LOAD FLOW STUDIES ON STAND ALONE MICROGRID SYSTEM IN RANAU, SABAH

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ABSTRACT

This paper presents the power flow or load flow analysis of Ranau microgrid, a standalone microgrid in the district of Ranau,West Coast Division of Sabah. Power flow for IEEE 9 bus also performed and analyzed. Power flow is define as an important tool involving numerical analysis applied to power system. Power flow uses simplified notation such as one line diagram and per-unit system focusing on voltages, voltage angles, real power and reactive power. To achieved that purpose, this research is done by analyzing the power flow analysis and calculation of all the elements in the microgrid such as generators, buses, loads, transformers, transmission lines using the Power Factory DIGSilent 14 software to calculate the power flow. After the analysis and calculations, the results were analysed and compared.

ABSTRAK

Kajian ini mengenai laluan kuasa atau laluan beban yang dijalankan ke atas grid mikro Ranau. Grid mikro Ranau terletak di daerah Ranau, Pantai Barat Sabah. Laluan kuasa bagi system IEEE 9 bas juga dijalankan dan di analisis. Laluan arus adalah alat penting yang melibatkan analisis bernombor yang dilakukan ke atas mana-mana sistem kuasa. Laluan kuasa melibatkan gambarajah segaris dan sistem per unit(p.u). Ia memfokuskan kepada voltan, sudut voltan, kuasa sebenar (P) dan kuasa reaktif (Q). Untuk mencapai analisis laluan kuasa yang jitu, analisis dilakukan terhadap mana-mana sistem kuasa dan pengiraan secara numerikal semua elemen-elemen yang terdapat di dalam sistem kuasa tersebut. Elemen-elemen tersebut adalah penjana, bas, beban, pengubah, talian penghantaran menggunakan software Power Factory DIGSilent 14. Selepas analisis dan pengiraan-pengiraan yang berkaitan, keputusannya di analisis dan dibandingkan antara kedua-dua sistem terlibat.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1   Project background

Figure 1.1: Ranau, Sabah

Figure 1.2: Location of Ranau, Sabah

Ranau, a district in Sabah, supplied with electricity in the early 1960s. The exact date was 15th June, 1964. During the early years, the supplies were 32kW, 12-hour system. Consumers living nearby the generation were supplied with electricity. During that time, consumers served from 0600 hours to 1800 hrs. Only three areas supplied with electricity namely Lohan, Bundu Tuhan and Kundasang. Each areas connected it's own generators. The three loads were interconnencted during the mid 1980s. Starting in 1971, Ranau district supplied with 24 hours electricity and the capacity was increased to 60 kW. The capacity even further increased to 90 kW several years later. Generation capacity further increased and the system able to produce 200 kW. The establishment of Ranau Grid was done in 1990.

At the same year as the establishment of Ranau grid, Carabau mini hydro station was developed by the Mamut Copper Mine (MCM). Mamut is an area in

Ranau which was Sabah largest producer of copper before the mineral finally runs out. The Carabau hydroelectric commenced into operation in June 15th, 1991. The pond located at Kg. Bambangan. The other pone located at Kg. Kimolohing and known as the "Head Pond". The installed capacity for this hydroelectric is 1000 kW. In 1996, Naradau mini hydroelectric was built with two dam. They are located at Mesilau river and Liwagu river.

At September 1st, 1998, Lembaga Lektrik Sabah (LLS) was privatised and taken over by Sabah Electricity Sendirian Berhad (SESB). At that time, SESB was 100 percent under Tenaga Nasional Berhad (TNB). The privatisation were commenced in August, 18th 1998. The major objective of the privatisation is to reduce to disruptions of power supplies commonly in the State of Sabah over three decades of operations. Another objective is to solve the financial woes for the sector of electrical generation in the state. As the result of the privatisation, the capacity of the electrical generation was increased and the distribution also increased to fulfil the increasing energy demand without burdening the state government. The government in the other hand will have better financial capacity to support other sectors to develop the state. The corporate mission for SESB is to supply continuous and reliable electricity to consumers.

At present Ranau electricity system, the only area serviced with 12-hour system is Matupang. At Paus village, infrastructures are currently developed to supply the village with solar powered electricity. About 80 houses will benefit from this solar powered generator.

In the Ranau district infrastructure masterplan, Rural Electrification Programme (BELB - Bekalan Elektrik Luar Bandar) currently installing electricity infrastructures at Melinsou, Segindai and Timbua area.

1.1.1 Brief History

Electricity started in Sabah as early as 1910 supplied by 3 separate organizations. In 1957 these three organizations combined to form North Borneo Electricity Board. When North Borneo joined Malaysia in 1963 and changed its name to Sabah, this

entity was renamed Sabah Electricity Board. On 1st of September 1998 Sabah Electricity Board was privatized and became Sabah Electricity Sdn. Bhd. (SESB).

1.1.2   About the Company

Sabah Electricity Sdn. Bhd. is an 80% owned subsidiary of Tenaga Nasional Berhad (TNB) and 20% by the State Government of Sabah. It is a vertically integrated utility providing reliable generation, transmission and distribution services in the state of Sabah and the Federal Territory Labuan.

