STABILITY ASSESSMENT OF 132KV SABAH GRID-CONNECTED SOLAR PV SYSTEM

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A project report submitted in partial
fulfillment of the requirement for the award of the
Degree of Master of Electrical Engineering

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JULY 2014

ABSTRACT

The population of the world is getting bigger and bigger, and the demand of electricity is thus increased from year to year. The fossil fuel which used to generate electricity are getting high demand and it will be exhausted one day. Apart from that, the rapid fluctuation and increase of fossil fuel price and the environment concerns related to the increase in the pollution and greenhouse gas emission accelerate the use of solar power to generate electricity. Therefore in this project, system study will be carried out to determine the largest possible capacity of Photovoltaic (PV) solar power generation to be injected to the Northern Grid of SESB’s 132kV network.The system study was first carried out by injection of 25MW of solar PV plant and the result showed some violation in the transformer at 275/132kV Segaliud substation. With that mitigation 1 and 2 were adopted in further system study to search for maximum solar capacity which the grid could sustain. Mitigation 1 is by adding one transformer to the overloaded existing transformer at 275/132kV Segaliud substation, whereas mitigation 2 is by limiting the power transfer from west coast grid to east coast grid. At the end of the study, the largest possible capacity of solar PV could be generated is 75MW with findings fulfilling the Planning Criteria. However this capacity are subjected to the land availability and also the solar irradiance factors in Northern of Sabah.

ABSTRAK

Populasi penduduk sedunia menjadi semakin membesar, dan permintaan tenaga elektrik menjadi semakin meningkat dari setahun ke setahun. Justeru, permintaan bahan api fosil yang digunakan untuk menjana elektrik menjadi semakin meningkat dan ia akan kehabisan pada suatu hari nanti. Selain itu, harga bahan api fosil yang meningkat dan menurun dengan pesat dan kebimbangan terhadap alam sekitar yang berkaitan dengan peningkatan dalam pelepasan gas rumah hijau dan pencemaran akan lebih menggalakkan penggunaan tenaga solar dalam penjanaan tenaga elektrik. Dengan itu, dalam project ini kajian sistem akan dijalankan untuk menentukan kapasiti terbesar tenaga solar yang boleh disuntik ke Grid Utara rangkaian 132kV SESB. Sebagai permulaan, kajian sistem telah dijalankan dengan menyuntik 25MW tenaga solar ke Grid Utara SESB dan hasilnya menunjukkan terdapat alat pengubah di 275/132kV Pencawang Masuk Utama Segaliud melebihi beban. Oleh yang demikian, terdapat 2 cara mitigasi yang diguna pakai dalam kajian sistem untuk mendapatkan kapasiti maksimum tenaga solar yang boleh dibekalkan ke grid SESB. Mitigasi 1 adalah dengan menambahkan satu lagi alat pengubah 275/132kV di Pencawang Segaliud, manakala mitigasi 2 adalah dengan mengehadkan pemindahan kuasa elektrik dari grid pantai barat ke grid pantai timur. Pada akhir kajian sistem ini, kapasiti terbesar tenaga solar yang berkemungkinan boleh dijana dan keputusan kajian memenuhi Kriteria Perancangan adalah sebanyak 75MW. Namun, kapasiti tersebut adalah tertakluk kepada penyediaan tanah dan faktor sinaran solar di sekitar kawasan Utara Sabah.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	- Alternating current
CAPEX	- Capital Expenditure
DC	- Direct current
ECG	- East Coast Grid
FF	- Fill factor
Hz	- Hertz
I	- Current
IEC	- International Electrotechnical Commision
kV	- kilovolt
MPPT	- Maximum Power Point Tracking
MVar	- Mega Volt Amper Reactive (Aparant power)
MW	- Megawatt
N-1 contingency	- Single contingency
N-2 contingency	- Double contingency
P	- Power
PSS/E	- Power System Simulation for Engineering
PV	- Photovoltaic
SESB	- Sabah Electricity Sdn. Bhd.
SGC	- Sabah Grid Code
UFLS	- Under Frequency Load Shedding
V	- Voltage
WCG	- West Cost Grid

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CHAPTER 1

INTRODUCTION

1.1 Project background

The rapid fluctuation of the fossil fuel price and the environmental concerns related to the increase in the pollution and greenhouse gas emission accelerate the search for clean, safe, low emission and economic energy sources. As a result, there has been a significantly increase in utilization of environment friendly renewable resources. The Malaysia Government has set up a new tariff program for those power producers on the usage of renewable energy for the generation of electricity. This new tariff program is called FiT which stands for “Fit In Tariff”.

In this proposal, system study will be carried out to determine the largest possible capacity of Photovoltaic (PV) Solar power generation to be injected to the Northern Grid of (Sabah Electricity Sdn. Bhd.) SESB’s 132kV network. The system study will be carried out to fulfill the requirement of Sabah Grid Code (SGC) and SESB planning practices.

The system study in this proposal is mainly on stability assessment to determine maximum capacity for grid connected PV Solar to SESB’s 132kV network in Northern part of Sabah. The simulation for this stability assessment consisted of steady state analysis and dynamic analysis.

1.2 Problem statements

It is known that the solar PV panels generate Direct Current (DC) and connected to a power electronic based inverter to convert direct current (DC) to alternating current (AC) before injected to the grid. The role and function of the inverter in this case is significant in producing stable output alternating current in terms of its frequency, voltage and current.

As the penetration of solar PV plant into the grid is increases, there will be impact on the stability and operation of the grid due to intermittency and other contingencies. Because of the intermittency of the output from solar plants, these impacts might be significant, especially when the solar irradiance drops from 100% to 20% in a minute, causing numerous problems in a high penetration scenario.

The tripping of the PV plant would also affect the system stability of the grid. The higher the amount of power injected by the PV plant to the grid, the system stability might be affected more seriously.

The dynamic modeling for the inverter or the electronic controller used in solar PV plant might have some issue to be modeled from software PSS/E (Power System Simulation for Engineering) library.

1.3 Project objectives

The major objective of this research is to perform a system study on the stability assessment to determine the largest possible capacity of grid connected solar PV to the Northern part of Sabah Grid.

Its measurable objectives are as follows:

(i) To determine the largest possible capacity of grid connected solar PV to be injected to 132kV network in Northern part of Sabah grid.

(ii) To perform stability assessment on grid connected solar PV to the 132kV network in Northern part of Sabah grid.

