Revnolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                       % Constants B and n
       if Re<=2650
                      % Conditions for B & n
                      % Constant
           B=0.641;
           n=0.471;
                     % Constant
       end
       if Re>2650
                    % Constant
           B=0.048;
           n=0.8;
                      % Constant
       end
       angle=90;
                      % wind approach angle
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
                  % Stefan-Boltzmann constant
   o=5.67*10^-8;
    e=0.85;
                       % emissivity of conductor
   tg=ta+5;
                       % ground temperature
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273;
                                     % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
         -----Current Carrying Capacity------
   Ic(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
    cc(:, xx) = ta - 35;
end
Power gain by solar heat input
8
a=0:
                       % Solar absorption coefficient set for 0 for night
                      % conditions
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
Idir=1000;
                      % Direct solar radiation intensity at W.m^-2
Idiff=100;
                      % Diffuse solar radiation intensity at W.m^-2
F=0.2;
                       % Albedo ground reflectance-reflected radiation
                       8 0.2
                                      General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                  Power loss by forced convection
0
tc=70;
                      % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta = -5 + (xx + 5);
                       % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                       %Wind speed
                       % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                       % Constants B and n
       if Re<=2650
                     % Conditions for B & n
           B=0.641; % Constant
           n=0.471;
                     % Constant
       end
```

```
if Re>2650
           B=0.048;
                       % Constant
           n=0.8;
                       % Constant
        end
        angle=90;
                       % wind approach angle
                       % Constants C and P
       C=0.58;
                       % Constant
       P=0.9;
                       % Constant
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                          Power loss by radiation
   o=5.67*10^-8;
                        Stefan-Boltzmann constant
    e=0.85;
                        % emissivity of conductor
                       \% ground temperature
    tg=ta-5;
                       % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273;
                                     % given formula
    %%% Radiated Loss %%%
    PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
    Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   dd(:,xx)=ta-15;
end
Ia=Ia./Ia(4)*100;
Ib=Ib./Ib(4)*100;
Ic=Ic./Ic(4)*100;
Id=Id./Id(4)*100;
figure (1)
hold on
pl=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[-15 15]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Ambient Temperature - ESAA
D(B)5', 'Fontsize',14);
xlabel('Temperature based on 35^{\circ}C Noon and 15^{\circ}C
Night', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

MATLAB Script – Sensitivity Analysis

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Direct Solar Radiation Intensity ESAA
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                   General Parameters
k=1.015;
                    % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
__Power gain by solar heat input
a=0.5;
                     % Solar absorption coefficient
                     % 0.5 for rural weathered conductor
                     % 0.85 for industrial weathered conductor
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
       Idir=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                        % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                         % Albedo ground reflectance-reflected radiation
                         % 0.2 General value
       %%% Solar heating %%%
       PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                        Power loss by forced convection
       tc=75;
                            % Max operating temperature
       ta=35;
                            % General Ambient Temperature
                            % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                             % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1;
                            % Wind speed
                            % Reynolds Number
       Re=v*D/vf;
                            % D is the diameter of conductor
                            % Constants B and n
       if Re <= 2.650
                            % Conditions for B & n
          B=0.641;
                            % Constant
          n=0.471;
                            % Constant
       end
       if Re>2650
          B=0.048;
                            % Constant
                            % Constant
          n=0.8;
       end
       angle=90;
                            % wind approach angle
                           % Constants C and P
       if angle<=24
                            % Constant
          C=0.68;
          P=1.08;
                            % Constant
       else
          C=0.58;
          P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
```

```
Power loss by radiation
       o=5.67*10^-8;
                        🛞 Stefan-Boltzmann constant
       e=0.5;
                         % emissivity of conductor
       tq=ta+5;
                         % ground temperature
                     % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                       % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %------Current Carrying Capacity-----
       Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       aa(:,xx)=Idir;
end
Power gain by solar heat input
8
a=0;
                     % Solar absorption coefficient set for 0 for night
                     % conditions
D=21*10^-3;
                     % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
       Idir=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                         % Diffuse solar radiation intensity at W.m^-2
                         % Albedo ground reflectance-reflected radiation
       F=0.2;
                         % 0.2 General value
       %%% Solar heating %%%
       PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                       ___Power loss by forced convection
       tc=75;
                             % Max operating temperature
       ta=10;
                             % General Ambient Temperature
                             % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                             \% Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                             % Wind speed
                             % Reynolds Number
       Re=v*D/vf;
                             % D is the diameter of conductor
                            % Constants B and n
       if Re<=2650
                            % Conditions for B & n
          B=0.641;
                            % Constant
                            % Constant
          n=0.471:
       end
       if Re>2650
          B=0.048;
                            % Constant
                            % Constant
          n=0.8;
       end
                            % wind approach angle
       angle=90;
                            % Constants C and P
       if angle<=24
          C=0.68;
                            % Constant
                            % Constant
          P=1.08;
       else
          C=0.58;
          P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                          Power loss by radiation
       o=5.67*10^-8;
                       % Stefan-Boltzmann constant
       e=0.5;
                        % emissivity of conductor
       tg=ta-5;
                         % ground temperature
                     % Sky temperature
       td=(0.0552*((ta+273)^{-1.5}))-273;
                                       % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity------
       Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       bb(:,xx)=Idir;
end
Power gain by solar heat input
```

```
a=0.85;
                       % Solar absorption coefficient
D=21*10^-3;
                       % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
       Idir=650+(xx*50);
                         % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                          % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           % 0.2 General value
        %%% Solar heating %%%
        PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                           Power loss by forced convection
       tc=75:
                               % Max operating temperature
        ta=35;
                               % General Ambient Temperature
                               % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                               % Wind speed
                               % Reynolds Number
       Re=v*D/vf;
                               % D is the diameter of conductor
                               % Constants B and n
        if Re<=2650
                               % Conditions for B & n
           B=0.641;
                               % Constant
           n=0.471;
                               % Constant
       end
        if Re>2650
           B=0.048;
                               % Constant
                               % Constant
           n=0.8;
       end
       angle=90;
                               % wind approach angle
                               % Constants C and P
        if angle<=24</pre>
                               % Constant
           C=0.68;
           P=1.08;
                               % Constant
        else
           C=0.58;
           P=0.9;
        end
        %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                              Power loss by radiation
                           % Stefan-Boltzmann constant
       o=5.67*10^-8;
       e=0.85;
                           % emissivity of conductor
                           % ground temperature
       tg=ta+5;
                       % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                          % given formula
       %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tq+273)^4))-((0.5*(td+273)^4)));
             ----- Current Carrying Capacity------
       Ic(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       cc(:,xx)=Idir;
end
8
               Power gain by solar heat input
a=0:
                       % Solar absorption coefficient set for 0 for night
                       % conditions
D=21*10^-3;
                       % Diameter of conductor AAC 37/3.00 Saturn
%Direct Solar Radiation Intensity 'For Loop'
for xx=1:1:13
       Idir=650+(xx*50);
                          % Direct solar radiation intensity at W.m^-2
       Idiff=100;
                          % Diffuse solar radiation intensity at W.m^-2
       F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           % 0.2 General value
        %%% Solar heating %%%
        PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
                           Power loss by forced convection
       tc=75;
                               % Max operating temperature
       ta=10;
                               % General Ambient Temperature
                               % Thermal conductivity of Air Film
        lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
```

```
% Viscosity of the Air Film
        vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
        v=1;
                                % Wind speed
                                % Reynolds Number
        Re=v*D/vf;
                                % D is the diameter of conductor
                                % Constants B and n
        if Re<=2650
                                % Conditions for B & n
           B=0.641;
                                % Constant
            n=0.471;
                                % Constant
        end
        if Re>2650
           B=0.048;
                                % Constant
            n=0.8;
                                % Constant
        end
        angle=90;
                                % wind approach angle
                                % Constants C and P
        if angle<=24
           C=0.68;
                                % Constant
            P=1.08;
                               % Constant
        else
            C=0.58;
            P=0.9;
        end
        %%% Forced Convection %%%
        PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                               Power loss by radiation
                         % Stefan-Boltzmann constant
        o=5.67*10^-8;
                           % emissivity of conductor
        e=0.85;
        tg=ta-5;
                           % ground temperature
                        % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273;
                                        % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity--
        Id(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        dd(:,xx)=Idir;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2)
plot(p1,p2,p3,p4)
set(gca, 'xlim',[700 1300]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Direct Solar Radiation Intensity - ESAA
D(b)5', 'Fontsize',14);
xlabel('Direct Solar Radiation Intensity (W/m^2) - 100% nominal CCC at
1000(W/m^2)', 'Fontsize', 14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

Cigré TB601

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Ambient Temperature Cigre
% Created by
% Ryan Murphy
8 22/05/2015
8----- set up program -----
clear all;
close all;
clc;
clf;
     ----- Conditions -----
8----
% AAC (37/3.00) - Saturn, summer noon conditions,2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
K=1.015;% Effective Resistance - supplied as 1.015Rdc=0.11*10^-3;% Conductor resistancealpha=0.00403;% Temperature
_____Power gain by solar heat input
a=0.5;
                     % Solar absorption coefficient set for 0 for night
                      % conditions
1=27.5667;
                        % Toowoomba latitude
Ns=1;
                        % Clear sky
v=632;
                        % meters above sea level
D=21*10^-3;
                        % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                        % Albedo ground reflectance-reflected radiation
                        8 0.2
                                     General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                % declination angle
Hs=asind(sind(1)*sind(ds)+cosd(1)*cosd(ds)*cosd(0));
                                                % solar altitude
                            % azimuth of the sun = o at noon
ys=0;
                                                 % solar beam angle
n=acosd((cosd(Hs)*cosd(ys)));
% diffuse radiation
Id=(430.5-0.3288*Iby)*sind(Hs);
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
             _____Power loss by forced convection_____
t.c=70;
                 % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta=15+(xx*5);
                     % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                    % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
                    %Wind speed
       v=1;
                    % Reynolds Number
       Re=v*D/vf;
                    % D is the diameter of conductor
                    % Constants B and n
       if Re<=2650
                   % Conditions for B & n
          B=0.641; % Constant
          n=0.471; % Constant
       end
```

```
if Re>2650
          B=0.048; % Constant
                     % Constant
          n=0.8;
       end
       angle=90;
                     % wind approach angle
                     % Constants C and P
       C=0.58:
                     % Constant
       P=0.9;
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
   o=5.67*10^-8;
                     % Stefan-Boltzmann constant
   e=0.5;
                     % emissivity of conductor
   tg=ta+5;
                      % ground temperature
                      % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
   Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=ta-35;
end
Power gain by solar heat input
8
a=0:
                      % Solar absorption coefficient set for 0 for night
                      % conditions
1=27.5667;
                         % Toowoomba latitude
                         % Clear sky
Ns=1:
v=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
                         % Albedo ground reflectance-reflected radiation
F=0.2;
                          8 0.2
                                        General value
8
ds=23.4*sind(2*pi*(284+1)/365);
                                                   % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                                     % azimuth of the sun = o at noon
vs=0;
n=acosd((cosd(Hs)*cosd(ys)));
                                                    % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                   % direct beam
Ibv=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                            % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                   % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
               Power loss by forced convection
tc=70;
               % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta=-5+(xx*5);
                      % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1:
                      %Wind speed
                      % Reynolds Number
       Re=v*D/vf;
                     % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650
                     % Conditions for B & n
          B=0.641;
                     % Constant
           n=0.471;
                    % Constant
       end
       if Re>2650
                    % Constant
           B=0.048;
           n=0.8;
                     % Constant
       end
       angle=90;
                     % wind approach angle
                     % Constants C and P
       C=0.58;
                     % Constant
```