SESB is committed to developing the electricity infrastructure in the state of Sabah and the Federal Territory Labuan including the implementation of the Rural Electrification Program. SESB generates, transmits and distributes electricity. It is the only power utility company in Sabah supplying electricity distributed over a wide area of 74,000 sq.km. As of August 2011, a total of 456.406 of which 82.8% of the customers are domestic customers contributing only 31.17% of the sale.

The SESB installed capacity (excluding IPP) of the Sabah Grid which supplies electricity for major towns from Federal Territory Labuan to Tawau is 430.9 MW and the maximum demand is 830 MW (as of August 2011). The Sabah Grid is made up of 66kV, 132kV and 275kV which links up all major towns in Sabah and Federal Territory of Labuan. As of March 2011 the total length of transmission line in Sabah is 3,263 km. The forecast demand growth of electricity is in a region of 7.7% per annum up to the year 2010. In order to support the growing demand, various generation, transmission and distribution projects will be implemented.

This project started with characteristics of standalone Ranau microgrid interconnected system, relative issues of Ranau microgrid. This project also introduces the basic principle and basic structure of Ranau microgrid and to analyze the power flow of a separate islanded mode high-voltage microgrid (MG) with various distributed resources (DRs). Figure 1.1 shows the location of Ranau district, SABAH. Figure 1.3 shows Sabah Grid Interconnection. Ranau microgrid are not connected to Sabah grid. Ranau microgrid is only operated on islanded operation, since several attempts to connect the microgrid to main power grid had failed. Grid-connected operation are not available.

First, related papers and technological reports were extensively surveyed. Accordingly, twelve different types of DRs and their controllable loads were considered for integration into six primary feeders.

SABAH GRID INTERCONNECTION & POWER STATIONS LOCATION

SABAH

SABAH GRID

SOUTH CHINA SEA

SULU SEA

M	Major Stations (6)	Mn	Minor Stations	R	Rural Stations (23)					MH	Mini Hydro (7)	IPP	Independent Power Plant (6)
M1	SJ Patau-Patau	Mn1	Ranau	R1	Pensiangan	R8	Kg. Paginatan	R15	Kg. Terusan	MH1	Sayap	IPP1	ARL Melawa
M2	SJ Hidro Tenom Pangi	Mn2	Telupid	R2	Sapulut	R9	Kg. Minihas	R16	Kg. Keniogan	MH2	Melangkap	IPP2	Powertron Sepanggar
M3	SJ Melawa	Mn3	Tungku	R3	Pinangah	R10	P. Gaya	R17	Kg. Tetabuan	MH3	Kiau	IPP3	Sandakan Power Corp (SPC)
M4	SJ Sandakan			R4	Tongod	R11	Kg. Timbua	R18	Kg. Nunuyan laut	MH4	Naradau	IPP4	Stratavest Sandakan
M5	SJ Tawau			R5	Kg. Karamuak Dalam	R12	P. Mantanani	R19	Kg. Tanjung Aru	MH5	Carabau	IPP5	Serudong Power Tawau
				R6	Kg. Tenaga Baru	R13	Karakit, P. Banggi	R20	Lihak-Lihak Bakung	MH6	Bombalai	IPP6	Sepanggar Bay Power Corp.
				R7	Kg. Kanang-Kanangan	R14a	Kg. TangkarasonA	R21	Lihak-Lihak Siaban	MH7	Merotai		
						R14b	Kg. TangkarasonB	R22	Sg. Tamang, P. Sebatik				

PMU	Pencawang Masuk Utama (34 PMU)				
PMUa	PMU Labuan	PMUf	PMU Kolopis	PMUk	PMU Kota Marudu	PMUp	PMU Lahad Datu
PMUb	PMU Beaufort	PMUg	PMU Inanam	PMUl	PMU Kudat	PMUq	PMU Kalumpang
PMUc	PMU Tenom	PMUh	PMU Sepanggar	PMUm	PMU Segaliud	PMUr	PMU Semporna
PMUd	PMU Keningau	PMUi	PMU Kota Belud	PMUn	PMU Sandakan	PMUs	PMU Tawau
PMUe	PMU Penampang	PMUj	PMU Simpang	PMUo	PMU Dam Road	Others	