(iii)To study on the dynamic behavior of the system with the solar PV injection by sudden loss of the solar PV plant, N-1contingency and N-2 contingency.

1.4 Project scopes

The scopes of this project are:

(i) The solar PV plant is injected to the 132kV network in Northern Sabah Grid through the interconnection to 132kV substation.

(ii) The stability assessment of the solar PV plant will be assessed through the terms of system’s frequency, voltage and rotor angle profile. The stability assessment would be performed under steady state analysis which consisted of N-1 contingency and N-2 contingency.

(iii)The dynamic analysis would be performed through frequency stability analysis when there is sudden loss of the solar PV plant, N-1 contingency and N-2 contingency.

1.5 Project structure

In this project, the PSS/E software was used to perform the system study on the injection of the solar PV into the 132kV Sabah grid. Before the simulation started, some information was searched and this project report was being developed which consisted of five chapters.

In chapter 1, a brief introduction on renewable energy being implemented in Malaysia was being included. One of the very attractive renewable energy which is solar energy has been choose to inject into 132kV of Sabah grid. With that a system study need to be done in order to achieve stability in Sabah grid system for the maximum power injection of solar PV. The objective and the project scope stated in this chapter have given a clear guidance towards the aim and task of this project. The objective of this project is to determine the largest possible of solar PV power injection to the Northern 132kV Sabah's grid network. Steady state and dynamic performance has been considered in this system study project.

In chapter 2, the definition of some of the important keyword such as power system stability, solar photovoltaic, grid connected solar PV, steady state and transient stability were included. Apart from that, some previous journals or studies have also been included in this chapter as information and benchmarking for this project. The journals being considered in this study was related to analysis of grid connected solar PV.

In chapter 3, the data and parameters to be inputted into PSS/E software were introduced. The modeling of the solar PV in the steady state and dynamic state were also mentioned in this chapter. In order to assess the system performance of this system study, SESB planning criteria was adopted.

The results and analysis for this system study were included in chapter 4. The system study has included simulation under normal condition (without mitigation), mitigation 1 and mitigation 2. Steady state assessment and dynamic assessment have been performed for each condition, except for normal condition where only steady state was performed.

As for chapter 5, the conclusions and recommendation for this system study were mentioned. From this project, for future recommendation, further study to determine the feasibility of grid connected solar PV into the 132kV network such as the study of sun irradiation in the proposed location, Sabah Northern region.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

A literature review is a body of test that aims to review the critical of current knowledge and or methodology approaches on a particular topic. In this literature review, the topic to be discussed is mainly about the stability assessment to determine the largest possible capacity of Solar PV power generation to be injected to the Northern Grid of SESB's 132kV network. Each important terms like stability assessment, grid connected solar PV, largest possible capacity, inverter and other related terms are defined in this chapter. Apart from that, there were also some previous related projects which had been done from all over the world being introduced in this chapter.

2.2 Theories

There are some related terms, definitions and theories are included in this part for a better approach to this project.

2.2.1 Stability assessment

The stability assessment here means that an assessment in term of system study by using the software PSS/E (Power System Simulation for Engineering) to determine the stability of the system when there is contingency happened. The system study is done for the stability assessment to comply with SESB's Planning criteria. The criteria to comply under the SESB's Planning Criteria are as follow:

(i) Steady-State Voltage

Table 2.1: The allowable range of voltage under Normal Operating and System Stress conditions

Under Normal Operating Conditions	± 5% at Transmission Network nominal voltage of 500 kV ± 5% at Transmission Network nominal voltages of 275 kV, 132 kV and 66 kV
Under System Stress conditions following a System fault	± 10% at all Power System voltages, however in the case of the Transmission Network, this condition should not occur for more than 30 minutes.

(ii) Frequency

Table 2.2: The allowable range of frequency under Normal Operating, System Stress, System Fault and Extreme System Fault conditions

Under Normal Operating Conditions	49.5 Hz to 50.5 Hz
Under System Stress conditions	49.0 Hz to 51.0 Hz
Maximum operating band for frequency excursions under System fault conditions.	48.75 Hz to 51.25 Hz
Under extreme System fault conditions all sets should have disconnected by this frequency unless agreed otherwise in writing with the Single Buyer.	51.5 Hz or above and 47.5 Hz or below

(iii) Short circuit

Short circuit calculations were carried out to check the impacts of the power plant connection to the fault levels in the system. The calculated fault levels were used to check the ratings of the existing equipment in the network. In this analysis, short circuit is calculated according to the IEC 60909 Standard.

2.2.2 IEC 60909 standard

The IEC 60909 International Standard is applicable for the calculation of short circuit current in three-phase a.c. systems operating at a nominal frequency of 50 or 60 Hz. Balanced (three-phase) and unbalanced faults were considered and in both cases, maximum and minimum values of the short circuit currents were calculated.

The short circuit current is considered as the sum of an a.c symmetrical component and of an aperiodic (d.c) decaying component. The Standard distinguishes between far-from-generator and near-to-generator (and motor) short-circuits. Moreover, different approaches are provided according to the network configuration – radial or meshed – and to fault location.

Under this study, the IEC standard method was applied in calculating the three-phase short-circuit current level.

The system should be planned in such that the maximum sub-transient three phase symmetrical short circuit fault levels are not greater than 90% of the switching equipment short-circuit ratings, the breaking and making capacities of switching equipment shall not exceed under the maximum system short circuit condition.

2.2.3 Power system stability

Power system stability denotes that the ability of an electric power system for a given initial operating condition to regain a state of operating equilibrium after being subjected to a physical disturbance with all the system variables bounded so that the system integrity is preserved [1]. The Integrity of the system is preserved when practically the entire power system remains intact with no tripping of generators or loads, except for those disconnected by isolation of the faulted elements or intentionally tripped to preserve the continuity of operation of the rest of the system.

It is the ability of electrical machine or power system to regain its original/previous state is called Steady state stability. The stability of a system refers to the ability of a system to return to its steady state when subjected to a disturbance. As mentioned before, power is generated by synchronous generators that operate in synchronism with the rest of the system. A generator is synchronized with a bus when both of them have same frequency, voltage and phase sequence. We can thus define the power system stability as the ability of the power system to return to steady state without losing synchronism. Usually power system stability is categorized into Steady State, Transient and Dynamic Stability

If the system is unstable, it will result in a run-away or run-down situation for example, a progressive increase in angular separation of generator rotors or a progressive decrease in bus voltages. An unstable system condition could lead to cascading outages, and a shut-down of a major portion of the power system.