```
P=0.9;
                    % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
   o=5.67*10^-8;
                     % Stefan-Boltzmann constant
   e=0.5;
                     % emissivity of conductor
   tg=ta-5;
                     % ground temperature
                     % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
   %-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   bb(:,xx) = ta - 15;
end
 ____Power gain by solar heat input
8
a=0.9:
                       % Solar absorption coefficient set for 0 for night
                      % conditions
1=27.5667;
                         % Toowoomba latitude
Ns=1;
                         % Clear sky
v=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
                         \ensuremath{\$ Albedo ground reflectance-reflected radiation
F=0.2;
                         8 0.2
                                      General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                  % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
vs=0;
                                 % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                   % solar beam angle
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                 % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                 __Power loss by forced convection
tc=70;
                  % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta=15+(xx*5);
                      % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                     %Wind speed
                     % Reynolds Number
       Re=v*D/vf;
                     % D is the diameter of conductor
                     % Constants B and n
       if Re<=2650
                    % Conditions for B & n
          B=0.641; % Constant
          n=0.471;
                    % Constant
       end
       if Re>2650
          B=0.048;
                     % Constant
          n=0.8;
                     % Constant
       end
       angle=90;
                     % wind approach angle
                     % Constants C and P
       C=0.58;
                     % Constant
       P=0.9;
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                       __Power loss by radiation
   o=5.67*10^-8; % Stefan-Boltzmann constant
   e=0.85:
                     % emissivity of conductor
```

```
% ground temperature
   tg=ta+5;
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
    %%% Radiated Loss %%%
    PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
    %-----Current Carrying Capacity------
   Ic(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   cc(:,xx)=ta-35;
end
8
               Power gain by solar heat input
a = 0;
                      % Solar absorption coefficient set for 0 for night
                       % conditions
1=27.5667;
                          % Toowoomba latitude
                          % Clear sky
Ns=1;
v=632;
                          % meters above sea level
                          % Diameter of conductor AAC 37/3.00 Saturn
D=21*10^-3;
F=0.2;
                          % Albedo ground reflectance-reflected radiation
8
                          8 0.2
                                         General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
vs=0;
                                       % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                      % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                     % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                               % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                     % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                  % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                  Power loss by forced convection
tc=70;
                  % Max operating temperature
% Ambient Temperature 'For Loop'
for xx=1:1:7
       ta = -5 + (xx + 5);
                       % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
       vf = (1.32 \times 10^{-5}) + ((9.5 \times 10^{-8}) \times ((tc+ta)/2));
                      %Wind speed
       v=1;
                      % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650
                     % Conditions for B & n
           B=0.641;
                      % Constant
           n=0.471;
                      % Constant
       end
       if Re>2650
           B=0.048; % Constant
                      % Constant
           n=0.8;
       end
       angle=90;
                     % wind approach angle
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                         _Power loss by radiation_
   o=5.67*10^-8;
                     % Stefan-Boltzmann constant
   e=0.85;
                       % emissivity of conductor
                      % ground temperature
   tq=ta-5;
                       % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273; % given formula
    %%% Radiated Loss %%%
    PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
    %-----Current Carrying Capacity------
    Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
```

```
dd(:,xx)=ta-15;
end
Ia=Ia./Ia(4)*100;
Ib=Ib./Ib(4)*100;
Ic=Ic./Ic(4)*100;
Id=Id./Id(4)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[-15 15]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Ambient Temperature - Cigre TB
601', 'Fontsize', 14);
xlabel('Temperature based on 35^{\circ}C Noon and 15^{\circ}C
Night', 'Fontsize', 14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Absorptivity Cigre
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
clf;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
2
          _____General Parameters
                % Effective Resistance - supplied as 1.015
k=1.015;
k=1.013,
Rdc=0.11*10^-3;
                   % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025); % Solar absorption coefficient
                               % Toowoomba latitude
       1=27.5667;
      Ns=1;
                               % Clear sky
       y=632;
                               % meters above sea level
       D=21*10^-3;
                               % Diameter of conductor AAC 37/3.00 Saturn
       F=0.2;
                               % Albedo ground reflectance-reflected
radiation
                               8 0.2
                                             General value
       ds=23.4*sind(2*pi*(284+1)/365);
                                                 % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));% solar altitude
       vs=0;
                     % azimuth of the sun = 0 at noon 0 at midnight
       n=acosd((cosd(Hs)*cosd(ys)));
       % solar beam angle
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs); % diffuse radiation
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It;
                        Power loss by forced convection
       tc=75;
                           % Max operating temperature
       ta=35;
                            % General Ambient Temperature
                            % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                            % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
                            % Wind speed
       v=1;
                            % Reynolds Number
       Re=v*D/vf;
                            % D is the diameter of conductor
                           % Constants B and n
       if Re<=2650
                           % Conditions for B & n
          B=0.641;
                           % Constant
          n=0.471;
                           % Constant
       end
       if Re>2650
                        % Constant
          B=0.048;
          n=0.8;
                          % Constant
       end
```

```
angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
           C=0.68;
                              % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                             Power loss by radiation
       o=5.67*10^-8;
                           % Stefan-Boltzmann constant
       e=0.5;
                          % emissivity of conductor
       tg=ta+5;
                           % ground temperature
                           % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                      % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %------Current Carrying Capacity-----
       Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65;
       aa(:,xx)=a;
end
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025);
                                  % Solar absorption coefficient
       1=27.5667;
                                  % Toowoomba latitude
                                  % Clear sky
       Ns=1:
                                  % meters above sea level
       v=632;
       D=21*10^-3;
                                  % Diameter of conductor AAC 37/3.00 Saturn
       F=0.2;
                                  % Albedo ground reflectance-reflected
radiation
                                  8 0.2
                                                  General value
       8
       ds=23.4*sind(2*pi*(284+1)/365);
                                                      % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));% solar altitude
       ys=0;
                           % azimuth of the sun = 0 at noon 0 at midnight
       n=acosd((cosd(Hs)*cosd(ys)));
                                                       % solar beam angle
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                            % direct beam
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       Id=(430.5-0.3288*Iby)*sind(Hs);
                                                  % diffuse radiation
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It*0;
                           Power loss by forced convection
       tc=75;
                              % Max operating temperature
       t.a=10;
                               % General Ambient Temperature
                              % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                               % Wind speed
                               % Reynolds Number
       Re=v*D/vf;
                              % D is the diameter of conductor
                              % Constants B and n
       if Re<=2650
                              % Conditions for B & n
                              % Constant
           B=0.641;
           n=0.471;
                              % Constant
       end
       if Re>2650
           B=0.048;
                              % Constant
           n=0.8;
                              % Constant
       end
       angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
```

```
C=0.68;
                              % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                             Power loss by radiation
       o=5.67*10^-8;
                           % Stefan-Boltzmann constant
                          % emissivity of conductor
       e=0.5;
       t \alpha = t a - 5:
                          % ground temperature
                      % Sky temperature
       td=(0.0552*((ta+273)^{-1.5}))-273;
                                        % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65;
       bb(:,xx)=a;
end
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025);
                                  % Solar absorption coefficient
       1=27.5667;
                                  % Toowoomba latitude
                                  % Clear sky
       Ns=1;
       y=632;
                                  % meters above sea level
       D=21*10^-3;
                                  % Diameter of conductor AAC 37/3.00 Saturn
       F=0.2;
                                  % Albedo ground reflectance-reflected
radiation
        8
                                  8 0.2
                                                General value
       ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));% solar altitude
                           % azimuth of the sun = 0 at noon 0 at midnight
       ys=0;
       n=acosd((cosd(Hs)*cosd(ys)));
                                                      % solar beam angle
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                          % direct beam
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       Id=(430.5-0.3288*Iby)*sind(Hs);
                                                    % diffuse radiation
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It;
                          Power loss by forced convection
       t = 7.5:
                              % Max operating temperature
       ta=35;
                              % General Ambient Temperature
                              % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                              % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1:
                              % Wind speed
                              % Reynolds Number
       Re=v*D/vf;
                              % D is the diameter of conductor
                              % Constants B and n
       if Re<=2650
                              % Conditions for B & n
           B=0.641;
                              % Constant
           n=0.471;
                              % Constant
       end
       if Re>2650
           B=0.048;
                              % Constant
           n=0.8;
                              % Constant
       end
       angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
           C=0.68;
                              % Constant
```

```
P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                             Power loss by radiation
       o=5.67*10^-8; % Stefan-Boltzmann constant
       e=0.85;
                           % emissivity of conductor
       tg=ta+5;
                          % ground temperature
                       % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                         % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
           -----Current Carrying Capacity------Current Carrying Capacity------
       Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       a=a-0.65;
       cc(:,xx)=a;
end
Power gain by solar heat input
% Absorptivity 'For Loop'
for xx=1:1:13
       a=0.475+(xx*0.025);
                                  % Solar absorption coefficient
       1=27.5667;
                                  % Toowoomba latitude
       Ns=1;
                                  % Clear sky
       v=632;
                                  % meters above sea level
       D=21*10^-3;
                                  % Diameter of conductor AAC 37/3.00 Saturn
       F=0.2;
                                  % Albedo ground reflectance-reflected
radiation
                                   8 0.2
                                                  General value
       ds=23.4*sind(2*pi*(284+1)/365);
                                                      % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));% solar altitude
                          \% azimuth of the sun = 0 at noon 0 at midnight
       ys=0;
                                                  % solar beam angle
       n=acosd((cosd(Hs)*cosd(ys)));
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                           % direct beam
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       Id=(430.5-0.3288*Iby)*sind(Hs);
                                                     % diffuse radiation
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It*0;
                           Power loss by forced convection
       8
       tc=75;
                               % Max operating temperature
       t_{a=10}:
                               % General Ambient Temperature
                               % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                               % Wind speed
                               % Reynolds Number
       Re=v*D/vf;
                               % D is the diameter of conductor
                              % Constants B and n
       if Re<=2650
                              % Conditions for B & n
           B=0.641;
                              % Constant
           n=0.471;
                              % Constant
       end
       if Re>2650
                              % Constant
           B=0.048;
           n=0.8;
                              % Constant
       end
       angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
                              % Constant
           C=0.68;
           P=1.08;
                              % Constant
       else
           C=0.58;
```

```
P=0.9;
        end
        %%% Forced Convection %%%
        PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                               Power loss by radiation
        o=5.67*10^-8;
                            % Stefan-Boltzmann constant
        e=0.5;
                            % emissivity of conductor
        tg=ta-5;
                            % ground temperature
                        % Sky temperature
        td=(0.0552*((ta+273)^{1.5}))-273;
                                           % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity------
        Id(:,xx)=sqrt((PR+PF)/(k*Rdc*(1+alpha*(tc-20))));
        Id=Ib;
        a=a-0.65;
        dd(:,xx)=a;
end
%plots
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure(1)
subplot(2,1,1)
%// Define the x values
x = aa.';
xMat = repmat(x, 1, 4); %// For plot3
%// Define y values
y = 1:1:4;
yMat = repmat(y, numel(x), 1); %//For plot3
%// Define z values
z1 = Ia';
z2 = Ic';
z3 = Ib';
z4 = Id';
zMat = [z1 z2 z3 z4]; %// For plot3
plot3(xMat, yMat, zMat); %// Make all traces blue
grid;
xlabel('x'); ylabel('y'); zlabel('z');
[xi,yi] = meshgrid(-0.15:0.125:0.15, 1:1:4);
zi = griddata(xMat,yMat,zMat,xi,yi);
surf(xi,yi,zi);
shading interp
axis tight
colorbar
view(180,0)
% xlabel('Longitude')
% ylabel('Latitude')
% zlabel('Depth in Feet')
subplot(2,1,2)
plot3(xMat, yMat, zMat); %// Make all traces blue
grid;
xlabel('x'); ylabel('y'); zlabel('z');
[xi,yi] = meshgrid(-0.15:0.125:0.15, 1:1:4);
zi = griddata(xMat,yMat,zMat,xi,yi);
surf(xi,yi,zi);
shading interp
axis tight
```
```
colorbar
view(60,30)
figure(3)
subplot(1,2,1)
%// Define the x values
x = aa.';
xMat = repmat(x, 1, 4); %// For plot3
%// Define y values
y = 1:1:4;
yMat = repmat(y, numel(x), 1); %//For plot3
%// Define z values
z1 = Ia';
z2 = Ic';
z3 = Ib';
z4 = Id';
zMat = [z1 z2 z3 z4]; %// For plot3
plot3(xMat, yMat, zMat); %// Make all traces blue
grid;
xlabel('x'); ylabel('y'); zlabel('z');
[xi,yi] = meshgrid(-0.15:0.125:0.15, 1:1:4);
zi = griddata(xMat,yMat,zMat,xi,yi);
surf(xi,yi,zi);
shading interp
axis tight
colorbar
view(180,0)
% xlabel('Longitude')
% ylabel('Latitude')
% zlabel('Depth in Feet')
subplot(1,2,2)
plot3(xMat, yMat, zMat); %// Make all traces blue
grid;
xlabel('x'); ylabel('y'); zlabel('z');
[xi,yi] = meshgrid(-0.15:0.125:0.15, 1:1:4);
zi = griddata(xMat,yMat,zMat,xi,yi);
surf(xi,yi,zi);
shading interp
axis tight
colorbar
view(60,30)
figure (2)
hold on
pl=plot(aa,Ia,'LineWidth',2);
p2=plot(bb, Ib, '--gr', 'LineWidth', 2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim', [-0.15, 0.15]);
legend([p1 p2 p3 p4], {'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Absorptivity - Cigre TB
601', 'Fontsize', 14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Emissivity Cigre
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
clf;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
8----- Define Parameters -----
2
         _____General Parameters
                % Effective Resistance - supplied as 1.015
k=1.015;
Rdc=0.11*10^-3;
                  % Conductor resistance
alpha=0.00403;
                  % Temperature coefficient
_____Power gain by solar heat input
a=0.5;
                      % Solar absorption coefficient
                      % 0.5 for rural weathered conductor
8
                      % 0.85 for industrial weathered conductor
1=27.5667;
                      % Toowoomba latitude
Ns=1;
                      % Clear sky
y=632;
                      % meters above sea level
D=21*10^-3;
                      % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                       % Albedo ground reflectance-reflected radiation
                       8 0.2
                                 General value
% azimuth of the sun = o at noon
vs=0;
n=acosd((cosd(Hs)*cosd(ys)));
                                              % solar beam angle
Id=(430.5-0.3288*Iby)*sind(Hs);
                                             % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
8
               Power loss by forced convection
tc=75;
                 % Max operating temperature
ta=35;
                   % General Ambient Temperature
                   % Thermal conductivity of Air Film
lambda=(2.42*10^-2)+((7.2*10^-5)*((tc+ta)/2));
                   % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
v=1;
                   % Wind speed
                   % Reynolds Number
Re=v*D/vf;
                   % D is the diameter of conductor
                   % Constants B and n
if Re<=2650
                   % Conditions for B & n
   B=0.641;
                   % Constant
                   % Constant
   n=0.471;
end
if Re>2650
                % Constant
% Constant
  B=0.048;
   n=0.8;
end
```