Figure 1.3: Sabah Grid Interconnection
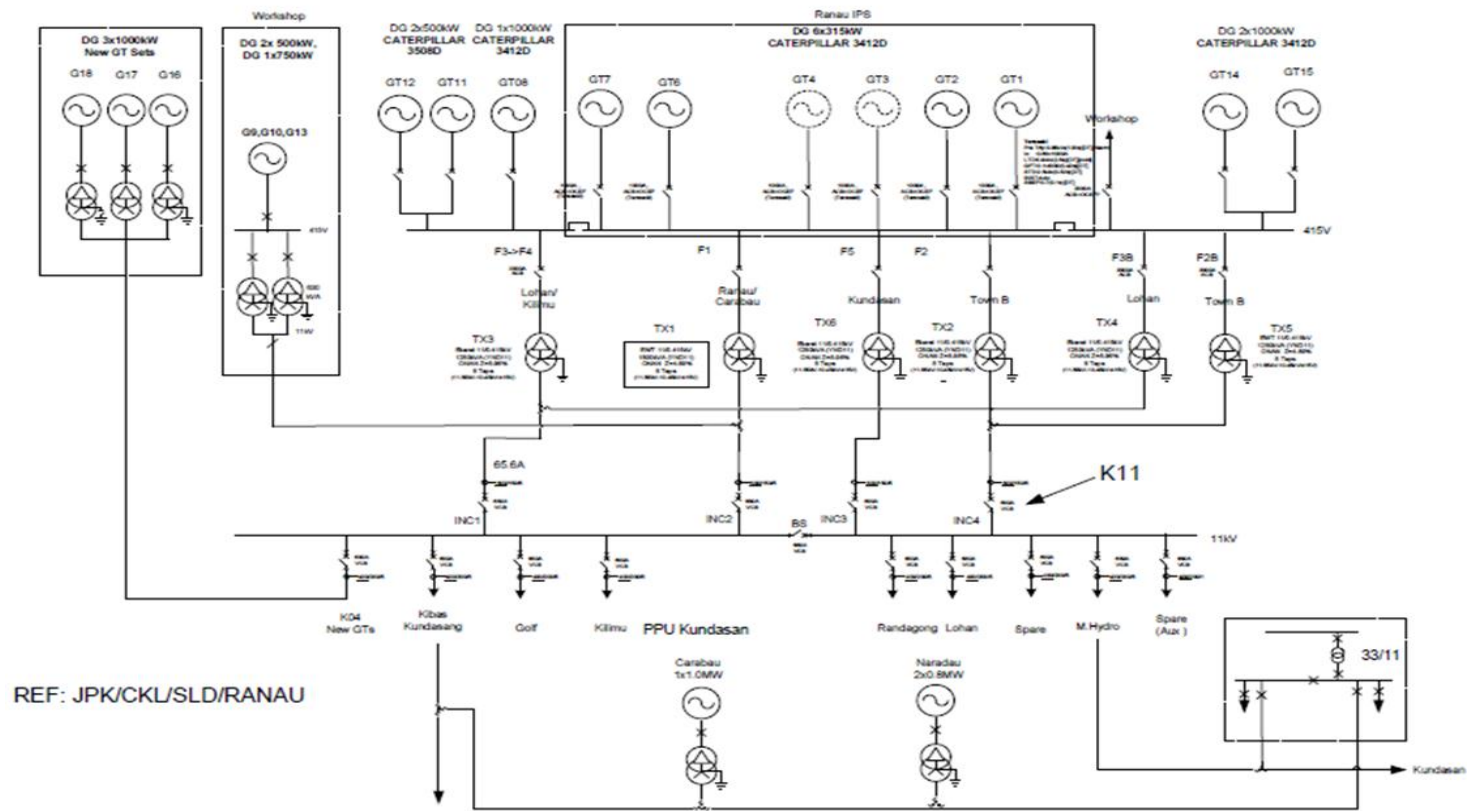
Figure 1.4: Ranau Micro Grid Connection Diagram

These DRs include four 1500 kW Cummins diesel engine generators, four 500 kW Cat diesel generators, two 1000 kW Cat diesel generators and two 1500 kW and 950 kW hydroelectrics. However, not all the generators are available and ready for generation. Some of the generators are under maintenance due to scheduled preventive maintenance and corrective maintenance. Most of the generators also due for servicing by clocking 500 hours of operation.

The Gen3 generator is currently under outage due to unusual noise detected. Some of its parts particularly the fuel filter was disassembled and reassembled at Gen8 generator. The Gen18 also not available for operation and was sent to Jayaland, Keningau for maintenance. Gen19 generator is another generator under outage due to lubricating oil leak and suffers compression leak.

Current running generator are also under quite bad conditions. Gen 8, Gen12, Gen13 and Gen20 are suffering lubrication oil leakage. Gen8 and Gen13 are currently due for major overhaul. Some of the generators which were put on standy status are not 100 percent ready to operate. There are Gen7, Gen12 and Gen14. These generators are with lubricating oil leakage and some of are due for major overhaul maintenance.

As for the Naradau and Carabau hydroelectrics, they are fully dependent on the weather conditions to generate electricity. Rainy season will increase the dam capacity and the generation capacity will increased. Dry season will decrease the dam capacity and the generation capacity will decreased. The installed capacity for both hydroelectric are 3.72 MW but normally they will generates power of about 0.7 MW.

Simulations will be carried out using PowerFactory DIGSilent 14 tool, of which the result presented the studies of capacity and power flow of microgrid. Finally, the program was used to simulate and analyze the power flow of the MG for one 24-hour period under the islanded operating mode. The outcomes of this paper should prove helpful for distribution engineers to further understand the behaviors and characteristics of 11 kV high-voltage Ranau microgrid. Enhancement of understanding of this Ranau microgrid is important for planning future expansion of power system as well as to determine the best operation of existing operating system.