Stability can be classify into various categories which greatly facilitates on the analysis of stability problems, identification of essential factors which contribute to instability and devising methods of improving stable operation. The classification is based on the considerations such as physical nature of the resulting instability, size of the disturbance considered most appropriate method of analysis devices, processes, and the time span involved [2].

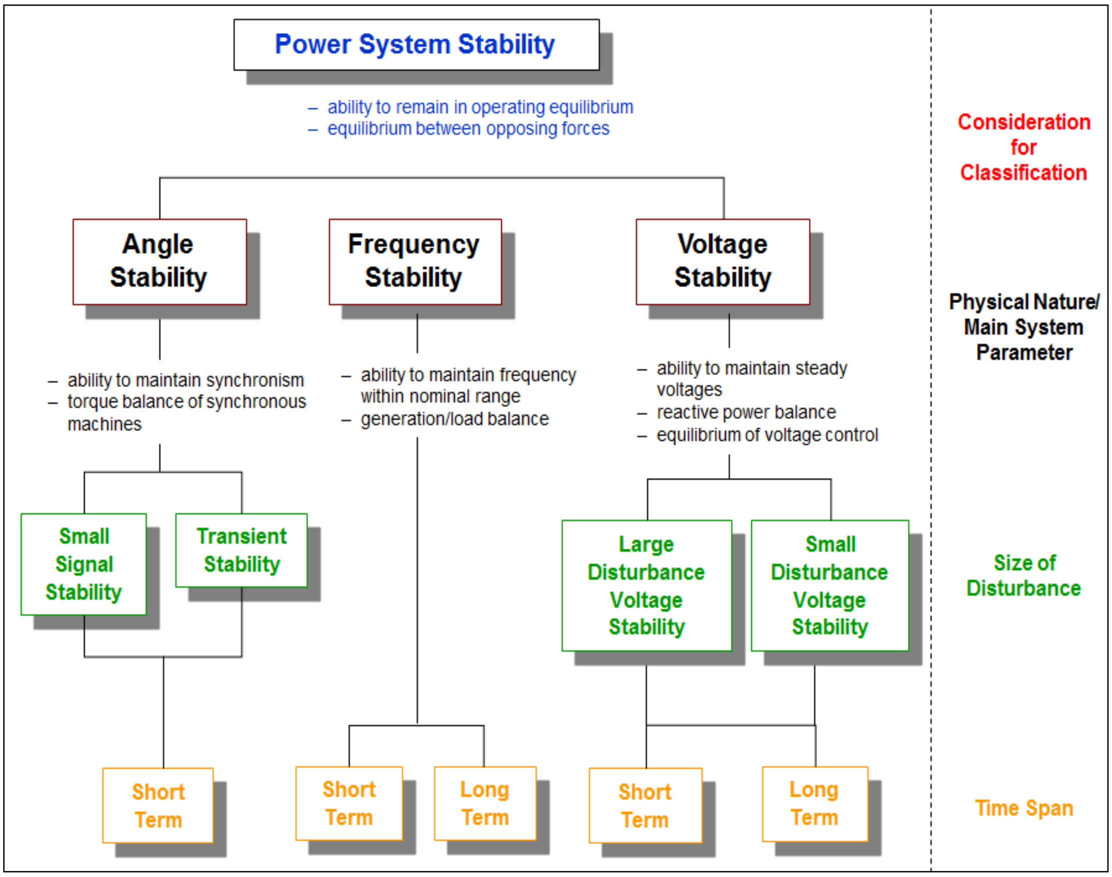

Figure 2.1: Classification of power system stability

2.2.4 Grid connected solar photovoltaic (PV)

Grid-connected photovoltaic power systems are power systems energised by photovoltaic panels which are connected to the utility grid. Grid-connected photovoltaic power systems consists of Photovoltaic panels, MPPT (Maximum Power Point Tracking), solar inverters, power conditioning units and grid connection equipment. For most of the Stand-alone photovoltaic power systems, these systems seldom have batteries.

2.2.5 Photovoltaic panels

A solar panel is a set of solar photovoltaic modules electrically connected and mounted on a supporting structure. A photovoltaic module is a packaged, connected assembly of solar cells. The solar module can be used as a component of a larger photovoltaic system to generate and supply electricity in commercial and residential applications. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output - an 8% efficient 230 watt module will have twice the area of a 16% efficient 230 watt module. A single solar module can produce only a limited amount of power; most installations contain multiple modules.

There are a few types of solar modules as indicated as below:

(i) Crystalline Silicon Modules

Most solar modules are currently produced from silicon photovoltaic cells. These are typically categorized as monocrystalline or polycrystalline modules.

(ii) Thin-Film Modules

Third generation solar cells are advanced thin-film cells. They produce a relatively high-efficiency conversion for the low cost compared to other solar technologies.

(iii)Rigid Thin-Film Modules

In rigid thin film modules, the cell is created on a glass substrate or superstrate, and the electrical connections are created in situ, a so-called “monolithic integration”. The substrate or superstrate is laminated with an encapsulant to a front or back sheet, usually another sheet of glass.

(iv)Flexible Thin-Film Modules

Flexible thin film cells and modules are created on the same production line by depositing the photoactive layer and other necessary layers on a flexible substrate.

(v) Smart Solar Modules

Several companies have begun embedding electronics into PV modules. This enables performing maximum power point tracking (MPPT) for each module individually and the measurement of performance data for monitoring and fault detection at module level. Some of these solutions make use of power optimizers, a DC-to-DC converter technology developed to maximize the power harvest from solar photovoltaic systems [3]. As of about 2010, such electronics can also compensate for shading effects, wherein a shadow falling across a section of a module causes the electrical output of one or more strings of cells in the module to fall to zero, but not having the output of the entire module fall to zero.

2.2.6 MPPT (Maximum Power Point Tracking)

MPPT is a technique that grid connected inverters, solar battery chargers and similar devices use to get the maximum possible power from one or more photovoltaic devices, typically solar panels, though optical power transmission systems can benefit from similar technology [4]. Solar cells have a complex relationship between solar irradiation, temperature and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve [5]. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are typically integrated into an electric power converter system that provides voltage or current conversion, filtering, and regulation for driving various loads, including power grids, batteries, or motors.