```
angle=90;
                      % wind approach angle
                      % Constants C and P
if angle<=24
   C=0.68;
                      % Constant
   P=1.08;
                      % Constant
else
   C=0.58;
   P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                    Power loss by radiation
o=5.67*10^-8;
                % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                             % emissivity of conductor
                             % ground temperature
       tg=ta+5;
                             % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity-----
       Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       e=e-0.65;
       aa(:,xx)=e;
end
__Power gain by solar heat input
8
                        % Solar absorption coefficient
a=0;
8
                         % 0.5 for rural weathered conductor
                         % 0.85 for industrial weathered conductor
2
1=27.5667;
                         % Toowoomba latitude
Ns=1:
                         % Clear sky
y=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                         % Albedo ground reflectance-reflected radiation
                          8 0.2
                                       General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                   % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));
                                                  % solar altitude
ys=0;
                                     % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                   % solar beam angle
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                  % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                  Power loss by forced convection
tc=75;
                      % Max operating temperature
ta=10;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                      % Wind speed
                      % Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                     % Conditions for B & n
   B=0.641;
                     % Constant
   n=0.471;
                     % Constant
end
if Re>2650
                     % Constant
   B=0.048;
   n=0.8;
                     % Constant
end
angle=90;
                     % wind approach angle
                      % Constants C and P
```

```
if angle<=24
   C=0.68;
                      % Constant
                       % Constant
   P=1.08;
else
   C=0.58;
   P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                     Power loss by radiation
o=5.67*10^-8; % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                               % emissivity of conductor
        tg=ta-5;
                               % ground temperature
                               % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273; % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %------Current Carrying Capacity------
        Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        e=e-0.65;
       bb(:,xx)=e;
end
8
               Power gain by solar heat input
                         % Solar absorption coefficient
a=0.9;
                           \% 0.5 for rural weathered conductor
8
2
                           % 0.85 for industrial weathered conductor
                           % Toowoomba latitude
1=27.5667;
                           % Clear sky
Ns=1;
                           % meters above sea level
v=632;
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           8 0.2
                                       General value
8
ds=23.4*sind(2*pi*(284+1)/365);
                                                       % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
ys=0;
                                        % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                       % solar beam angle

      Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
      % direct beam

      Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
      % direct beam at height y

Id=(430.5-0.3288*Iby)*sind(Hs);
                                                      % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                    % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                   Power loss by forced convection
tc=75;
                       % Max operating temperature
ta=35;
                       % General Ambient Temperature
                        % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                        % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                        % Wind speed
                        % Reynolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
                       % Constants B and n
if Re<=2650
                       % Conditions for B & n
   B=0.641;
                       % Constant
   n=0.471;
                       % Constant
end
if Re>2650
                      % Constant
   B=0.048;
   n=0.8;
                       % Constant
end
angle=90;
                       % wind approach angle
                       % Constants C and P
```

```
if angle<=24
   C=0.68;
                      % Constant
                      % Constant
   P=1.08;
else
   C=0.58;
   P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                    Power loss by radiation
            % Stefan-Boltzmann constant
o=5.67*10^-8;
%Emissivity 'For Loop'
for xx=1:1:13
       e=0.475+(xx*0.025);
                              % emissivity of conductor
       tg=ta+5;
                              % ground temperature
                              % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273; % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %------Current Carrying Capacity-----
       Ic(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       e=e-0.65;
       cc(:,xx)=e;
end
Power gain by solar heat input
a=0;
                         % Solar absorption coefficient
                          % 0.5 for rural weathered conductor
8
                          % 0.85 for industrial weathered conductor
8
1=27.5667;
                          % Toowoomba latitude
                          % Clear sky
Ns=1:
                          % meters above sea level
v=632;
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          8 0.2
                                         General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));
                                                     % solar altitude
                                 % azimuth of the sun = o at noon
vs=0:
                                                     % solar beam angle
n=acosd((cosd(Hs)*cosd(ys)));
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                     % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                     % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                  % radiation intensity
% %%% Solar heating %%%
PS=a*D*Tt:
                   Power loss by forced convection
tc=75;
                      % Max operating temperature
                       % General Ambient Temperature
ta=10;
                       % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
v=1;
                       % Wind speed
                       % Reynolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                      % Conditions for B & n
   B=0.641;
                      % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                      % Constant
                       % Constant
   n=0.8;
end
angle=90;
                      % wind approach angle
                      % Constants C and P
if angle<=24
```

```
C=0.68;
                         % Constant
    P=1.08;
                         % Constant
else
    C=0.58;
    P=0.9;
end
%%% Forced Convection %%%
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                        Power loss by radiation
o=5.67*10^-8;
                    % Stefan-Boltzmann constant
%Emissivity 'For Loop'
for xx=1:1:13
        e=0.475+(xx*0.025);
                                 % emissivity of conductor
        tg=ta-5;
                                 % ground temperature
                                 % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273;
                                            % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity-------
        Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        e=e-0.65;
        dd(:,xx)=e;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[-0.15,0.15]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Emissivity - Cigre TB
601', 'Fontsize',14);
xlabel('100% nominal CCC at 0.65', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

MATLAB Script – Sensitivity Analysis

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Direct Solar Radiation Intensity Cigre
% Created by
% Ryan Murphy
8 22/05/2015
%-----
clear all;
close all;
clc;
     ----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                    General Parameters
k=1.015;
                     % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                     % Conductor resistance
alpha=0.00403;
                     % Temperature coefficient
% Solar absorption coefficient
a=0.5;
8
                         \% 0.5 for rural weathered conductor
                         % 0.85 for industrial weathered conductor
0
1=27.5667;
                         % Toowoomba latitude
Ns=1:
                         % Clear sky
y=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                         % Albedo ground reflectance-reflected radiation
                         8 0.2
                                        General value
for xx=1:1:13
       Id=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       ds=23.4*sind(2*pi*(284+1)/365);
                                                  % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar
altitude
       ys=0;
                                      % azimuth of the sun = o at noon
       n=acosd((cosd(Hs)*cosd(ys)));
                                                   % solar beam angle
       n=acosd((cosd(Hs)*cosd(ys)));  % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));  % direct beam
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));% radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It;
       2
                         Power loss by forced convection
       tc=75;
                             % Max operating temperature
       ta=35;
                             % General Ambient Temperature
                             % Thermal conductivity of Air Film
       lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                             % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
                             % Wind speed
       v=1;
                             % Reynolds Number
       Re=v*D/vf;
                             % D is the diameter of conductor
                             % Constants B and n
       if Re<=2650
                             % Conditions for B & n
          B=0.641;
                             % Constant
                             % Constant
          n=0.471;
       end
       if Re>2650
                          % Constant
          B=0.048;
          n=0.8;
                            % Constant
       end
```

```
angle=90;
                               % wind approach angle
                               % Constants C and P
       if angle<=24
           C=0.68;
                               % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9;
       end
        %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                             Power loss by radiation
       o=5.67*10^-8;
                           % Stefan-Boltzmann constant
       e=0.5;
                          % emissivity of conductor
       tg=ta+5;
                           % ground temperature
                       % Sky temperature
       td=(0.0552*((ta+273)^1.5))-273;
                                          % given formula
        %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity------
        Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       aa(:,xx)=Id;
end
Power gain by solar heat input
2
a=0;
                         % Solar absorption coefficient
8
                           % 0.5 for rural weathered conductor
                           % 0.85 for industrial weathered conductor
2
1=27.5667;
                           % Toowoomba latitude
Ns=1;
                           % Clear sky
v=632;
                           % meters above sea level
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           8 0.2
                                          General value
for xx=1:1:13
       Id=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
       Hs=asind(sind(1)*sind(ds)+cosd(1)*cosd(ds)*cosd(0));
                                                             % solar
altitude
       vs=0;
                                        % azimuth of the sun = o at noon
       n=acosd((cosd(Hs)*cosd(ys)));
                                                       % solar beam angle
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                            % direct beam
        Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));% radiation intensity
       % %%% Solar heating %%%
       PS=a*D*It;
                           Power loss by forced convection
       t = 75:
                              % Max operating temperature
       ta=10;
                               % General Ambient Temperature
                               % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
       v=1:
                               % Wind speed
                               % Reynolds Number
       Re=v*D/vf;
                               % D is the diameter of conductor
                              % Constants B and n
        if Re<=2650
                              % Conditions for B & n
           B=0.641;
                              % Constant
           n=0.471;
                              % Constant
       end
       if Re>2650
           B=0.048;
                              % Constant
           n=0.8;
                               % Constant
       end
       angle=90;
                              % wind approach angle
                              % Constants C and P
       if angle<=24
           C=0.68;
                               % Constant
```

```
P=1.08;
                               % Constant
       else
           C=0.58;
           P=0.9;
        end
        %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                             Power loss by radiation
                         % Stefan-Boltzmann constant
       o=5.67*10^-8;
       e=0.5;
                           % emissivity of conductor
       tg=ta-5;
                           % ground temperature
                       % Sky temperature
                                          % given formula
        td=(0.0552*((ta+273)^1.5))-273;
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
           -----Current Carrying Capacity------Current Carrying Capacity------
       Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       bb(:,xx) = Id;
end
Power gain by solar heat input
8
                           % Solar absorption coefficient
a=0.9;
                           % 0.5 for rural weathered conductor
8
                           % 0.85 for industrial weathered conductor
2
1=27.5667;
                           % Toowoomba latitude
Ns=1;
                           % Clear sky
v=632;
                           % meters above sea level
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           8 0.2
                                         General value
for xx=1:1:13
       Id=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       ds=23.4*sind(2*pi*(284+1)/365); % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar
altitude
       ys=0;
                                        % azimuth of the sun = o at noon
                                                  % solar beam angle
        n=acosd((cosd(Hs)*cosd(ys)));
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                          % direct beam
        Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
       It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));% radiation intensity
        % %%% Solar heating %%%
       PS=a*D*It;
                           Power loss by forced convection
        8
        tc=75;
                               % Max operating temperature
       ta=35:
                               % General Ambient Temperature
                               % Thermal conductivity of Air Film
       lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                               % Viscosity of the Air Film
       vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
       v=1;
                               % Wind speed
                               % Reynolds Number
       Re=v*D/vf;
                               % D is the diameter of conductor
                               % Constants B and n
        if Re<=2650
                              % Conditions for B & n
           B=0.641;
                               % Constant
           n=0.471;
                               % Constant
        end
        if Re>2650
                               % Constant
           B=0.048;
           n=0.8;
                               % Constant
       end
       angle=90;
                               % wind approach angle
                               % Constants C and P
        if angle<=24
           C=0.68;
                               % Constant
           P=1.08;
                               % Constant
       else
           C=0.58;
```