1.2   Problem Statement
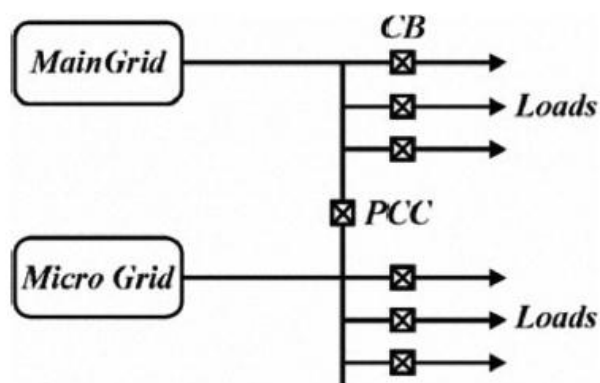
Figure 1.5: Model of Main Grid and Micro Grid

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. Power flow are typically used in operational and planning stages[15],[16]. It shows the importance of power flow even from planning stages. 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 analyzes the power systems in normal steady-state operation. A number of software implementations of power flow studies exist. PSS/ADEPT is an example of software to implement power flow studies.

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 load dispatch analysis. In particular, some programs use linear programming to find the optimal power flow, the conditions which give the lowest cost per kilowatthour delivered.

Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. The principal information obtained from the power flow study is the magnitude and

phase angle of the voltage at each bus, and the real and reactive power flowing in each line.

Commercial power systems are usually too large to allow for hand solution of the power flow. Special purpose network analyzers were built between 1929 and the early 1960s to provide laboratory models of power systems; large-scale digital computers replaced the analog methods.

As to the large scale microgrid interconnection, new problems as main power grid plan and designation, dispatching and operation, protection and control will emerge due to the influence of microgrid upon the steady-state power flow distribution and the dynamic fault characteristics of the main power grid.[1]

This project will help the power engineers to have a deeper understanding on this microgrid. Deeper understanding will pave the way for better grid operation. The authors present the issues relating to the islanded operation of microgrid including coordination of microsources and storage device to maintain the satisfactory islanding operation of microgrid. This particular microgrid is only operated on islanded operation, since several attempts to connect the microgrid to main power grid had failed.

1.3   Project Objectives

The major objective of this research is to study the power flow of Ranau microgrid. The other objectives are:

a) To analyze the voltage profiling of Ranau Microgrid under islanded mode of operation.

b) To study the active power (KW) and reactive power (KVAR) of the microgrid.

c) To study the reliability of Ranau microgrid by using the spinning reserve analysis.

1.4   Project Scopes

This project is primarily concerned with the islanded operation of the microgrid. The scopes of this project are:

a) To analyze the power flow of Ranau microgrid into PowerFactory DIGSilent 14 software in islanded mode of operation, 11 kV only.

b) To analyze the voltage profiling of 11kV Ranau Microgrid of a separate islanded mode only since for the time being this microgrid operates in islanded mode. Several attempts to connect the microgrid to main power grid had failed.

1.5   Thesis outline

The written report was layout as follows:

1.   Chapter 1 – Introduction

It briefly discussed on the importance of power flow analysis of a system. Power flow or load flow is a tool to analyse a system or grid. Power flow analysis will study the real power, reactive power, voltage, current loading, load analysis and voltage angles. Power flow or load-flow studies are important for planning future expansion of power systems as well as in determining the best operation of existing systems. many software implementations perform other types of analysis, such as short-circuit fault analysis, stability studies (transient & steady-state), unit commitment and economic load dispatch analysis

2.   Chapter 2 – Literature Review

This chapter reviewed on past researches which have significant contributions to this study. Many software implementations perform other types of analysis, such as short-circuit fault analysis, stability studies (transient & steady-state), unit commitment and economic load dispatch analysis. Studies on microgrid topologies

also performed. Among others are DERs, loads, transmission lines, controls and protections. The terms of voltage profiling and fault analysis also sufficiently explored. Finally the description of previous methods in power flow explained briefly. Among the methods are The Newton-Raphson method and Newton Trust Region Method.

3.   Chapter 3 – Methodology

Chapter 3 touched on the methodology of power flow analysis in achieving the ultimate objective of this study which was power flow analysis. The methodology was done accordingly by three phases, namely literature review on previous works, Ranau microgrid data gathering and simulations and results analysis. Project planning also included in Chapter 3.

4.   Chapter 4 – Results

The findings of this study were presented under the Results section of Chapter 4. This chapter not only showed the graphs and data tables, but brief comments were also given upon the statistical simulation analysis. And on enhancing the results, they were neatly organized under different system, first for the IEEE9 system and then Ranau microgrid. Among the results are active power (P), reactive power (Q), voltage angles, grid losses (MW), spinning reserves (MW), system reliability, generation data, load data, installed capacity, current loading for transformer and transmission lines as well as detailed every bus analysis.

5.   Chapter 5 – Conclusion

Chapter 5 provided the conclusion of this study. After the lengthy studies and simulations, we can conclude which system is better in term of reliability. We also can compare both systems for capacity and power flow analysis as well as current loading. It also brought up few potential further works that can be done in improving the research area.

1.6   Summary

The objective of this chapter is to give the readers an understanding of the case studies involves IEEE9 system and Ranau microgrid. Readers can assess the performance and reliability of each system by reading the detailed analysis and conclussions. It also points out the motivation behind the study, giving out its objectives and scope of work before laying out the thesis outline.