Photovoltaic cells have a complex relationship between their operating environment and the maximum power they can produce. The fill factor abbreviated *FF*, is a parameter which characterizes the non-linear electrical behavior of the solar cell. Fill factor is defined as the ratio of the maximum power from the solar cell to the product of Open Circuit Voltage V_{oc} and Short-Circuit Current I_{sc}. In tabulated data it is often used to estimate the maximum power that a cell can provide with an optimal load under given conditions,

$$P = FF * V_{oc} * I_{sc} \tag{2.1}$$

For most purposes, FF, V_{oc}, and I_{sc} are enough information to give a useful approximate model of the electrical behavior of a photovoltaic cell under typical conditions.

For a given set of operational conditions, cells have a single operating point where the values of the current (I) and voltage (V) of the cell result in a maximum power output. These values correspond to a particular load resistance, which is equal to V/I as specified by Ohm’s Law. The power P is given by

$$P = V * I \tag{2.2}$$

A photovoltaic cell, for the majority of its useful curve, acts as a constant current source [6]. However, at a photovoltaic cell's MPP region, its curve has an approximately inverse exponential relationship between current and voltage. From basic circuit theory, the power delivered from or to a device is optimized where the derivative (graphically, the slope) *dI/dV* of the I-V curve is equal and opposite the *I/V* ratio (where d*P/dV*=0) [7]. This is known as the maximum power point (MPP) and corresponds to the "knee" of the curve.

A load with resistance *R=V/I* equal to the reciprocal of this value draws the maximum power from the device. This is sometimes called the characteristic resistance of the cell. This is a dynamic quantity which changes depending on the level of illumination, as well as other factors such as temperature and the age of the cell. If the resistance is lower or higher than this value, the power drawn will be less than the maximum available, and thus the cell will not be used as efficiently as it could be. Maximum power point trackers utilize different types of control circuit or logic to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell [8].

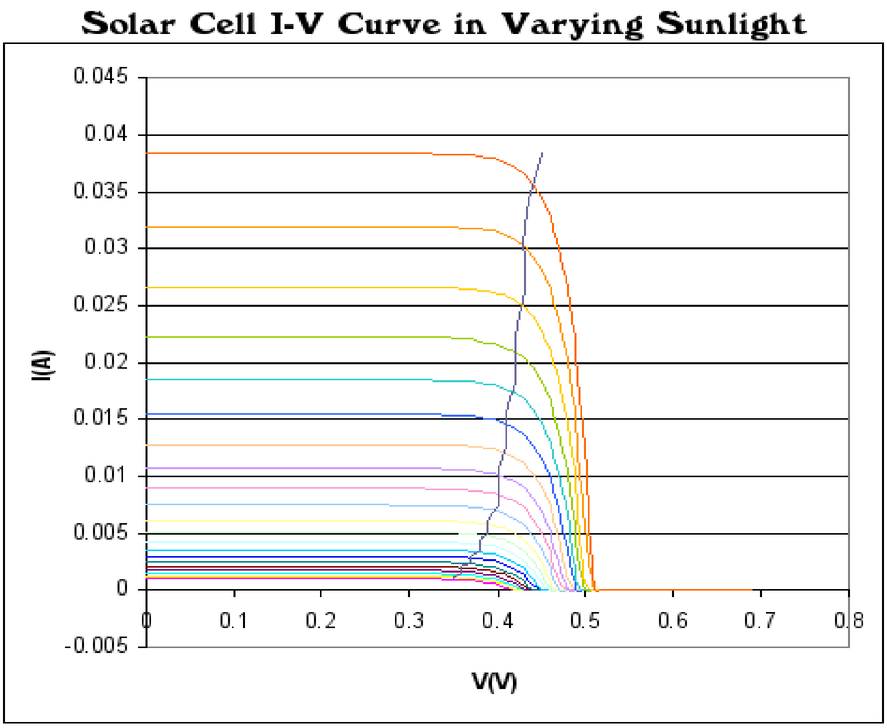

Figure 2.2: Solar cell I-V curves where a line intersects the knee of the curves where the maximum power point is located

2.2.7 Inverter

A power inverter or inverter is an electronic device or circuitry that changes direct current (DC) to alternating current (AC) [9]. The input voltage, output voltage and frequency, and overall power handling, are dependent on the design of the specific device or circuitry.

A solar inverter can be fed into a commercial electrical grid or used by an off-grid electrical network. Solar inverters have special functions adapted for use with photovoltaic arrays, including maximum power point tracking and anti-islanding protection. Micro-inverters convert direct current from individual solar panels into alternating current for the electric grid. They are grid tie designs by default.

2.2.8 Steady state

Steady state is the system that the measurement index such as voltage amplitude and phase angle, power ffrequency variation, the quantity of the power flow is stable or in mathematic called the system is not vary in the time of the state variable.

Steady State Stability studies are restricted to small and gradual changes in the system operating conditions. In this we basically concentrate on restricting the bus voltages close to their nominal values. We also ensure that phase angles between two buses are not too large and check for the overloading of the power equipment and transmission lines. These checks are usually done using power flow studies

2.2.9 Transient stability

Transient Stability involves the study of the power system following a major disturbance. Following a large disturbance the synchronous alternator the machine power (load) angle changes due to sudden acceleration of the rotor shaft. The objective of the transient stability study is to ascertain whether the load angle returns to a steady value following the clearance of the disturbance.

The ability of a power system to maintain stability under continuous small disturbances is investigated under the name of Dynamic Stability (also known as small-signal stability). These small disturbances occur due random fluctuations in loads and generation levels. In an interconnected power system, these random variations can lead catastrophic failure as this may force the rotor angle to increase steadily.

2.2.10 N-0 contingency

N-0 contingency which also known as normal condition is the system that operates without any tripped transmission equipment or power plant.

2.2.11 N-1 contingency

N-1 contingency or also known as a single contingency condition is the loass of any power system element that has only one of the transmission equipment or power plant tripped but not include the bus bas and radial line.

2.3 Description of Previous Methods

There are some literature reviews on the previous methods that have been developed by other researches.

2.3.1 Intermittency of solar radiation

Solar irradiance is a measure of the irradiance (power per unit area on the Earth's surface) produced by the Sun in the form of electromagnetic radiation, which is perceived by humans as sunlight. Solar irradiance in a specific area may be measured as insolation, the solar radiation energy per unit area during a given time, or as direct insolation, insolation which reaches a location on Earth after absorption and scattering in the atmosphere. Total solar irradiance (TSI), is a measure of the amount of solar radiative energy incident on the entirety of the Earth's upper atmosphere. This represents a fraction of the Solar constant, the total amount of electromagnetic radiation emanating from the Sun in all directions.