```
P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                            Power loss by radiation
       o=5.67*10^-8;
                          % Stefan-Boltzmann constant
       e=0.85;
                          % emissivity of conductor
       tg=ta+5;
                          % ground temperature
                      % Sky temperature
       td=(0.0552*((ta+273)^{1.5}))-273;
                                       % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %-----Current Carrying Capacity------
       Ic(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
       cc(:,xx)=Id;
end
%
               Power gain by solar heat input
a=0;
                        % Solar absorption coefficient
                          \% 0.5 for rural weathered conductor
8
                          % 0.85 for industrial weathered conductor
2
1=27.5667;
                          % Toowoomba latitude
Ns=1;
                          % Clear sky
y=632;
                          % meters above sea level
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          8 0.2
                                         General value
for xx=1:1:13
       Idir=650+(xx*50); % Direct solar radiation intensity at W.m^-2
       ds=23.4*sind(2*pi*(284+1)/365);
                                                   % declination angle
       Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar
altitude
       ys=0;
                                       % azimuth of the sun = o at noon
       n=acosd((cosd(Hs)*cosd(ys)));
                                                     % solar beam angle
       Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                         % direct beam
       Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
```

It=Iby*(sind(n)+0.5*F*sind(Hs))+Idir*(1+(pi/2*F));% radiation

```
intensity
```

% %%% Solar heating %%%	
PS=a*D*It;	
%Power	loss by forced convection
tc=75; %	Max operating temperature
ta=10; %	General Ambient Temperature
%	Thermal conductivity of Air Film
lambda=(2.42*10^-2)+((7.2*10^-5)*((tc+ta)/2));	
00	Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));	
v=1; %	Wind speed
00	Reynolds Number
Re=v*D/vf; %	D is the diameter of conductor
00	Constants B and n
if Re<=2650 %	Conditions for B & n
B=0.641; %	Constant
n=0.471; %	Constant
end	
if Re>2650	
B=0.048; %	Constant
n=0.8; %	Constant
end	
angle=90; %	wind approach angle
- -	Constants C and P
if angle<=24	
C=0.68; %	Constant
P=1.08; %	Constant
else	
C=0.58;	
P=0.9;	
end	
%%% Forced Convection %%%	

```
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                               Power loss by radiation
        o=5.67*10^-8;
                            % Stefan-Boltzmann constant
        e=0.85;
                             % emissivity of conductor
        tg=ta-5;
                            % ground temperature
                        % Sky temperature
        td=(0.0552*((ta+273)^{-1.5}))-273;
                                            % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity------
        Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
        dd(:,xx)=Idir;
end
Ia=Ia./Ia(7)*100;
Ib=Ib./Ib(7)*100;
Ic=Ic./Ic(7)*100;
Id=Id./Id(7)*100;
figure (1)
hold on
p1=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[700 1300]);
legend([p1 p2 p3 p4], {'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Direct Solar Radiation Intensity - Cigre
TB601', 'Fontsize',14);
xlabel('Direct Solar Radiation Intensity (W/m^2) - 100% nominal CCC at
1000(W/m^2)', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Wind Speed Cigre
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all:
clc;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
% ESAA Formula
%----- Define Parameters -----
                  General Parameters
k=1.015;
                    % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                   % Conductor resistance
alpha=0.00403;
                   % Temperature coefficient
Power gain by solar heat input
8
a=0.5;
                        % Solar absorption coefficient
8
                        % 0.5 for rural weathered conductor
                        \% 0.85 for industrial weathered conductor
2
1=27.5667;
                        % Toowoomba latitude
Ns=1:
                        % Clear sky
y=632;
                        % meters above sea level
D=21*10^-3;
                        % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                        % Albedo ground reflectance-reflected radiation
                        8 0.2
                                   General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
ys=0;
                                   % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                % solar beam angle
Id=(430.5-0.3288*Iby)*sind(Hs);
                                              % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                             % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
8
                 Power loss by forced convection
tc=75;
                   % Max operating temperature
ta=35;
                    % General Ambient Temperature
                    % Thermal conductivity of Air Film
lambda=(2.42*10^-2)+((7.2*10^-5)*((tc+ta)/2));
                     % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
      v=xx*0.25;
                    % Reynolds Number
      Re=v*D/vf;
                    \% D is the diameter of conductor
                    % Constants B and n
       if Re<=2650
                   % Conditions for B & n
          B=0.641; % Constant
          n=0.471;
                   % Constant
       end
       if Re>2650
```

```
B=0.048; % Constant
                     % Constant
           n=0.8;
       end
       angle=90;
                      % wind approach angle
                      % Constants C and P
                      % Constant
       C=0.58;
       P=0.9;
                      % Constant
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                  ____Power loss by radiation
8
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
                    % emissivity of conductor
   e=0.5;
   tg=ta+5;
                      % ground temperature
                      % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        -----Current Carrying Capacity------
   Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=v;
end
Power gain by solar heat input
8
                          % Solar absorption coefficient set for 0 for night
a=0:
2
                          % 0.5 for rural weathered conductor
                          % 0.85 for industrial weathered conductor
2
                          % Toowoomba latitude
1=27.5667;
Ns=1;
                          % Clear sky
y=632;
                          % meters above sea level
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                                         General value
                          8 0.2
ds=23.4*sind(2*pi*(284+1)/365);
                                                    % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));
                                                    % solar altitude
vs=0;
                                % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                     % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                    % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                    % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                 % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                  Power loss by forced convection
tc=75;
                     % Max operating temperature
ta=10;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                      % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                      % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
       if Re<=2650
                      % Conditions for B & n
          B=0.641;
                      % Constant
           n=0.471;
                     % Constant
       end
       if Re>2650
           B=0.048; % Constant
           n=0.8;
                     % Constant
       end
       angle=90;
                              % wind approach angle
                      % Constants C and P
```

```
C=0.58;
                       % Constant
       P=0.9;
                       % Constant
                       \% if wind angle between 0-24 C=0.68, P=1.08
                       % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                         Power loss by radiation
    o=5.67*10^-8;
                       % Stefan-Boltzmann constant
    e=0.5;
                       % emissivity of conductor
    tq=ta-5;
                       % ground temperature
                       % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273; % given formula
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   bb(:,xx)=v;
 end
___Power gain by solar heat input_
8
a=0.9:
                           % Solar absorption coefficient
2
                           % 0.5 for rural weathered conductor
                           % 0.85 for industrial weathered conductor
2
1=27.5667;
                           % Toowoomba latitude
Ns=1;
                           % Clear sky
y=632;
                           % meters above sea level
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
8
                           % 0.2
                                        General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                      % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
ys=0;
                                        % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                      % solar beam angle
                                                     % direct beam
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                               % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                     % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                  % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                   Power loss by forced convection
tc=75;
                       % Max operating temperature
ta=35:
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
%Wind speed 'For Loop'
 for xx=1:1:24;
       v=xx*0.25;
                       % Reynolds Number
       Re=v*D/vf;
                      % D is the diameter of conductor
                       % Constants B and n
        if Re<=2650
                      % Conditions for B & n
           B=0.641;
                      % Constant
                      % Constant
           n=0.471;
       end
       if Re>2650
           B=0.048;
                       % Constant
           n=0.8;
                      % Constant
       end
       angle=90;
                      % wind approach angle
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
```

```
%%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
8
                   Power loss by radiation
                 % Stefan-Boltzmann constant
   o=5.67*10^-8;
   e=0.85;
                       % emissivity of conductor
   tg=ta+5;
                      % ground temperature
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tq+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   cc(:,xx)=v;
end
8
               Power gain by solar heat input
                          % Solar absorption coefficient
a=0:
8
                          % 0.5 for rural weathered conductor
2
                          % 0.85 for industrial weathered conductor
                          % Toowoomba latitude
1=27.5667;
Ns=1:
                          % Clear sky
v=632;
                          % meters above sea level
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          8 0.2
                                      General value
2
ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));
                                                    % solar altitude
vs=0;
                                       % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                     % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                     % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                               % direct beam at height y
                                                    % diffuse radiation
Id=(430.5-0.3288*Iby)*sind(Hs);
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                 % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                  Power loss by forced convection
tc=75;
                      % Max operating temperature
ta=10;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
%Wind speed 'For Loop'
for xx=1:1:24;
       v=xx*0.25;
                      % Reynolds Number
                      % D is the diameter of conductor
       Re=v*D/vf;
                      % Constants B and n
                      % Conditions for B & n
       if Re<=2650
           B=0.641;
                      % Constant
           n=0.471;
                      % Constant
       end
       if Re>2650
           B=0.048; % Constant
           n=0.8;
                     % Constant
       end
       angle=90;
                              % wind approach angle
                      % Constants C and P
       C=0.58;
                      % Constant
       P=0.9;
                      % Constant
                      % if wind angle between 0-24 C=0.68, P=1.08
                       % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                         Power loss by radiation
   o=5.67*10^-8; % Stefan-Boltzmann constant
   e=0.85;
                       % emissivity of conductor
```