CHAPTER 2

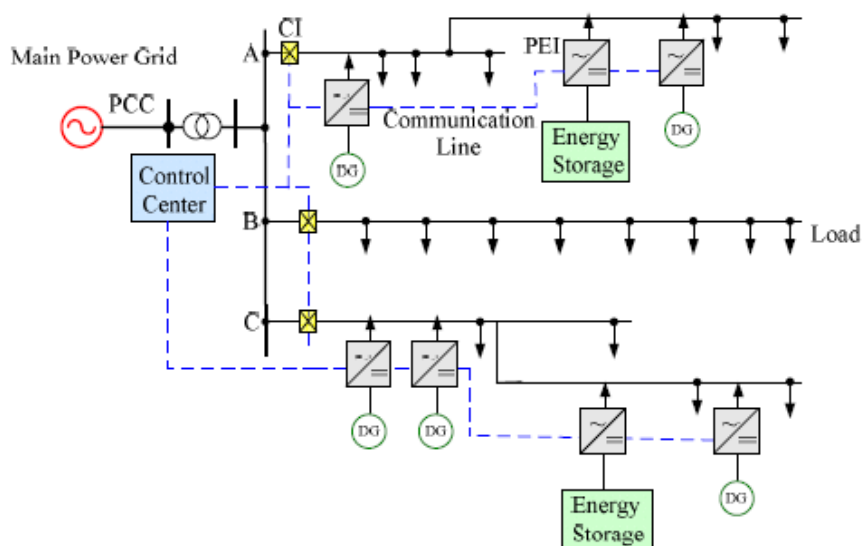**LITERATURE REVIEW**

2.1   Theories - Microgrid

Figure 2.1: Microgrid basic system topology.

Microgrid is an organic system which consists of loads, micro power, i.e. DG in microgrid, and energy storage devices. The point where the microgrid and the main power grid interconnects is the Point of Common Coupling (PCC). Connection

Interface (CI) which is commonly configured by microgrid specific control switch is arranged near PCC. Each unit is connected to the microgrid bus via the Power Electronics Interface (PEI). Energy storage devices which can be battery, supercapacitor, superconducting energy storage and flywheel will realize the power balancing adjustment within the microgrid, reducing the influence of DG on the main power grid significantly and enhancing the controllability of the power flow.

In a typical microgrid, the microsources may be rotating generators or Distributed Energy Resources (DER) interfaced by power electronic inverters. The installed DERs may be biomass, fuel cells, geothermal, solar, wind, steam or gas turbines and reciprocation internal combustion engines. The overall efficiency may be improved by using combined heat and power sources (CHP)[2].

Loads also can be various, mainly are impedance loads, motors and heat loads. The connected loads may be critical or non-critical. Critical loads require reliable source of energy and good power quality. These loads are supported by their own microsources because they require an uninterrupted supply of energy. Noncritical loads may be shed when required decided by the microgrid operating policies. Since the power level of utility grid is higher than that of the microgrid, the same is dominated mainly by the existing power grid. But the actual performance is judged when the microgrid works in islanded mode[3].

Within the microgrid, control units are interconnected by communication line which gathered at the control center to manage the optimal operation and the coordinated control, dynamically matching the load demand and achieving the power flow between the microgrid and the main power grid to be adjusted directionally and quantitatively. It should be pointed out that not all the elements are necessary for the microgrid, the possible combination depends upon the microgrid size and specific requirements of local loads on microgrid. Figure 2.1 is a basic microgrid system topology. Feeder lines in microgrid are usually radial distributed, and DGs are connected through several points. Power exchange between the microgrid and the main power grid is conducted via the connecting line. DGs within the microgrid and the main power grid are interacted through the middle and low-voltage transformation[1].

As an effective way to solve various problems in modem power systems, micro grid is increasingly adopted in many developed countries. MGs have become a

new development trend in power systems nowadays. Microgrid can operate online, but also according to the actual fault occurs which planning maintenance etc or run independently.

Microgrid protection is considered one of the most important challenges facing the implementation of microgrid. The brittleness of the stand-alone running microgrid can be defined as natural disasters, strong external disturbance, system components failure, recessive fault and power quality impact factors, etc.

To this extent, we study the steady-state characteristics of a high-voltage MG with two different types of DRs, namely, diesel engine generators and hydroelectric generators. This MG contain renewable and non-renewable DRs under islanded operating mode, with the assumption that the system is three-phase balanced We anticipate that the nature of the 11 kV high-voltage MG will be thoroughly understood after detailed analysis of the power flow under the islanded operation mode.

Renewable sources of energy such as hydroelectric in Ranau microgrid is highly dependent on weather conditions and geographical factors. In their ntermittent nature, hydroelectric are highly variable[4].

Consequently, the incorporation of DRs in this particular MG reduces total power system loss because no transmission losses are incurred, and DRs usually offer the advantages of low environmental effects and high efficiency. These can be operated in grid-connected or islanding modes[5].

2.1.1   Voltage Profiling

During the grid connected mode, main system reactive power resources such as generation units, switched shunt capacitors and long lines charging may contribute to the reactive power support of the Micro Grid and help keep the Micro Grid voltage profile within acceptable ranges. However, Micro Grid Voltage profile control within an islanded Micro Grid is more critical due to the lack of reactive power support from upstream main system[6].