Regarding this topic, there are a few studies which had been done by using mathematical modelling. One of the paper was by T. Alquthami, Student Member, IEEE, H. Ravindra, M. O. Faruque, Member, IEEE, M. Steurer,Senior Member, IEEE, and T. Baldwin, Fellow, IEEE and the paper title was “Study Of Photovoltaic

Integration Impact On System Stability Using Custom Model Of PV Arrays Integrated With PSS/E".

This paper focuses on the impact of large solar plants on power systems due to rapid variation in power injection caused by various factors such as the intermittency of solar radiation, changes in temperature and tripping out of power electronic based converters connected to the system [10].

In the first step of this research, incorporating the Maximum Power Point Tracking (MPPT) algorithm, a mathematical model of PV (Photovoltaic) array based solar plant has been developed. The model produces changes in DC power output for changes in its two inputs; solar irradiance and temperature. In the next step, the mathematical model is integrated with the dynamic simulation software PSS/E through user written model integration technique [11]. The dynamic model for the inverter and the electrical controller are used from the PSS/E library. The PV plants are added to the 39-bus New England test system at three different locations .

To demonstrate a high penetration of PV, the power generation from PV has been increased up to 20% and was randomly distributed between three plants. The dynamic behavior of the system was studied by changing the solar irradiance. The responses obtained from these studies indicate that vulnerability of the system increases with the increase in penetration of PV power [12].

There was also another related paper published on solar irradiance impact to the grid by T. Alquthami, Student Member, IEEE, H. Ravindra, M. O. Faruque, Member, IEEE, M. Steurer,Senior Member, IEEE, and T. Baldwin, Fellow, IEEE with their title of paper "Three-Phase Probabilistic Power Flow In Distribution System With Grid-Connected Photovoltaic System".

This paper analyzes a method of three-phase probabilistic power flow in unbalanced radial distribution system with single-phase and three-phase grid-connected photovoltaic (PV) systems using sequential Monte Carlo techniques [13]. The output power of grid-connected PV system is simulated for each hour, considering the solar irradiance with random variation of weather, the effect of shadow, the conversion efficiency's change of the photovoltaic arrays with time, the efficiency of PV inverter and the reliability of the overall photovoltaic system.

Then the time-varying load model with randomness is incorporated in the probabilistic power flow and a program has been developed based on the method

[14]. At last, two cases have been implemented to verify the applicability of the method by giving the probability of voltages beyond limit for each hour in one day.

2.3.2 Tripping of solar PV plant

The effect of tripping the solar PV plant was analysed from the simulation of the software PSS/E which had been done previously in the paper of “Study Of Photovoltaic Integration Impact On System Stability Using Custom Model Of PV Arrays Integrated With PSS/E”.

This paper has shown that the penetration level of PV plants has significant impact on the bus frequency. With the increase of penetration level, the severity of impact on system stability also increases. For 20% penetration level, the bus frequency goes down to almost 59.55 Hz which is below the acceptable frequency of operation (in this paper it is 59.7 Hz). The under frequency load shedding relay (UFLS) of that bus needs to take necessary actions to keep the system stable in such a case [15].

2.3.3 Three phase fault

In an electric power system, a fault is any abnormal electric current. For example, a short circuit is a fault in which current bypasses the normal load. An open-circuit fault occurs if a circuit is interrupted by some failure. In three-phase systems, a fault may involve one or more phases and ground, or may occur only between phases. In a "ground fault" or "earth fault", charge flows into the earth. The prospective short circuit current of a fault can be calculated for power systems. In power systems, protective devices detect fault conditions and operate circuit breakers and other devices to limit the loss of service due to a failure

In a polyphase system, a fault may affect all phases equally which is a "symmetrical fault". If only some phases are affected, the resulting "asymmetrical fault" becomes more complicated to analyze due to the simplifying assumption of equal current magnitude in all phases being no longer applicable. The analysis of this type of fault is often simplified by using methods such as symmetrical components. Design of systems to detect and interrupt power system faults is the main objective of power system protection.

The purpose of three phase fault analysis is to identify whether there is any overflow of current in the injected bus by the solar power generation. The bus with different voltage level would have different bus bar rating. The three phase fault analysis can be performed by the software PSS/E during the steady state condition.

CHAPTER 3

METHODOLOGY

3.1 Project methodology

This research is adopting methods approach involving develops and performs a stability assessment on grid connected solar PV to the 132kV network in Northern part of Sabah grid. The assessment would be in the form of system study using PSS/E software to determine the largest possible capacity of the grid connected solar PV in maintaining the stability of the grid system.

There are two assessments being conducted in this study for the stability analysis, there are steady state performance assessment and dynamic stability performance assessment. The study focuses on the snapshot of system peak and based load conditions in year 2015.

The study is to identify the maximum possible PV power that could be injected to the system. Hence, four possible outputs of the PV plant ranging from 25 MW, 50MW, 75MW and 100 MW were considered for the study.

Preparation of study scenarios for the different PV plant output was done by re-dispatching the generators according to the generation merit order (see **APPENDIX A**) and at the same time maintaining the system spinning reserves at 100 MW. The flow of this study is shown in Figure 3.1 below.

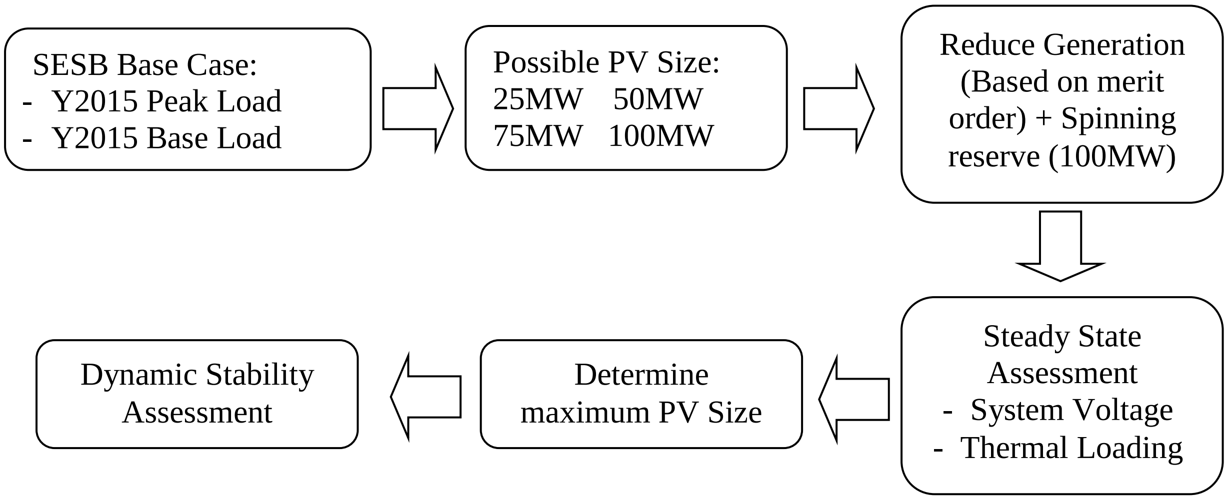

Figure 3.1: Study flows to assess the maximum power that could be injected by the PV plant