```
tg=ta-5;
                       % ground temperature
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273;
                                     % given formula
    %%% Radiated Loss %%%
   PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
%-----Current Carrying Capacity-----
   Id(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   dd(:,xx)=v;
end
Ia=Ia./Ia(8)*100;
Ib=Ib./Ib(8)*100;
Ic=Ic./Ic(8)*100;
Id=Id./Id(8)*100;
figure (1)
hold on
pl=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[0.25 6]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer','Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Wind Speed - Cigre TB
601', 'Fontsize', 14);
xlabel('V (m/s) - 100% nominal CCC at 2m/s', 'Fontsize',14);
ylabel('% Variation in CCC', 'Fontsize',14);
grid on;
```

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Sensitivity analysis
% Wind Angle Cigre
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
clf;
%----- Conditions -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
8----- Define Parameters -----
2
           General Parameters
k=1.015:
                    % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3;
                    % Conductor resistance
alpha=0.00403;
                    % Temperature coefficient
8
              Power gain by solar heat input
a=0.5;
                        % Solar absorption coefficient
                         \% 0.5 for rural weathered conductor
2
                        % 0.85 for industrial weathered conductor
1=27.5667;
                        % Toowoomba latitude
                        % Clear sky
Ns=1;
y=632;
                        % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                         % Albedo ground reflectance-reflected radiation
                         80.2
                                   General value
2
% azimuth of the sun = o at noon
vs=0;
n=acosd((cosd(Hs)*cosd(ys)));
                                                  % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314))); % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
Id=(420.5.0.228*thu) taind(Ua);
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                              % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
            Power loss by forced convection
% use Toowoomba reference as GPS coordinates for calculations for CCC
t_{c=75}
                    % Max operating temperature
ta=35;
                     % General Ambient Temperature
                     % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                     % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
                     % Wind speed
v=1;
                     % Reynolds Number
Re=v*D/vf;
                     % D is the diameter of conductor
                     % Constants B and n
if Re<=2650
                     % Conditions for B & n
                     % Constant
   B=0.641;
   n=0.471;
                    % Constant
end
if Re>2650
   B=0.048;
                    % Constant
```

```
n=0.8;
                      % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5);% wind approach angle
    % Constants C and P
       if angle<=24
           C=0.68;
                              % Constant
           P=1.08;
                              % Constant
       else
           C=0.58;
           P=0.9;
       end
   \% if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
   %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                     _Power loss by radiation
8
   o=5.67*10^-8;
                  % Stefan-Boltzmann constant
   e=0.5;
                      % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4));
%-----Current Carrying Capacity-----
  Ia(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   aa(:,xx)=angle;
end
___Power gain by solar heat input
8
a=0;
                       % Solar absorption coefficient set for 0 for night
                       % conditions
1=27.5667;
                          % Toowoomba latitude
                          % Clear sky
Ns=1;
v=632;
                          % meters above sea level
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          8 0.2
8
                                        General value
ds=23.4*sind(2*pi*(284+1)/365);
                                                     % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));
                                                    % solar altitude
ys=0;
                                       % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                      % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                     % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                               % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                    % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                  % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                   Power loss by forced convection
tc=75;
                      % Max operating temperature
ta=10;
                      % General Ambient Temperature
                      % Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
v=1;
                       % Wind speed
                      % Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
                      % Constants B and n
if Re<=2650
                      % Conditions for B & n
   B=0.641;
                      % Constant
   n=0.471;
                      % Constant
end
if Re>2650
   B=0.048;
                      % Constant
                      % Constant
   n=0.8;
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5); % wind approach angle
```

```
% Constants C and P
       if angle<=24
                               % Constant
           C=0.68;
           P=1.08;
                               % Constant
        else
           C=0.58;
           P=0.9;
       end
    % if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                  Power loss by radiation
8
   o=5.67*10^-8; % Stefan-Boltzmann constant
   e=0.5;
                       % emissivity of conductor
   tg=ta-5;
                       % ground temperature
                       % Sky temperature
   td=(0.0552*((ta+273)^1.5))-273; % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4));
%-----Current Carrying Capacity-----
   Ib(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   bb(:,xx)=angle;
end
___Power gain by solar heat input
8
                          % Solar absorption coefficient
a=0.9;
                           % 0.5 for rural weathered conductor
8
2
                           % 0.85 for industrial weathered conductor
1=27.5667;
                           % Toowoomba latitude
                           % Clear sky
Ns=1;
                           % meters above sea level
v=632;
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           8 0.2
                                       General value
8
ds=23.4*sind(2*pi*(284+1)/365);
                                                       % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
ys=0;
                                        % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                       % solar beam angle

      Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
      % direct beam

      Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
      % direct beam at height y

Id=(430.5-0.3288*Iby)*sind(Hs);
                                                      % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F));
                                                   % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                   Power loss by forced convection
tc=75;
                       % Max operating temperature
ta=35;
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                        % Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
v=1;
                       % Wind speed
                       % Reynolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
                       % Constants B and n
if Re<=2650
                       % Conditions for B & n
   B=0.641;
                       % Constant
   n=0.471;
                       % Constant
end
if Re>2650
                      % Constant
   B=0.048;
   n=0.8;
                      % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
```

```
angle=-5+(xx*5);% wind approach angle
    % Constants C and P
       if angle<=24
           C=0.68;
                               % Constant
           P=1.08;
                               % Constant
       else
           C=0.58:
           P=0.9;
       end
    % if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
8
                     Power loss by radiation
   o=5.67*10^-8;
                      % Stefan-Boltzmann constant
    e=0.85;
                       % emissivity of conductor
   tg=ta+5;
                       % ground temperature
                       % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273;
                                     % given formula
   %%% Radiated Loss %%%
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4));
   -----Current Carrying Capacity-----
8 ---
   Ic(:,xx)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
    cc(:,xx) = angle;
 end
8
               Power gain by solar heat input
                       % Solar absorption coefficient set for 0 for night
a=0:
                       % conditions
1=27.5667;
                           % Toowoomba latitude
                           % Clear sky
Ns=1:
                           % meters above sea level
v=632;
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                           % Albedo ground reflectance-reflected radiation
                           8 0.2
                                          General value
ds=23.4*sind(2*pi*(284+1)/365); % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                                  % azimuth of the sun = o at noon
vs=0:
n=acosd((cosd(Hs)*cosd(ys)));
                                      % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314))); % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
                                           % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                          % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
                   Power loss by forced convection
t.c=75;
                       % Max operating temperature
ta=10;
                       % General Ambient Temperature
                       % Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                       % Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
v=1;
                       % Wind speed
                       % Reynolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
                       % Constants B and n
if Re<=2650
                       % Conditions for B & n
   B=0.641;
                       % Constant
    n=0.471;
                       % Constant
end
if Re>2650
   B=0.048;
                       % Constant
   n=0.8;
                       % Constant
end
%Wind Angle 'For Loop'
for xx=1:1:19
       angle=-5+(xx*5);% wind approach angle
    % Constants C and P
       if angle<=24
```

```
C=0.68;
                                % Constant
            P=1.08;
                                 % Constant
        else
            C=0.58;
            P=0.9;
        end
    % if wind angle between 0-24 C=0.68, P=1.08
    % if wind angle between 24-90 C=0.58, P=0.9
    %%% Forced Convection %%%
    PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
8
                       Power loss by radiation
   o=5.67*10^-8;
                        % Stefan-Boltzmann constant
    e=0.85;
                         % emissivity of conductor
   tg=ta-5;
                        % ground temperature
                        % Sky temperature
    td=(0.0552*((ta+273)^1.5))-273;
                                       % given formula
    %%% Radiated Loss %%%
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4));
%-----Current Carrying Capacity-----
   Id(:,xx) = sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
    dd(:,xx) = angle;
end
Ia=Ia./Ia(19)*100;
Ib=Ib./Ib(19)*100;
Ic=Ic./Ic(19)*100;
Id=Id./Id(19)*100;
figure (1)
hold on
pl=plot(aa,Ia,'LineWidth',2);
p2=plot(bb,Ib,'--gr','LineWidth',2);
p3=plot(cc,Ic,':m','LineWidth',2);
p4=plot(dd,Id,'-.r','LineWidth',2);
plot(p1,p2,p3,p4)
set(gca, 'xlim',[0 90]);
legend([p1 p2 p3 p4],{'Rural Weathered Summer', 'Rural Weathered
Winter', 'Industrial Weathered Summer', 'Industrial Weathered
Winter'}, 'Fontsize', 12)
title('% Variation in CCC as per Variation in Approach Angle - Cigre TB
601', 'Fontsize', 14);
xlabel('Angle (Degrees) - 100% nominal CCC at 90 Degrees', 'Fontsize', 14);
```

Appendix E

MATLAB Script – Dynamic Components Analysis

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Cigre
% Current Carrying Conditions for Wind Conditions
% Created by
% Ryan Murphy
8 22/05/2015
%----- set up program -----
clear all;
close all;
clc;
clf;
%----- Conditions -----
%four conditions of this analysis, the point of this is to establish how
%the change in component effects the current carrying capacity of the
%conductor. Test conducted with Rural weathered Summer Noon conditions
%----- Define Parameters -----
% AAC (37/3.00) - Saturn, summer noon conditions, 2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
%----- Define Parameters -----
k=1.015;% Effective Resistance - supplied as 1.015Rdc=0.11*10^-3;% Conductor resistancealpha=0.00403;% Temperature
$_____
2
                                              Albedo Changes
8
                                      Power gain by solar heat input
for xx=1:20
   F=xx*0.05;
   a=0.5;
                           % Solar absorption coefficient
                           % Toowoomba latitude
   1=27.5667;
   Ns=1;
                           % Clear sky
   y=632;
                           % meters above sea level
   D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
   ds=23.4*sin(2*pi*(284+1)/365);
                                              % declination angle
   Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                                 % azimuth of the sun = o at noon
   vs=0;
   n=acosd((cosd(Hs)*cosd(ys)));
                                                % solar beam angle
   Id=(430.5-0.3288*Iby)*sind(Hs);
                                             % diffuse radiation
   It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
   PS=a*D*It;
                           % Solar Heating
8
                                            Power loss by radiation
   tc= 70;
                       % Max operating temperature
   ta= 35;
                       % Summer noon 35
   o=5.67*10^-8;
                       % Stefan-Boltzmann constant
   e=0.5;
                       % emissivity of conductor
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
8
                                      Power loss by forced convection
   % Thermal conductivity of Air Film
   lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
   v=1;
                        %transverse of wind velocity
   % Viscosity of the Air Film
   vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
   % Reynolds Number
   Re=v*D/vf;
                       % D is the diameter of conductor
   angle=70:
                      % wind approach angle
   % Constants C and P
```

```
if angle<=24
       C=0.68;
                          % Constant
       P=1.08;
                          % Constant
    end
    if angle>24
                         % Constant
       C=0.58;
       P=0.9;
                          % Constant
    end
    % Constants B and n
    if Re<=2650
                         % Conditions for B & n
                         % Constant
       B=0.641;
       n=0.471:
                         % Constant
    end
    if Re>2650
       B=0.048;
                          % Constant
       n=0.8;
                           % Constant
    end
    PF=pi*lambda*(tc-ta)*B*Re^n; %(0.42+(C*sind(angle)^P));
    %current carrying capacity
    I A(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
<u>9</u>_____
                                             Wind speed Changes
0
8
                                           Power gain by solar heat input
F=0.2;
                          % Albedo
                          % Solar absorption coefficient
a=0.5;
1=27.5667;
                          % Toowoomba latitude
                          % Clear sky
Ns=1:
y=632;
                           % meters above sea level
D=21*10^-3;
                           % Diameter of conductor AAC 37/3.00 Saturn
ds=23.4*sin(2*pi*(284+1)/365);
                                                % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                           % azimuth of the sun = o at noon
vs=0;
                                          % solar beam angle
n=acosd((cosd(Hs)*cosd(ys)));
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                     % direct beam
Ibu=Nb ((1200 bind(nb), (clnd(nb), (clnd(nb), fill));
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
% diffuse radiation
Id=(430.5-0.3288*Iby)*sind(Hs);
                                                % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
PS=a*D*It;
                          % Solar Heating
8
                                                 Power loss by radiation
tc= 70;
                      % Max operating temperature
ta= 35;
                      % Summer noon 35
o=5.67*10^-8;
                      % Stefan-Boltzmann constant
                     % emissivity of conductor
e=0.5;
PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
2
                                          Power loss by forced convection
for xx=1:20
    v=0+(xx*0.25); % Velocity of wind
    % Thermal conductivity of Air Film
   lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
    % Viscosity of the Air Film
   vf = (1.32 \times 10^{-5}) + ((9.5 \times 10^{-8}) \times ((tc+ta)/2));
    % Reynolds Number
   Re=v*D/vf;
                           % D is the diameter of conductor
   angle=70;
                          % wind approach angle
    % Constants C and P
    if angle<=24
       C=0.68;
                          % Constant
       P=1.08;
                          % Constant
    end
    if angle>24
       C=0.58;
                     % Constant
% Constant
       P=0.9;
    end
```

```
% Constants B and n
   if Re<=2650
                       % Conditions for B & n
      B=0.641;
                   % Constant
% Constant
       n=0.471;
   end
   if Re>2650
                    % Constant
      B=0.048;
      n=0.8;
                       % Constant
   end
   PF=pi*lambda*(tc-ta)*B*Re^n; %*(0.42+(C*sind(angle)^P));
   %current carrying capacity
   I Ws(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
%_____
                                                Wind angle Changes
8
8
                                      Power gain by solar heat input
F=0.2;
                        % Albedo
a=0.5;
                        % Solar absorption coefficient
                        % Toowoomba latitude
1=27.5667;
Ns=1;
                        % Clear sky
y=632;
                        % meters above sea level
D=21*10^-3;
                        % Diameter of conductor AAC 37/3.00 Saturn
ds=23.4*sin(2*pi*(284+1)/365);
                                            % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                          % azimuth of the sun = o at noon
vs=0;
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
PS=a*D*It;
                        % Solar Heating
8
                                            Power loss by radiation
% Max operating temperature
PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
                                     Power loss by forced convection
v=1; % Velocity of wind
% Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
% Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
% Reynolds Number
Re=v*D/vf;
                   % D is the diameter of conductor
for xx=1:20
   angle=0+(4.5*xx);
                              % wind approach angle
   % Constants C and P
   if angle<=24
      C=0.68;
                       % Constant
      P=1.08;
                       % Constant
   end
   if angle>24
      C=0.58;
                      % Constant
      P=0.9;
                       % Constant
   end
   end