2.1.2   Fault analysis

The fault analysis of a power system is required in order to provide information for the selection of switchgear, setting of relays and stability of system operation. A power system is not static but changes during operation (switching on or off of generators and transmission lines) and during planning (addition of generators and transmission lines). Thus fault studies need to be routinely performed by utility engineers.

Faults usually occur in a power system due to either insulation failure, flashover, physical damage or human error. These faults, may either be three phase in nature involving all three phases in a symmetrical manner, or may be asymmetrical where usually only one or two phases may be involved. Faults may also be caused by either short-circuits to earth or between live conductors, or may be caused by broken conductors in one or more phases. Sometimes simultaneous faults may occur involving both short-circuit and broken conductor faults (also known as open-circuit faults).

2.1.3 Reactive Power

Voltage 415 V and 11 kV are available on Ranau microgrid system. Reactive power flow is needed in an alternating-current transmission system to support the transfer of real power over the systems. In AC system, energy is stored temporarily in inductive and capacitive elements. On the other hand, real power, P, is the energy to accomplished desired work. Due to inductive and capacitive elements in the network, a portion of power flow returned back to source. It is known as reactive power. It transfers no energy, but have important function in electrical grids.

Reactive power increased as energy stored in capacitive or inductive elements. It will influence the voltage level on the system. Voltage levels and rective power should be carefully controlled to allow any system to operate within acceptable limits.
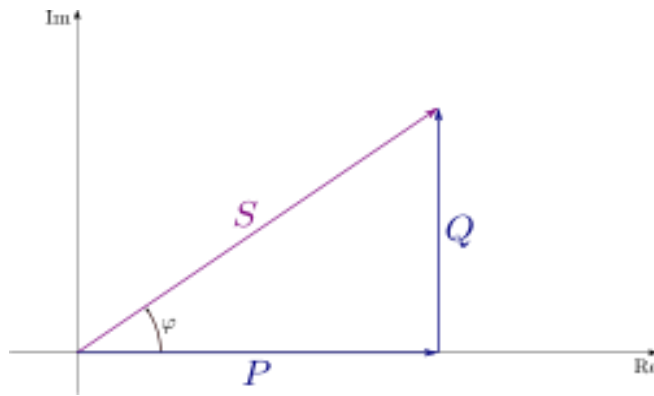
Realpower (P)

Reactivepower (Q)

Complex power (S)

Figure 2.2: Real, Reactive and Complex Power

2.1.4 Real Power

Real power, measured in Watt, both the current and voltage reverse their polarity at the same time. At any instant, the product of voltage and current is positive, indicating that the direction of energy flow does not reverse. In this case, only real power is transferred. Practical loads have resistance, inductance, and capacitance, so both real and reactive power will flow to real loads. The actual amount of power being used, or dissipated, in a circuit is called true power or real power.

Active power consumed in the systems, while reactive power moves from load to source and vice versa, and it is not consumed in the system. If a system has 0.86 power factor then it means that it has 86% active power and 14% reactive power. Engineers care about apparent power, because even though the current associated with reactive power does no work at the load, it heats the wires, wasting energy. Conductors, transformers and generators must be sized to carry the total current, not just the current that does useful work.

2.2 Power Flow

Power flow analysis is fundamental to the study of power systems. In fact, power flow forms the core of power system analysis. Load flow studies are carried out to

study any interconnected power system. Power flow study plays a key role in the planning of additions or expansions to transmission and generation facilities. Power flow analysis is at the heart of contingency analysis and the implementation of real-time monitoring systems. For a given power network, with known complex power loads and some set of specifications or restrictions on power generations and voltages, solve for any unknown bus voltages and unspecified generation and finally for the complex power flow in the network components.

Such studies facilitate us in determination of best size as well as the most favourable location for the power capacitors for both power factor improvement and also for raising the network voltages. The load flow studies also helps us in determination of best location as well as optimal capacity of the proposed generating stations, substations and new transmission lines. Thus load flow studies are very important for planning existing system as well as its future expansion.

For optimized operation of an interconnected system, some informations such as bus bar voltage levels, machine excitation, tap change and reactive compensation are required which are provided by load flow studies. The main information obtained from load flow studies comprises the magnitude and phase angles of bus voltages, reactive powers of generator buses, active and reactive power flow in transmission lines, other variable being specified.

For many years, load flow studies were carried out by means of special purpose analogue computer, called the AC network analyser, but the advent of high speed digital computers has tended to replace their use for a large system studies. This change from AC network analyser to the digital computer has resulted in greater flexibility, economy, accuracy and faster operation. However for system studies of a more local character, the network analyser is still used, particularly in the initial planning stages.

2.2.1   Power Flow Study Steps

These are the steps undertaken to study power flow in a system.

1. Determine element values for passive network components.

2. Determine locations and values of all complex power loads.

3. Determine generation specifications and constraints.

4. Develop a mathematical model describing power flow in the network.

5. Solve for the voltage profile of the network.

6. Solve for the power flows and losses in the network.

7. Check for constraint violations.

2.2.2   Load Flow Solution

There are four quantities of interest associated with each bus:

1. Real Power, P

2. Reactive Power, Q

3. Voltage Magnitude, V

4. Voltage Angle, δ

At every bus of the system, two of these four quantities will be specified and the remaining two will be unknowns. Each of the system buses may be classified in accordance with which of the two quantities are specified.