3.2 Steady state performance assessment

In power engineering, the power-flow study, also known as load-flow study, is an important tool involving numerical analysis applied to a power system. A power-flow study usually uses simplified notation such as a one-line diagram and per-unit system, and focuses on various forms of AC power (i.e. voltages, voltage angles, real power and reactive power). It analysed the power systems in normal steady-state operation. A number of software implementations of power-flow studies exist.

In addition to a power-flow study, sometimes called the base case, many software implementations perform other types of analysis, such as short-circuit fault analysis, stability studies (transient & steady-state), unit commitment and economic dispatch. In particular, some programs use linear programming to find the optimal power flow, the conditions which give the lowest cost per kilowatt hour delivered.

Steady state performance assessment was performed in order to examine the impact of PV connection to SESB's network. The assessment performed covers the following steady state contingency:

(i) N-1 contingency
(ii) N-2 contingency

The N-1 contingency is an event involving the loss of one network element (such as a line, or a transformer). Under this condition, overloading of the network elements is not allowed and the system design shall fulfil the criteria provided in section 2.2.1 without any corrective measures.

The N-2 contingency is an event involving the loss of two network elements such as simultaneous loss of two lines, transformers, etc. This condition is considered an extreme condition hence, assessment on the impact of this contingency to the grid is required. Under this condition, corrective measures are allowed to prevent severe cascading outages and system black-out.

The results obtained from the contingency analyses will provide critical information on the system performances, which are summarised as follows:

(i) Voltage violation – any voltage that exceed the limits (refer Section 2.2.1).

(ii) Loading violation – any component loading that exceeds 100% of the continuous rating.

For the case with system violation, mitigation measures would be proposed to eliminate/reduce the impact of the contingency.

There are four (4) possible PV plant's capacities starting from 25MW to 100MW were studied. The generation was re-dispatched according to the merit order to allow the injection of PV plant. Additional violation (voltage and thermal overload) if encountered in the study will be highlighted. The study scenarios developed are shown in Figure 3.2.

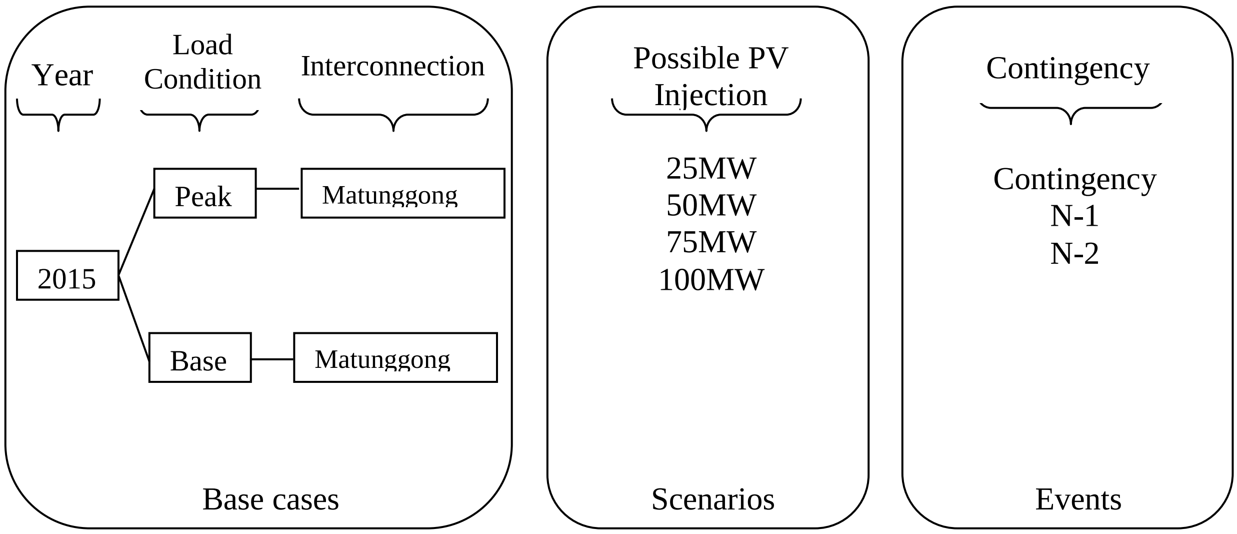

Figure 3.2: Development of study cases and scenarios

In this steady state analysis, the solar PV plant is modelled as a direct current (DC) source injected into the 132kV grid. The modelling of the DC source in the PSS/E software is without the generation of reactive power (in MVar unit) into the grid which is different from the modelling used for other power producer who used gas turbine and/ or steam turbine. The data to be inputted into PSS/E is shown in Figure 3.3 below. The data for the solar PV plant to be modelled as a DC source is highlighted black as shown in Figure 3.3. The plant was modelled as a negative load as shown in red colour dotted line circle. Figure 3.4 shows the single line diagram for the interconnection of the Solar PV plant to 132/11kV Matunggung substation.