% Constants B and n

if Re<=2650 % Conditions for B & n

~ ^ 641. % Constant
                       % Constant
      n=0.471;
   end
   if Re>2650
       B=0.048;
                       % Constant
```

```
n=0.8;
                         % Constant
   end
   PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
   %current carrying capacity
   I Wa(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
<u>9</u>_____
8
                                           Ambient Temp Changes
8
                                         Power gain by solar heat input
F=0.2;
                         % Albedo
a=0.5;
                         % Solar absorption coefficient
1=27.5667;
                         % Toowoomba latitude
Ns=1;
                         % Clear sky
v=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
ds=23.4*sin(2*pi*(284+1)/365);
                                              % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
vs=0;
                                  % azimuth of the sun = o at noon
n=acosd((cosd(Hs)*cosd(ys)));
                                                % solar beam angle
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
PS=a*D*It;
                         % Solar Heating
8
                                               Power loss by radiation
tc= 70;
                     % Max operating temperature
o=5.67*10^-8;
                      % Stefan-Boltzmann constant
e=0.5;
                      % emissivity of conductor
for xx=1:20
   ta= 0+(2.5*xx);
                                 % Ambient changes
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
   2
                                        Power loss by forced convection
   v=1:
                 % Velocity of wind
   % Thermal conductivity of Air Film
   lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
   % Viscosity of the Air Film
   vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
   % Reynolds Number
   Re=v*D/vf;
                         % D is the diameter of conductor
   angle=70;
                         % wind approach angle
   % Constants C and P
   if angle<=24
       C=0.68;
                         % Constant
                         % Constant
       P=1.08;
   end
   if angle>24
       C=0.58;
                         % Constant
       P=0.9;
                         % Constant
   end
   % Constants B and n
   if Re<=2650
                         % Conditions for B & n
       B=0.641;
                         % Constant
       n=0.471;
                         % Constant
   end
   if Re>2650
       B=0.048;
                         % Constant
       n=0.8;
                         % Constant
   end
   PF=pi*lambda*(tc-ta)*B*Re^n; %*(0.42+(C*sind(angle)^P));
   %current carrying capacity
   I T(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
```

```
$_____
2
                                                         Default
8
                                         Power gain by solar heat input
F=0.2;
                         % Albedo
a=0.5;
                          % Solar absorption coefficient
1=27.5667;
                         % Toowoomba latitude
                          % Clear sky
Ns=1:
y=632;
                          % meters above sea level
D=21*10^-3;
                          % Diameter of conductor AAC 37/3.00 Saturn
ds=23.4*sin(2*pi*(284+1)/365);
                                               % declination angle
Hs=asind(sind(1)*sind(ds)+cosd(1)*cosd(ds)*cosd(0)); % solar altitude
                         % azimuth of the sun = o at noon

vs=0;
                                         % solar beam angle
n=acosd((cosd(Hs)*cosd(ys)));
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                                    % direct beam
Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1)); % direct beam at height y
Id=(430.5-0.3288*Iby)*sind(Hs);
                                               % diffuse radiation
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
PS=a*D*It;
                         % Solar Heating
2
                                               Power loss by radiation
tc= 70;
                      % Max operating temperature
ta= 35;
                      % Summer noon 35
o=5.67*10^-8;
                      % Stefan-Boltzmann constant
e=0.5;
                      % emissivity of conductor
PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
8
                                        Power loss by forced convection
             % Velocity of wind
v=1:
% Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
% Viscosity of the Air Film
vf = (1.32 \times 10^{-5}) + ((9.5 \times 10^{-8}) \times ((tc+ta)/2));
% Reynolds Number
Re=v*D/vf;
                      % D is the diameter of conductor
angle=70;
                      % wind approach angle
   % Constants C and P
    if angle<=24
       C=0.68;
                        % Constant
       P=1.08;
                         % Constant
   end
   if angle>24
       C=0.58;
                         % Constant
       P=0.9;
                         % Constant
   end
    % Constants B and n
                      % Conditions for B & n
    if Re<=2650
       B=0.641;
                         % Constant
                         % Constant
       n=0.471;
   end
    if Re>2650
       B=0.048;
                          % Constant
       n=0.8;
                         % Constant
   end
PF=pi*lambda*(tc-ta)*B*Re^n; % *(0.42+(C*sind(angle)^P));
%current carrying capacity
for xx=1:20
   I_D(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
```

\$_____

8

8

```
for xx=1:20
   F=0.2;
                            % Albedo
   a=0+(xx*0.05);
                            % Solar absorption coefficient
   1=27.5667;
                            % Toowoomba latitude
   Ns=1;
                            % Clear sky
   y=632;
                            % meters above sea level
   D=21*10^-3;
                            % Diameter of conductor AAC 37/3.00 Saturn
   ds=23.4*sin(2*pi*(284+1)/365);
                                               % declination angle
   Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                               % azimuth of the sun = o at noon
   ys=0;
   n=acosd((cosd(Hs)*cosd(ys)));
                                                 % solar beam angle
   It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
   PS=a*D*It;
                            % Solar Heating
8
                                              Power loss by radiation
   tc= 70;
                        % Max operating temperature
   ta= 35;
                        % Summer noon 35
   o=5.67*10^-8;
                        % Stefan-Boltzmann constant
   o=5.67*10^-8; % Stefan-Boltzmann constar
e=0+(xx*0.05); % emissivity of conductor
   PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
0
                                       Power loss by forced convection
   % Thermal conductivity of Air Film
   lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
   v=1;
                         %transverse of wind velocity
   % Viscosity of the Air Film
   vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
   % Reynolds Number
   Re=v*D/vf;
                        % D is the diameter of conductor
   angle=70;
                        % wind approach angle
   % Constants C and P
   if angle<=24
      C=0.68;
                        % Constant
      P=1.08;
                        % Constant
   end
   if angle>24
      C=0.58;
                       % Constant
       P=0.9;
                        % Constant
   end
   % Constants B and n
   if Re<=2650
                       % Conditions for B & n
      B=0.641;
                       % Constant
                        % Constant
      n=0.471;
   end
   if Re>2650
                    % Constant
      B=0.048;
      n=0.8;
                        % Constant
   end
   PF=pi*lambda*(tc-ta)*B*Re^n; %*(0.42+(C*sind(angle)^P));
   %current carrying capacity
   I a(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
end
8_____
8
                                                Collaborate data
zMat=[I_D I_A I_a I_Wa I_Ws I_T];
<u>&_____</u>
                                                    Develop 3D plots
8
% figure(1)
% x values
FIG=figure(1);
% set(FIG, 'units', 'normalized', 'outerposition', [0 0 1 1]);
x=1:20;
xMat = repmat(x', 1, 6);
```

```
% y values
y = 1:1:6;
yMat = repmat(y, numel(x), 1);
% plot components
plot3(xMat, yMat, zMat, 'LineWidth',3);
grid;
% Format
xlabel('Changing Condition', 'FontSize', 14);
ylabel('Variable','FontSize', 14);
zlabel('Current Carrying Capacity (A)','FontSize', 14);
set(get(gca, 'ZLabel'), 'Rotation', 90);
axis tight
legend('Static','Albedo','Absorptivity and Emissivity','Wind Angle', ...
    'Wind Speed', 'Ambient Temperature', 'northwest')
view(-60,30)
title('Dynamic Current Carrying Capacity for Different Variables', 'FontSize',
14)
% x values
FIG=figure(2);
% set(FIG, 'units', 'normalized', 'outerposition', [0 0 1 1]);
x=1:20;
xMat = repmat(x', 1, 6);
% y values
y = 1:1:6;
yMat = repmat(y, numel(x), 1);
% plot components
plot3(xMat, yMat, zMat, 'LineWidth',4,'Marker','x');
grid;
% Format
xlabel('Step Change in Condition', 'FontSize', 14);
ylabel('Variable','FontSize', 14);
zlabel('Current Carrying Capacity (A)','FontSize', 14);
set(get(gca, 'ZLabel'), 'Rotation', 90);
axis tight
title('Dynamic Current Carrying Capacity for Different Variables', 'FontSize',
14)
legend('Static','Albedo','Absorptivity and Emissivity','Wind Angle', ...
  'Wind Speed', 'Ambient Temperature', 'northwest', 'Fontsize', 14)
view(90,0)
hold on
IDmn=min(I D);
IDmx=max(I_D);
plot([1 1], [IDmx IDmn], '+');
```

- % Annealing Properties of Homogenous Conductor
- % Across Varying Conditions

```
% Engineering Dissertation
% Cigre
% Wind speed vs wind angle
% Created by
% Ryan Murphy
8 22/05/2015
°-----
            ----- set up program -----
clear all;
close all:
clc:
clf;
%----- Conditions -----
%----- Define Parameters -----
% AAC (37/3.00) - Saturn, summer noon conditions,2m/s wind conditions,
% Maximum Design operating temperature 75 degrees celcius
% Maximum allowable temperature 50 degrees celcius
2
%----- Define Parameters -----
        _____General Parameters_
00
k=1.015; % Effective Resistance - supplied as 1.015
Rdc=0.11*10^-3; % Conductor resistance
k=1.015;
alpha=0.00403; % Temperature coefficient
___Power gain by solar heat input
a=0.5;
                         % Solar absorption coefficient
8
                          % 0.5 for rural weathered conductor
2
                          % 0.85 for industrial weathered conductor
1=27.5667;
                          % Toowoomba latitude
                          % Clear sky
Ns=1:
y=632;
                         % meters above sea level
D=21*10^-3;
                         % Diameter of conductor AAC 37/3.00 Saturn
F=0.2;
                          % Albedo ground reflectance-reflected radiation
                          % 0.2
                                  General value
ds=23.4*sin(2*pi*(284+1)/365);
                                                  % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
                            % azimuth of the sun = o at noon
ys=0;

      Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
      % solar beam angle

      Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
      % direct beam

      Id=(430.5-0.3288*Iby)*sind(Hs);
      % direct beam at height y

It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
% %%% Solar heating %%%
PS=a*D*It;
%___
                  Power loss by radiation
8
             % Max operating temperature
% Summer noon 35
tc= 85;
ta= 35;
                     % winter night 10
o=5.67*10^-8;
                     % Stefan-Boltzmann constant
                     % emissivity of conductor
e=0.5;
                      % 0.5 rural weathered conductor
                      % 0.85 industrial weathered conductor
%%% Radiated Loss %%%
PR=pi*D*o*e*((tc+273)^4-(ta+273^4));
         Power loss by forced convection_
% Thermal conductivity of Air Film
lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
v=0; %transverse of wind velocity
% Viscosity of the Air Film
```

```
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
% Reynolds Number
Re=v*D/vf;
                        % D is the diameter of conductor
angle=70;
                         % wind approach angle
% for the condition of change in wind speed
for y=1:1:20;
        angle = -5 + (y*5);
                                % wind approach angle
        % Constants C and P
        if angle<=24
            C=0.68;
                                 % Constant
            P=1.08;
                                 % Constant
        end
        if angle>24
            C=0.58;
                                % Constant
                                % Constant
            P=0.9;
        end
        for x=1:20
            v=v+0.25;
            Re=v*D/vf;
            % Constants B and n
            if Re<=2650
                                    % Conditions for B & n
                B=0.641;
                                    % Constant
                n=0.471;
                                    % Constant
            end
            if Re>2650
                                    % Constant
                B=0.048;
                n=0.8;
                                     % Constant
            end
            PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
            I(x,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
            A(x, :) = v;
        end
        z(y,:)=I;
        v=0;
        %current carrying capacity
    FIG=figure(1);
    set(FIG, 'units', 'normalized', 'outerposition', [0 0 1 1]);
    plot(A,I,'LineWidth',2);
    title('Wind Speed Vs Wind Angle', 'FontSize', 20);
    legend('Current Carrying Capacity');
    xlabel('Wind Speed (m/s)','FontSize', 16);
    ylabel('Current (A)', 'FontSize', 16);
    axis([0 7 400 1300])
    grid on;
    hold on
end
% use gtext to click on the voltage contours to label them
% gtext('5 degrees'); gtext('10 degrees'); gtext('15 degrees');
% gtext('20 degrees'); gtext('25 degrees'); gtext('30 degrees');
% gtext('45 degrees'); gtext('90 degrees')
FIG=figure(2);
% set(FIG, 'units', 'normalized', 'outerposition', [0 0 1 1]);
%// Define x values
x = A;
xMat = repmat(x, 1, 20); %// For plot3
%// Define y values
y = 1:1:20;
yMat = repmat(y, numel(x), 1); %//For plot3
yMat=(yMat.*5)-5
%// Define z values
zMat = z'; %// For plot3
plot3(xMat, yMat, zMat); %// Make all traces blue
grid;
```