2.2.3   Bus Classifications

Slack Bus — The slack bus for the system is a single bus for which the voltage magnitude and angle are specified.

- The real and reactive power are unknowns.
- The bus selected as the slack bus must have a source of both real and reactive power, since the injected power at this bus must "swing" to take up the "slack" in the solution.
- The best choice for the slack bus (since, in most power systems, many buses have real and reactive power sources) requires experience with the particular system under study.

The behaviour of the solution is often influenced by the bus chosen.

2.2.4   Load Bus (P-Q Bus) :

A load bus is defined as any bus of the system for which the real and reactive power are specified.

- Load buses may contain generators with specified real and reactive power outputs; however, it is often convenient to designate any bus with specified injected complex power as a load bus.

Voltage Controlled Bus (P-V Bus) :

- Any bus for which the voltage magnitude and the injected real power are specified is classified as a voltage controlled (or P-V) bus.
- The injected reactive power is a variable (with specified upper and lower bounds) in the power flow analysis.
- (A P-V bus must have a variable source of reactive power such as a generator.)

2.2.5   Solution Methods

The solution of the simultaneous nonlinear power flow equations requires the use of iterative techniques for even the simplest power systems. There are many methods for solving nonlinear equations such as:

- Gauss Seidel.
- Newton Raphson.
- Fast Decoupled.

The electrical power system is currently undergoing major changes. The nonstop growing energy demand being fed by distributed generation (DG) units. This in turn, increases the microgrid system modularity and expandability. Then, the need for power flow analysis is essential. Among the purpose for power flow are distribution automation, network optimization, Var planning and reliability assessment. These purposes are to ensure better operated power system.

Power flow also will prove helpful in planning of Energy Management System (EMS) and power sharing, and stability analysis. Many power flow solutions and algorithms have been proposed since the early studies of power flow. Most of them are classified as branch based methods [17],[18].

2.3   Description of previous methods

There are several methods available for power flow analysis. Among the are Newton-Raphson method and New Trust Region Method.

2.3.1   The Newton-Raphson method

The Newton-Raphson method is one of the most commonly used techniques for solving nonlinear algebraic equations, and presents better convergence than does the Gauss-Seidel method. Thus, it is popularly applied in power flow analysis. The iteration numbers of the Newton-Raphson approach is independent of the scale of system and can solve the problem through a few iterations[7]. However, its Jacobian matrix requires recalculation and updating in each iterative step[8].
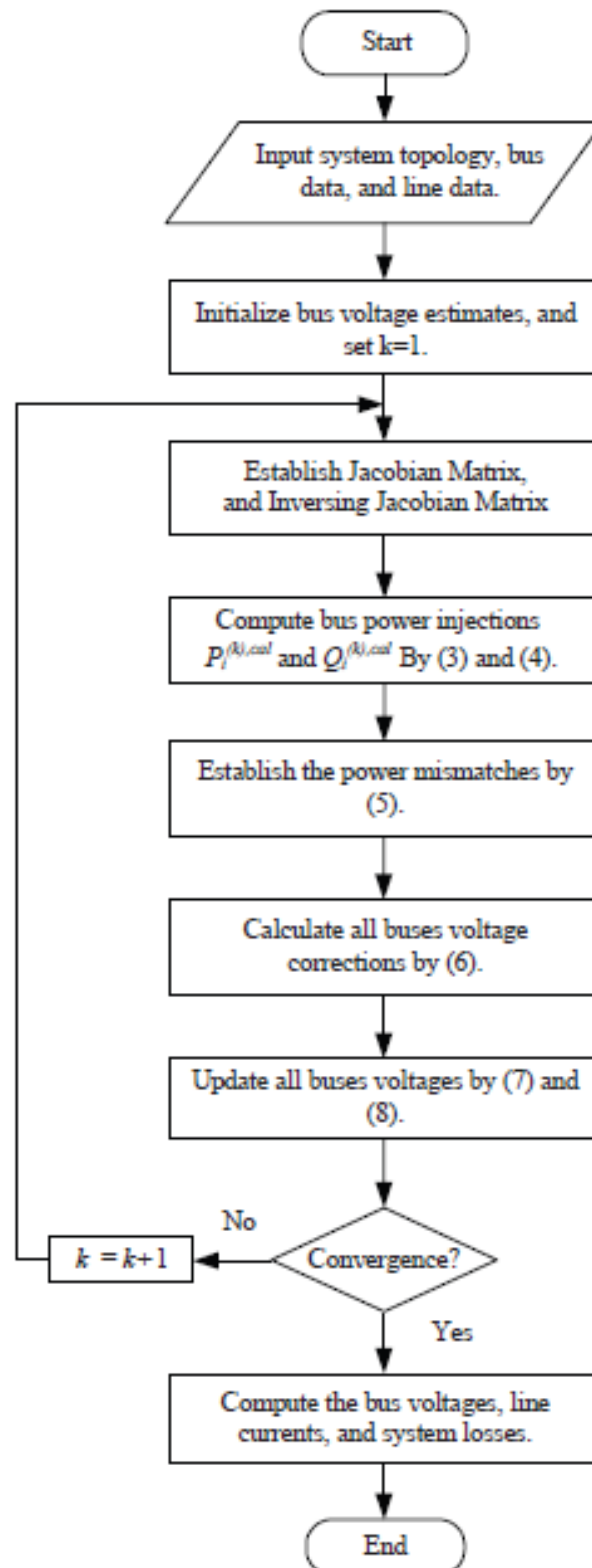
Figure 2.3: The Newton-Raphson Method

The loads and DRs are assumed to be equivalent injected powers in power flow analysis. Newton-Raphson method was applied to solve the power flow of the high-voltage microgrid. A 24-hour operating analysis was explored in detail in this section, after rigorous engineering analyses and discussions on the voltage profiles, line flow profiles, and system losses.