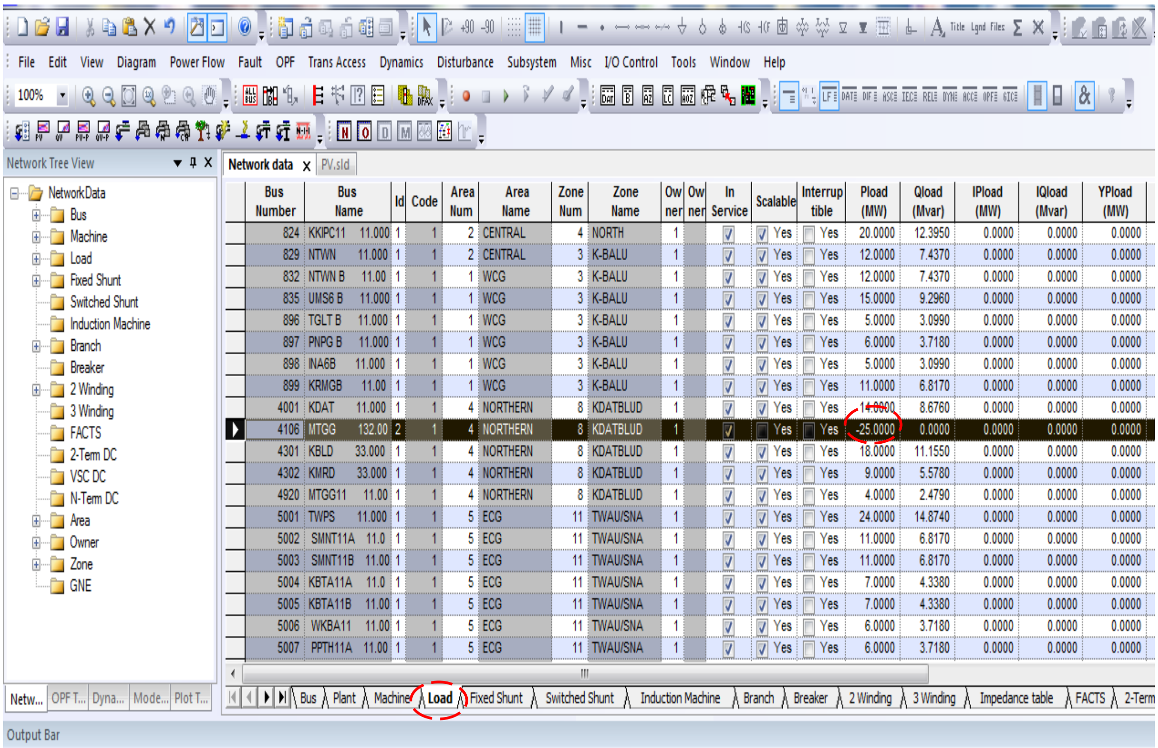

Figure 3.3: Solar PV plant is modelled as negative load i.e. -25MW in this case

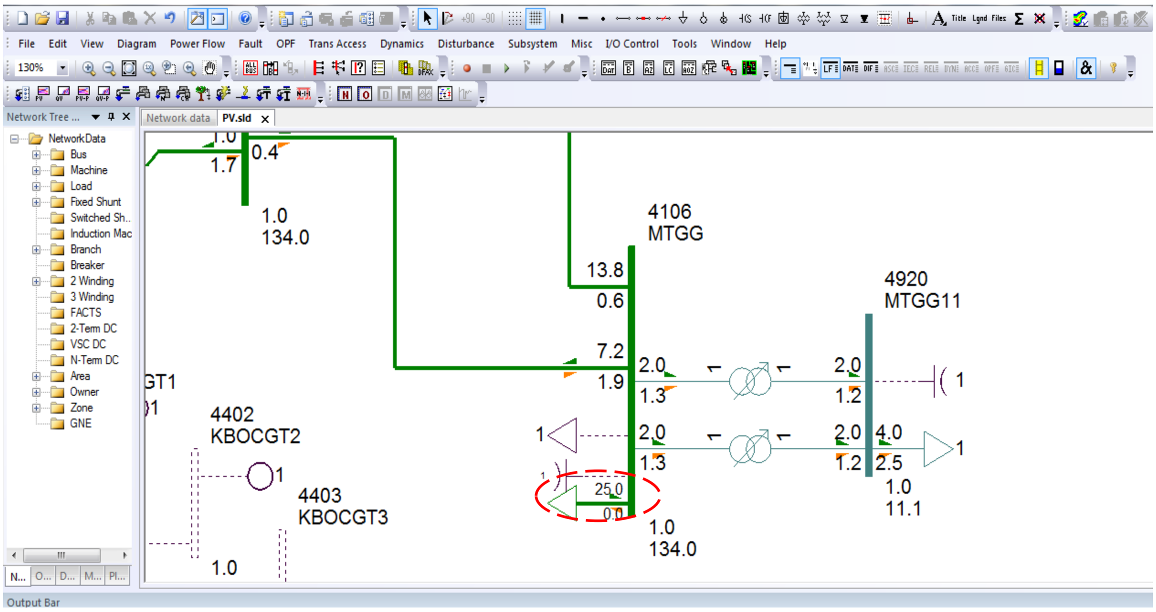

Figure 3.4: Single line diagram for the interconnection of Solar PV plant to 132/11kV Matunggung substation

In order to start the simulation for steady state analysis, there are some data which needed to be input into PSS/E software such as the interconnected solar PV bus and transformer used to step up the output voltage from 33kV to 132kV. In this study, there are some assumptions as below are being considered:

(i) The location of the solar PV is located near to 132/11kV Matunggong substation.

(ii) The solar PV plant was modelled as negative load at steady state simulation as the output power of the solar PV plant is in DC.

(iii) Wind model was used as the model for solar PV plant as recommended by the manual of PSS/E which was shown in **APPENDIX B**.

(iv) The solar PV was generated power at 33kV level and step up to 132kV to be injected to 132kV Matunggong substation.

The solar PV plant was generated power at 33kV level and stepped up to 132kV to be injected to Matunggong substation. The model of the step up transformer is shown in Figure 3.5 below.