```
xlabel('x'); ylabel('y'); zlabel('z');
% Format
[xi,yi] = meshgrid(0:0.25:5, 0:5:90);
zi = griddata(xMat,yMat,zMat,xi,yi);
surf(xi,yi,zi);
colormap
shading interp
axis tight
colorbar
view(-60,30)
xlabel('Change in Wind Speed (m/s)','FontSize', 14);
ylabel('Change in Wind Angle (Degrees)', 'FontSize', 14);
zlabel('Current Carrying Capacity (A)', 'FontSize', 14);
set(get(gca, 'ZLabel'), 'Rotation', 90);
title('Current Carrying Capacity for Wind Speed Vs Wind Angle (3D
Interpolation)', 'FontSize', 14)
axis tight
```

Appendix F

MATLAB Script – Cigré Latitude Test

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Cigre
% Change in Latitude - Cigre
% Created by
% Ryan Murphy
8 19-09-2015
%----- set up program -----
clear all;
close all;
clc;
                 ____General Parameters
k=1.015;% Effective Resistance - supplied as 1.015Rdc=0.11*10^-3;% Conductor resistancealpha=0.00403;% Temperature coefficient
8------
                                         Cigre Default
2
                                       Power gain by solar heat input
F=0.2;
                        % Albedo
a=0.5;
                         % Solar absorption coefficient
for l=17:1:29;
                         % latitude loop
Ns=1;
                         % Clear sky
v=10;
                        % meters above sea level
D=21*10^-3;
                        % Diameter of conductor AAC 37/3.00 Saturn
for N=1:364;
                        % Day of the year
ds=23.4*sin(2*pi*(284+(N+365/2))/365);
                                                 % declination angle
xxx(N,:) = ds;
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0)); % solar altitude
% azimuth of the sun = o at noon
Id=(430.5-0.3288*Iby)*sind(Hs);
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation intensity
PS=a*D*It;
                        % Solar Heating
8
                                             Power loss by radiation
tc= 70;
                    % Max operating temperature
ta= 35;
                    % Summer noon 35
0=5.67*10^-8;
                    % Stefan-Boltzmann constant
e=0.5:
                     % emissivity of conductor
PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
2
                                       Power loss by forced convection
            % Velocity of wind
v=5;
% Thermal conductivity of Air Film
lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
% Viscosity of the Air Film
vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
% Reynolds Number
Re=v*D/vf;
                     % D is the diameter of conductor
angle=70;
                     % wind approach angle
   % Constants C and P
   if angle<=24
      C=0.68;
                        % Constant
       P=1.08;
                        % Constant
   end
   if angle>24
       C=0.58;
                        % Constant
       P=0.9;
                         % Constant
   end
   end
% Constants B and n
% Conditions for B & n
   % Constants
if Re<=2650
                        % Constant
```

```
n=0.471;
                            % Constant
    end
    if Re>2650
       B=0.048;
                            % Constant
        n=0.8;
                            % Constant
    end
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
%current carrying capacity
Ic(N,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
xx(N,:) = N;
end
    FIG=figure(1);
    set(FIG, 'units', 'normalized', 'outerposition', [0 0 1 1]);
    plot(xx,Ic,'LineWidth',2);
    title('Cigre TB601 Solar Heating due to Change in Latitude', 'FontSize',
16);
    legend('Current Carrying Capacity');
    xlabel('Day of the Year', 'FontSize', 12);
    ylabel('Current (A)', 'FontSize', 12);
    axis tight
    grid on;
   hold on
```

```
end
```

Appendix G

MATLAB Script – Case Studies
MATLAB Script – Case Studies

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Case Study 1
% Current Carrying Conditions Case Studies
% Created by
% Ryan Murphy
8 19-09-2015
%----- set up program -----
clear all;
close all;
clc;
8_____
                                            Plot load data default
2
[num,txt,raw]=xlsread('aCasestudy2.xlsx'); % Load data
t=num(:,6); % Extract Temperature
ws=num(:,32);
                               % Extract Wind speed
                               % Wind direction
wd=num(:,30);
time=num(1:91,4);
% Wind direction is based on North = 0 degrees, location of line is E-W,
% Therefore rotate wd by 90 degrees to real value
wd=wd-90;
                % Change orientation
% Make positive values
for i=1:length(wd)
       if wd(i)<0
       wd(i)=wd(i)*-1;
       end
end
% angle=wd;
                          % angle for load calc
8
                                              General Parameters
k=1.015; % Effective Resistance - supplied as 1.015
Rdc=0.451*10^-3; % Conductor resistance - fly
alpha=0.00403; % Temperature coefficient
%CIGRE
$_____
                                      Power gain by solar heat input
8
F=0.2;
                         % Albedo
a=0.5;
                         % Solar absorption coefficient
1=19.2564;
                         % Toowoomba latitude
Ns=1;
                         % Clear sky
y=10;
                         % meters above sea level
D=10.2*10^-3;
                         % Diameter of conductor AAC 7/3.4 Fly
ds=23.4*sin(2*pi*(284+17)/365);
                                               % declination angle
Hs=asind(sind(l)*sind(ds)+cosd(l)*cosd(ds)*cosd(0));% solar altitude
                           % azimuth of the sun = o at noon
vs=0;
n=acosd((cosd(Hs)*cosd(ys)));
                                               % solar beam angle
Ibo=Ns*((1280*sind(Hs)/(sind(Hs)+0.314)));
                                              % direct beam

      Iby=Ibo*(1+1.4*10^-4*y*((1367/Ibo)-1));
      % direct beam at height y

      Id=(430,5-0,3288*Iby)*sind(Hs);
      % direct beam at height y

Id=(430.5-0.3288*Iby)*sind(Hs);
It=Iby*(sind(n)+0.5*F*sind(Hs))+Id*(1+(pi/2*F)); % radiation inte
% Solar Heating
                                             % diffuse radiation
                                               % radiation intensity
xPS=PS;
for xx=1:91
                                               Power loss by radiation
8
tc= 70;
                    % Max operating temperature
% for xx=1:117
ta=t(xx);
                        % Ambient temperature
o=5.67*10^-8; % Stefan-Boltzmann constant
e=0.5: % emissivity of conductor
                     % emissivity of conductor
e=0.5:
PR=pi*D*o*e*((tc+273)^4-(ta+273^4)); % Solar radiation
```

```
0
                                           Power loss by forced convection
                            % Wind Speed
v=ws(xx);
% Thermal conductivity of Air Film
lambda=(2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
% Viscosity of the Air Film
vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
% Reynolds Number
Re=v*D/vf;
                       % D is the diameter of conductor
angle=wd(xx);
                          % Wind Angle
    % Constants C and P
    if angle<=24
       C=0.68;
                           % Constant
        P=1.08;
                           % Constant
    end
    if angle>24
       C=0.58;
                           % Constant
       P=0.9;
                            % Constant
    end
    % Constants B and n
    if Re<=2650
                           % Conditions for B & n
        B=0.641;
                           % Constant
                           % Constant
       n=0.471;
    end
    if Re>2650
       B=0.048;
                           % Constant
       n=0.8;
                            % Constant
    end
PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
%current carrying capacity
Id(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
x(xx, :) = xx;
end
$_____
% ESAA
% Solar absorption coefficient
a=0.5;
D=10.2*10^-3; % Diameter of conductor AAC 5775.00 Sector
Idir=1000; % Direct solar radiation intensity at W.m^-2
Idiff=100; % Diffuse solar radiation intensity at W.m^-2
                   % Albedo ground reflectance-reflected radiation
F=0.2;
                   % 0.2 General value
%%% Solar heating %%%
PS=a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F)));
xPS=PS:
    for xx=1:91
       Nt=time(xx);
       if Nt>8 & Nt<16
                                                           % Solar heating
night
        PS=xPS;
       else PS=0;
        end
                           Power loss by forced convection
        2
        tc=70;
                               % Max operating temperature
        ta=t(xx);
                                   % General Ambient Temperature
                                \ensuremath{\$\xspace{-1.5}} Thermal conductivity of Air Film
        lambda=(2.42*10^{-2})+((7.2*10^{-5})*((tc+ta)/2));
                                % Viscosity of the Air Film
        vf=(1.32*10^-5)+((9.5*10^-8)*((tc+ta)/2));
        v=ws(xx);
                                     % Wind speed
                                % Reynolds Number
        Re=v*D/vf;
                                \% D is the diameter of conductor
                               % Constants B and n
        if Re<=2650
                               % Conditions for B & n
           B=0.641;
                               % Constant
           n=0.471;
                               % Constant
        end
        if Re>2650
                             % Constant
           B=0.048;
           n=0.8;
                               % Constant
        end
```

```
% wind approach angle
       angle=wd(xx);
                            % Constants C and P
       if angle<=24</pre>
          C=0.68;
                            % Constant
          P=1.08;
                            % Constant
       else
          C=0.58;
          P=0.9;
       end
       %%% Forced Convection %%%
       PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                           Power loss by radiation
       o=5.67*10^-8;
                         % Stefan-Boltzmann constant
       e=0.5;
                         % emissivity of conductor
       tg=ta+5;
                         % ground temperature
                         % Sky temperature
       td=(0.0552*((ta+273)^{1.5})-273;
                                    % given formula
       %%% Radiated Loss %%%
       PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
       %------Current Carrying Capacity-----
       Ia(xx,:)=sqrt((PR+PF-PS)/(k*Rdc*(1+alpha*(tc-20))));
   end
%====
         %IEC
<u>&______</u>
tk=t+272.15;
a=0.5; % Solar absorption coefficient
                 \% 0.5 for rural weathered conductor
                  % 0.85 for industrial weathered conductor
D=10.2*10^-3;
                  % Diameter of conductor AAC 37/3.00 Saturn
Si=900;
                 % Solar intensity
%%% Solar heating %%%
PS=a*D*Si;
xPS=PS;
      for xx=1:91
       Nt=time(xx);
       if Nt>8 & Nt<16
                                                     % Solar heating
night
       PS=xPS:
       else PS=0;
       end
                    Power loss by forced convection
   t2=348.15;
                     % Max operating temperature (75 celcius)
                   % General Ambient Temperature (35 celcius)
   t1=tk(xx);
                     % Thermal conductivity of Air Film
   lamda=0.02585;
   v=ws(xx);
                         %Wind speed 'For Loop'
                    % Reynolds Number
       Re=1.644*10^9*v*D*((t1+(0.5*(t2-t1))))^-1.78;
                     % Nusselt Number
       Nu=(0.65*Re^0.2)+(0.23*Re^0.61);
       angle=90;
                     % wind approach angle
                     % Constants C and P
       C=0.58;
                     % Constant
       P=0 9:
                     % Constant
   %%% Forced Convection %%%
   PF=pi*lamda*Nu*(t2-t1);
8
                    Power loss by radiation
   o=5.67*10^-8;
                     % Stefan-Boltzmann constant
   e=0.5;
                     % emissivity of conductor
   %%% Radiated Loss %%%
   PR=pi*D*o*e*(t2^4-t1^4);
%-----Current Carrying Capacity-----
   Ix(xx,:) = sart((PR+PF-PS)/Rdc);
     end
$_____
% plot wind conditions
figure(3)
[hAx, hLine1, hLine2]=plotyy(x, wd, x, ws, 'stem');
set(hLine1, 'Marker', 'o', 'Linewidth', 2, 'LineStyle', ':');
```