This method successfully analyse the voltage profiles, line flow profiles, and system losses. This method shows the DRs integrated into the distribution network are clearly helpful to the system voltage profiles. The DRs also proven to share load demands and lessen the power supply requirement from the upstream utility grid. system losses also concluded to decrease because of to the incorporation of DRs.

This method is among the most used techniques for solving nonlinear algebraic equations and better convergences than Gauss-Siedel method[9].

In the case of islanded microgrids, Newton Raphson methods may fail to get a solution even with starting from a flat initial guess. Typically this situation is due to the fact that the region of attraction of the power flow solution in the islanded microgrid is narrow[10]. Moreover, the system is operating close to the boundary between the solvable and unsolvable region as there is no infinite bus in the system.

2.3.2   Newton Trust Region Method

Traditionally the non-linear equations of the power flow problem are solved using the Newton Raphson (NR) algorithms. Generally, the NR algorithms provide fast quadratic convergence characteristics. However they face several challenges when dealing with distribution systems due to several factors such as the high R/X ratio as well as the sparse Jacobian matrix inversion.

Newton Trust Region Method three-phase power flow algorithm is formulated for islanded microgrids. The algorithm is novel since it adapts the real characteristics of the islanded microgrid operation. All possible operation modes of DG units (droop, PV, or PQ) have been considered. The problem has been formulated as a set of nonlinear equations. A globally convergent Newton-trust region method has been proposed to solve this set of nonlinear equations. The proposed algorithm is a helpful tool to perform accurate steady state studies of the islanded microgrid.

Newton-Trust region method as an alternative to the NR algorithms. Trust region methods are simple and powerful tools for solving systems of nonlinear equations and large scale optimization problems[4]. The proposed algorithm has been validated by comparing its results with the results of a detailed time-domain simulation. The results show good convergence characteristics in all operating conditions. The proposed algorithm is a powerful tool to study the power flow in an islanded microgrid. This power flow analysis helps to consider the islanded microgrid in both operational and planning studies.

2.4   DIGSILENT PowerFactory 14.0

The calculation program PowerFactory, as written by DIgSILENT, is a computer aided engineering tool for the analysis of industrial, utility, and commercial electrical power systems. It has been designed as an advanced integrated and interactive software package dedicated to electrical power system and control analysis in order to achieve the main objectives of planning and operation optimization.

The name DIgSILENT stands for "DIgital SImuLation and Electrical NeTwork calculation program". DIgSILENT Version 7 was the world's first power system analysis software with an integrated graphical one-line interface. That interactive one-line diagram included drawing functions, editing capabilities and all relevant static and dynamic calculation features.

The PowerFactory package was designed and developed by qualified engineers and programmers with many years of experience in both electrical power system analysis and programming fields. The accuracy and validity of the results obtained with this package has been confirmed in a large number of implementations, by organizations involved in planning and operation of power systems.

In order to meet today's power system analysis requirements, the DIgSILENT power system calculation package was designed as an integrated engineering tool which provides a complete 'walk-around' technique through all available functions,

rather than a collection of different software modules. The following key-features are provided within one single executable program:

1   PowerFactory core functions: definition, modification and organization of cases; core numerical routines; output and documentation functions
2   Integrated interactive single line graphic and data case handling
3   Power system element and base case database
4   Integrated calculation functions (e.g. line and machine parameter calculation based on geometrical or nameplate information)
5   Power system network configuration with interactive or on-line access to the SCADA system
6   Generic interface for computer-based mapping systems

By using just a single database, containing all the required data for all equipment within a power system (e.g. line data, generator data, protection data, harmonic data, controller data), PowerFactory can easily execute any or all available functions, all within the same program environment. Some of these functions are load-flow, short-circuit calculation, harmonic analysis, protection coordination, stability calculation and modal analysis.

Load flow calculations are used to analyze power systems under steady-state and nonfaulted (short-circuit-free) conditions. The load flow calculates the active and reactive power flows for all branches, and the voltage magnitude and phase for all nodes. The main areas for the application of load flow calculations are:

- Calculation of branch loadings, system losses and voltage profiles for system planning and operation (normal and abnormal conditions).
- Contingency analysis, network security assessment (abnormal conditions).
- Optimization tasks, i.e. minimizing system losses, minimizing generation costs, open tie optimization in distributed networks, etc. (normal or abnormal conditions).
- Verification of system conditions during reliability calculations.
- Automatic determination of optimal system resupplying strategies.
- Optimization of load-shedding (abnormal conditions).
- Calculation of steady-state initial conditions for stability simulations or

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