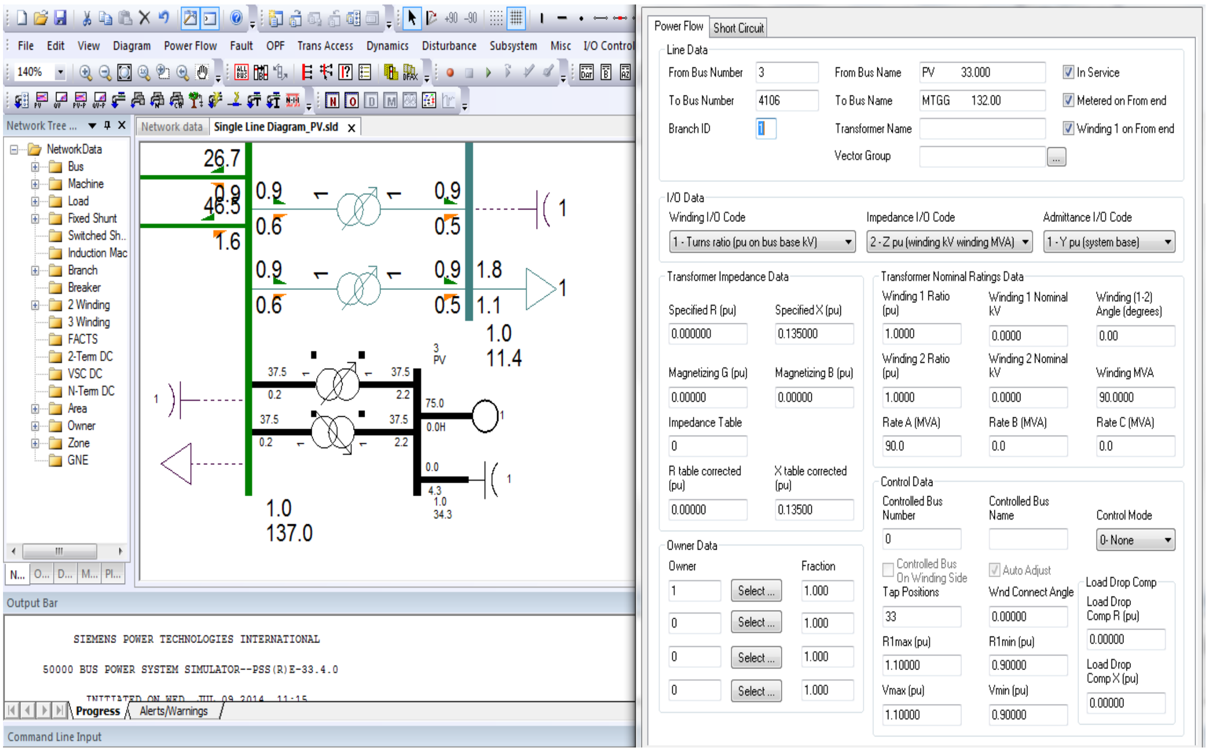

Figure3.5: Model of step up transformer for solar PV plant

3.3 Dynamic performance assessment

The goal of transient stability simulation of power systems is to analyse the stability of a power system in a time window of a few seconds to several tens of seconds. Stability in this aspect is the ability of the system to quickly return to a stable operating condition after being exposed to a disturbance such as for example a tree falling over an overhead line resulting in the automatic disconnection of that line by its protection systems. In engineering terms, a power system is deemed stable if the rotational speeds of motors and generators, and substation voltage levels must return to their normal values in a quick and stable manner.

In this system study, after steady state assessment were being performed and the system being improved, for example with mitigation 1 and mitigation 2, the simulation being proceeded for dynamic performance assessment. The assessment performed covers the following transient contingency:

(i) N-1 contingency analysis

(ii) N-2 contingency analysis

(iii)Frequency stability analysis

In this dynamic performance assessment, the Solar PV plant was modelled as a wind machine as shown in Figure 3.6 below where the setting of control mode for solar PV and wind power plant are set to no.2 +, - Q limits based on WPF, a wind machine which controls a remote bus voltage within the given range [Qmin; Qmax] of reactive power. As for load flow models of most power electronic devices, the source reactance of this machine was set as infinite: XSORCE = 99999.

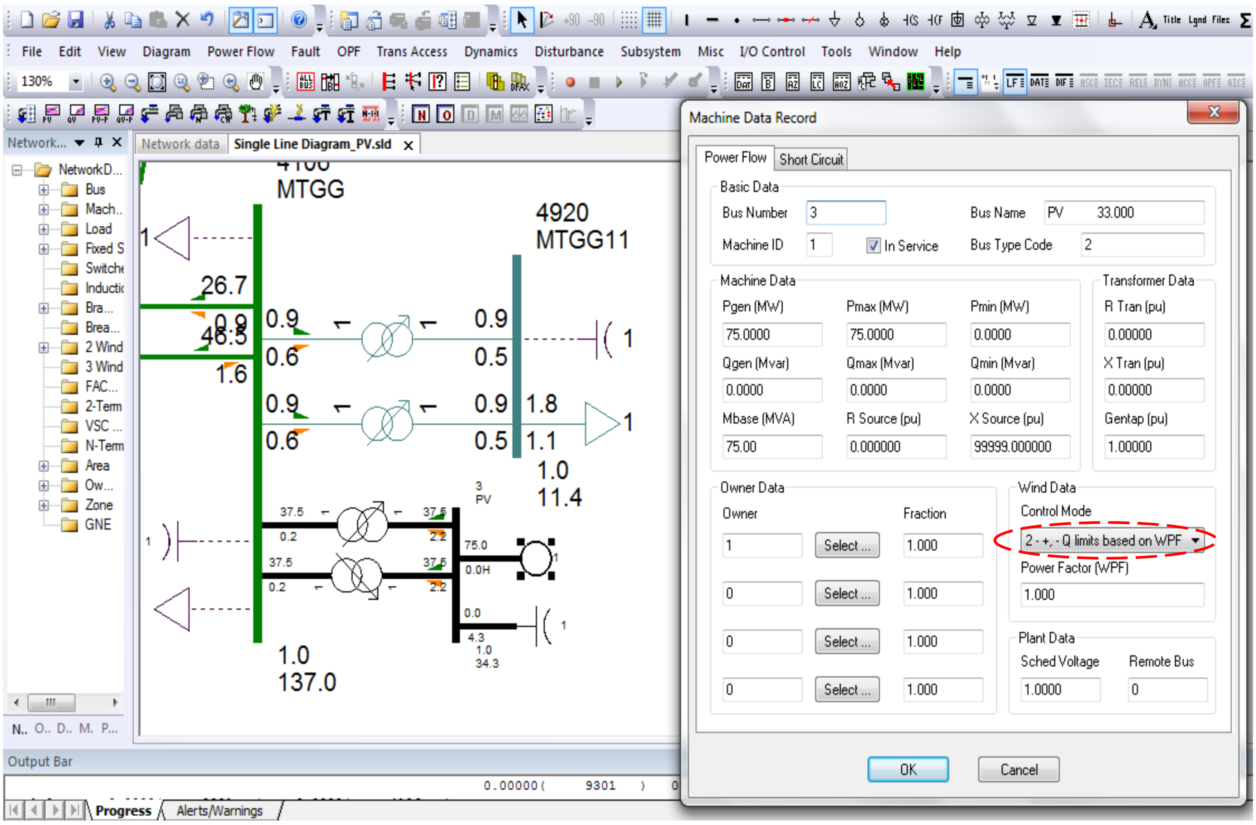

Figure 3.6: Wind model was used for the solar PV

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