```
set(hLine2, 'Marker', 'o', 'Linewidth', 2, 'LineStyle', '-');
arid on
xlabel('Samples (27 Jan 2015 - 28 Jan 2015)', 'FontSize', 12);
ylabel(hAx(2),'Wind speed (m/s)','FontSize', 12);
ylabel(hAx(1),'Wind Direction (degrees)','FontSize', 12);
title('Feeder "x" Wind Conditions', 'Fontsize',16)
legend('Wind Direction (^o)', 'Wind Speed (m/s)')
                           _____
% Plot dynamic CCC
figure (1)
% subplot(2,1,1)
hold on
plot(x, Id, '--')
plot(x,Ia,'g','Linewidth',2)
plot(x,Ix,':r','Linewidth',2)
grid on
xlabel('Samples (27 Jan 2015 - 28 Jan 2015)', 'FontSize', 12);
ylabel('Current Carrying Capacity (A)', 'FontSize', 12);
title('Cigre TB601 Vs ESAA D(b)5 Vs IEC 61597', 'FontSize', 16)
axis tight
legend('Cigre TB601 CCC', 'ESAA D(b)5 CCC', 'IEC 61597 CCC')
Ş_____
%Plot load data default
Data=xlsread('engweb trend export 18-8-2015.xls'); % Load data
%identify NaN entries and rectify
In=Data(:,1);
x=isnan(In);
                    % Identify the NaN Entries
sum(x);
xx=find(x);
TWh=In(1:xx(1)-1);
TBl=In(xx(1)+1:xx(2)-1);
TRd=In(xx(2)+1:xx(3)-1);
IBl=In(xx(3)+1:xx(4)-1);
IWh=In(xx(4)+1:length(x));
optemp=ones(length(IWh));
optemp=optemp.*60;
%plot load and temperature data
figure(2)
x=1:size(TBl);
hold on
[hAx, hLine1, hLine2]=plotyy(x, TBl, x, IBl);
set(hLine1,'Linewidth',2,'LineStyle','--');
set(hLine2,'Linewidth',2,'LineStyle','-');
grid on
xlabel('Samples (27 Jan 2015 - 28 Jan 2015)', 'FontSize', 12);
ylabel(hAx(2),'Load (A)','FontSize', 12);
ylabel(hAx(1),'Temperature (Celcius)','FontSize', 12);
title('Feeder "x" Temperature and Current Samples', 'Fontsize',16)
legend('Feeder "x" Temp (Celcius)', 'Feeder "x" Load (A)')
```

Appendix H

MATLAB Script – Annealing Analysis

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% AS 7000
% Annealing from elevated temperature operation
% Created by
% Ryan Murphy
8 19-09-2015
8----- set up program -----
clear all;
close all;
clc;
%_____
                                                     Define Parameters
2
% Using Saturn conductor 37/3.00 AAC
% Conductor parameters
Do=9.5;
                  % 9.5mm according to AS 7000
                  % 3.00mm for size of strands in Saturn Conductor
Dw=1.00;
R=100*(1-((Dw/Do)^2));
                       % reduction in cross sectional during wire drawing
% Derived experimental data
A=5.2;
                  % Value prescribed by MORGAN for AAC conductor
                  % Value prescribed by MORGAN for AAC conductor
B=85;
C = -5300;
                  % Value prescribed by MORGAN for AAC conductor
D=7.5;
                  % Value prescribed by MORGAN for AAC conductor
% Loss of tensile strength in fully annealed state (%)
Wa=56;
                  % Value prescribed by AS7000 for AAC conductor
% Construct loop to test the temperature and occurrence
% loop runs from 51 to 80 degrees celcius
% time runs from 200 hours to 10000 hours
for i=1:7
   T=(i*5)-5+273+50;
                               % Convert temperature to Kelvin
   t=0:1:10000;
                           % Time step for occurrence
   % Loss of tensile strength in partially annealed state (%)
   W(i,:)=100-(Wa*(1-exp(-exp((A+(B/T)*log(t)+(C/T)+D*log(R/80))))));
    figure (1)
    semilogx(t,W,'r','LineWidth',2);
    title('Tensile Strength Reduction Due To Annealing', 'FontSize', 16);
    legend('AAC 37/3.00 Saturn');
    xlabel('time (hours)', 'FontSize',12);
    ylabel('Percentage reduction in Tensile Strength', 'FontSize', 12);
    grid on;
0
     hold on
 end
   gtext('50^{\circ}C'); gtext('55^{\circ}C'); gtext('60^{\circ}C');
   gtext('65^{\circ}C');gtext('70^{\circ}C');gtext('75^{\circ}C');
   gtext('80^{\circ}C');
```

% Annealing Properties of Homogenous Conductor

[%] Dynamic Conductor Ratings:

[%] Across Varying Conditions

```
% Engineering Dissertation
% AS 7000
% Annealing from elevated temperature operation
% Created by
% Ryan Murphy
8 19-09-2015
°_____
             ----- set up program -----
clear all;
close all:
clc;
°6_____
% Damage analysis
% Parameters
y=10; % years available
% hours in a day
             % years available in network
d=7;
             % 7 days exposure maximum per year
t=y*h*d;
for i=1:7
   r(i,:)=0.00+(i*0.01); % percentage risk in over heating conductor
   x(i,:)=t*r(i);
                            % Hours of exposure over 10 years
   tx(i,:)=t;
   figure(2)
   stem(r,tx,'r','Linewidth',2)
   hold on
   stem(r,x,'LineWidth',2)
   title('Exposure to Annealing Damage', 'FontSize', 16);
   legend('maximum Exposure', '% Damage Exposure');
   xlabel('% Exposure','FontSize',12);
ylabel('time (hr)','FontSize',12);
   grid on;
end
0/0
8
                                                     Define Parameters
% Conductor parameters
          % 9.5mm according to AS 7000
D_{0}=9.5:
Dw=2.00;
                 % 3.00mm for size of strands in Saturn Conductor
R=100*(1-((Dw/Do)^2)); % reduction in cross sectional during wire drawing
% Derived experimental data
A=19.7;
                        % Value prescribed by MORGAN for AAC conductor
B=200;
                        % Value prescribed by MORGAN for AAC conductor
C = -9000:
                        \% Value prescribed by MORGAN for AAC conductor
D=3;
                        % Value prescribed by MORGAN for AAC conductor
% Loss of tensile strength in fully annealed state (%)
Wa=41;
                        % Value prescribed by AS7000 for AAC conductor
for i=1:7
   T = (i * 5) - 5 + 273 + 50;
                              % Convert temperature to Kelvin
   t=0:1:10000;
                               % Time step for occurrence
   % Loss of tensile strength in partially annealed state (%)
   W(i,:) = 100 - (Wa*(1-exp(-exp((A+(B/T)*log(t)+(C/T)+D*log(R/80))))));
    figure (1)
    semilogx(t,W,'r','LineWidth',2);
    title('Tensile Strength Reduction Due To Annealing', 'FontSize', 16);
```

```
legend('% Reduction','7/2.00 HDBC');
xlabel('time (hours)','FontSize',12);
ylabel('Percentage reduction in Tensile Strength','FontSize',12);
grid on;
y=85:100;
z=ones(1,length(y));
z=z'*x(i);
semilogx(z,y,'g','LineWidth',2)
hold on
axis([10^1 10^3 95 100])
end
gtext('50^{\circ}C'); gtext('55^{\circ}C'); gtext('60^{\circ}C');
gtext('65^{\circ}C');gtext('70^{\circ}C');gtext('60^{\circ}C');
gtext('65^{\circ}C');
gtext('80^{\circ}C');
gtext('1%'); gtext('2%'); gtext('3%'); gtext('4%');gtext('5%');gtext('6%');
gtext('7%');
```

Appendix I

MATLAB Script – Rywung Case Study

```
% Dynamic Conductor Ratings:
% Annealing Properties of Homogenous Conductor
% Across Varying Conditions
% Engineering Dissertation
% Case Study 1
% Current Carrying Conditions for Wind Conditions
% Created by
% Ryan Murphy
8 19-09-2015
%----- set up program -----
clear all;
close all;
clc;
%_____
                                           Plot load data default
2
[num,txt,raw]=xlsread('Rywung1.xlsx'); % Load data
t=num(7263:11679,6);
                                  % Extract Temperature
ws=num(7263:11679,32);
                                   % Extract Wind speed
wd=num(7263:11679,30);
                                   % Wind direction
time=num(7263:11679,4);
% Wind direction is based on North = 0 degrees, location of line is E-W,
% Therefore rotate wd by 90 degrees to real value
wd=wd-90;
                     % Change orientation
% Make positive values
for i=1:length(wd)
      if wd(i)<0</pre>
         wd(i)=wd(i)*-1;
      end
end
 % set calm conditions to zero approach angle
for i=1:length(wd)
      if wd(i) == 10
         wd(i)=wd(i)*0;
      end
end
°c-----
%build array for day and night
x=1:length(time);
y=1;
z=0;
for i=1:length(x)
   if x(i)>48
      x(i) = x(i) - (48*y);
      z = z + 1;
      if z==48
         y=y+1;
          z=0:
      end
   end
end
display('done')
8_____
8
                                              General Parameters
k=1.015; % Effective Resistance - supplied as 1.015
Rdc=0.815*10^-3; % Conductor resistance - 7/2.00 HDBC
alpha=0.00403; % Temperature coefficient
<u><u><u></u></u></u>
% ESAA
%_____
a=0.5; % Solar absorption coefficient
D=6*10^-3;
               % Diameter of conductor HDBC 7/2.00
```

```
Idir=1000;
                    % Direct solar radiation intensity at W.m^-2
Idiff=100;
                    % Diffuse solar radiation intensity at W.m^-2
F=0.2; vvv=0;
                         % Albedo ground reflectance-reflected radiation
 display('done')
                                   % 0.2 General value
%%% Solar heating %%%
y=length(time);
PS=(a*D*((Idir*(1+F*(pi/2)))+(Idiff*(pi\2)*(1+F))));
for i=1:y
         if x(i)<6 || x(i)>18
                                                 % Solar heating night
            xPS(i)=0;
         else xPS(i)=PS;
         end
end
   for xx=1:y
                           _Power loss by forced convection
        8
        tc=80;
                                % Max operating temperature
        ta=t(xx);
                                   % General Ambient Temperature
                                % Thermal conductivity of Air Film
        lambda = (2.42*10^{-2}) + ((7.2*10^{-5})*((tc+ta)/2));
                                % Viscosity of the Air Film
        vf = (1.32*10^{-5}) + ((9.5*10^{-8})*((tc+ta)/2));
                                     % Wind speed
        v=ws(xx);
                                % Reynolds Number
        Re=v*D/vf;
                                % D is the diameter of conductor
                                % Constants B and n
        if Re<=2650
                                % Conditions for B & n
                                % Constant
           B=0.641;
           n=0.471;
                                % Constant
        end
        if Re>2650
           B=0.048;
                                % Constant
           n=0.8;
                                % Constant
        end
                                    % wind approach angle
        angle=wd(xx);
                                % Constants C and P
        if angle<=24
           C=0.68;
                                % Constant
           P=1.08;
                                % Constant
        else
            C=0.58;
           P=0.9;
        end
        %%% Forced Convection %%%
        PF=pi*lambda*(tc-ta)*B*Re^n*(0.42+(C*sind(angle)^P));
                               Power loss by radiation
        o=5.67*10^-8;
                            % Stefan-Boltzmann constant
        e=0.5;
                            % emissivity of conductor
        tg=ta+5;
                            % ground temperature
                            % Sky temperature
        td=(0.0552*((ta+273)^1.5))-273;
                                           % given formula
        %%% Radiated Loss %%%
        PR=pi*D*o*e*(((tc+273)^4)-((0.5*(tg+273)^4))-((0.5*(td+273)^4)));
        %-----Current Carrying Capacity------
        Ia(xx,:)=sqrt((PR+PF-xPS(xx))/(k*Rdc*(1+alpha*(tc-20))));
        j(xx,:)=xx;
    end
    Ia=abs(Ia);
    for n=1:y
        if x(n)<19||x(n)>43
           night=Ia(n);
        else if x(n)>18 && x(n)<34
                day=Ia(n);
            else if x(n)>34 && x(n)<44
                    even=Ia(n);
                end
           end
        end
```

end

mean(day)
mean(even)
mean(night)


```
% Plot dynamic CCC
figure (1)
```