PROTECTION SCHEME FOR LOW VOLTAGE DISTRIBUTION NETWORK WITH HIGH PENETRATION OF DISTRIBUTED GENERATION

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A project report submitted in partial fulfillment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic Engineering

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"PROTECTION SCHEME FOR LOW VOLTAGE DISTRIBUTION NETWORK WITH HIGH PENETRATION OF DISTRIBUTED GENERATION"** was prepared by **TANG JUN HUAT** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Electrical and Electronic at Universiti Tunku Abdul Rahman.

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ABSTRACT

Present distribution grid network protection scheme in general, not suitable to cope with the significant distributed generation capacity. Distribution systems are generally radial in nature, characterized by a single source feeding a number of downstream networks whose protection scheme has been designed such a way by assuming a unidirectional power flows in the network. The integration of DG has possibility to incur a bi-directional power flows. Hence the setting for the traditional protection relays has become unsuitable to the future distribution system with high penetration of distributed generation. In order to ensure the quality and reliability of power supply, the issues raised by DG need to be solved. In this study, the impacts of high penetration of distributed generated to existing protection scheme are investigated. The new protection schemes are designed for the distribution network with high penetration of DG.

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LIST OF SYMBOLS / ABBREVIATIONS

c_p	specific heat capacity, J/(kg·K)
h	height, m
K_d	discharge coefficient
M	mass flow rate, kg/s
P	pressure, kPa
P_b	back pressure, kPa
R	mass flow rate ratio
T	temperature, K
v	specific volume, m^3
α	homogeneous void fraction
η	pressure ratio
ρ	density, kg/m^3
ω	compressible flow parameter
ID	inner diameter, m
MAP	maximum allowable pressure, kPa
MAWP	maximum allowable working pressure, kPa
OD	outer diameter, m
RV	relief valve

CHAPTER 1

INTRODUCTION

1.1 Background

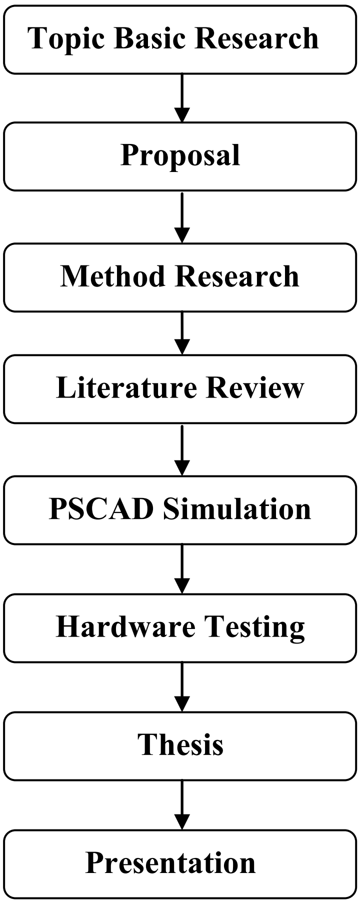
The renewable energy is a fast gaining ground as a new growth area for many countries worldwide including Malaysia with the vast potential it presents environmentally as well as economically. The 10^{th} Malaysia Plan re-emphasized the use of renewable demands, in particular hydro power for electricity generation and blending of bio fuels. The promotion of energy efficiency and renewable energy by the Malaysia Government has resulted in increasing the number of renewable energy developer. Besides that, moving to green environment with less pollution, reduce the dependent on the limited resources, decrease the cost of electrical bill, and increase the reliability of the power system has lead to the increasing number of distributed generation.

The existing protection scheme for controlling the low voltage distribution network is based on the assumption of radial or unidirectional flow of the power. The power and fault current are assumed to be fed from the higher voltage level toward lower ones. With the high penetration of distributed generation (DG), the protection issues need to the handle precisely in order to safeguard the entire system to maintain continuity of supply, to minimize damage and repair costs, as well as to ensure safety of human personnel.

1.2 Aims and Objectives

The main objective of the proposed project is to mitigate the problem rises and, investigate the protection issues cause by high penetration of distributed generation as well as integrate a new protection scheme for low voltage network with distributed generation.

1.3 Project Flow Chart



CHAPTER 2

LITERATURE REVIEW

2.1 Thermocouple

This chapter is about the research of the proposed project, protection scheme for low voltage distribution network with high penetration of distributed generation. The reading material are mainly from IEEE journal, online article, books and the list go on. The research aims to investigate the network problem raises on protection coordination due various levels of distributed generation and come out with a new adaptive protection scheme for future distribution network with high penetration of distributed generation. In addition, examination and comment is made on the literature relevant to the area of the proposed project research.

2.2 Overview

In this section, the focus point will be onto few relevant papers of the protection scheme for distribution network with high level of distributed generation. The reviewed papers are listed below:

i) Technical issues on distributed generation connected and guidelines.

ii) Reviewing the impacts of distributed generation on distribution system protection.

iii) Problem related to islanding protection of DG in distribution network.

iv) A new adaptive current protection scheme of distribution network with distributed generation.

v) Development of adaptive protection scheme for distribution system with high penetration of distributed generation.

2.2.1 Technical issues on distributed generation connected and guidelines. [6]

In this paper, they discusses the guidelines and recommendations of the guidebook on various technical issues encompassing capacity adequacy, network losses, voltage regulation and control, fault level, protection, interface design, operational safety and system stability to ensure that system reliability, safety and efficiency is not negatively impacted following the connection of a distributed generation.

The network voltage control is normally done using on load tap changer, but with synchronous generator embedded in the network would normally equip with an automatic voltage regulator capable of controlling the output voltage. Synchronous generators contributed fault currents in response to fault in the network. When generator is connected, the prospective short circuit or fault level will increase due to the fault contribution.

Protection system is essential for both the network and the generator to ensure safe operation. Network and the generator protection systems do interact and will be designed to coordinate with each other. Generator transient stability is not normally an issue with generator connected to a distribution system. However, generator connected to very long lines subject to long protection clearance times could experience transient instability.

This paper point out most of the problem face with distributed generation connected to the existing network grid. Referring to this paper will help to understand more deeply about the current issues and develop the new adaptive to solve the problem.

2.2.2 Review the impacts of DG on the distribution system protection. [4]

This paper point out some of the more common problem and resulting malfunction of the protection scheme incurred with the distributed generation connected into distribution grid. The impact of DG on system protection and coordination particularly in case where DG is added to the distribution feeder with existing lines reclosers and fuses.

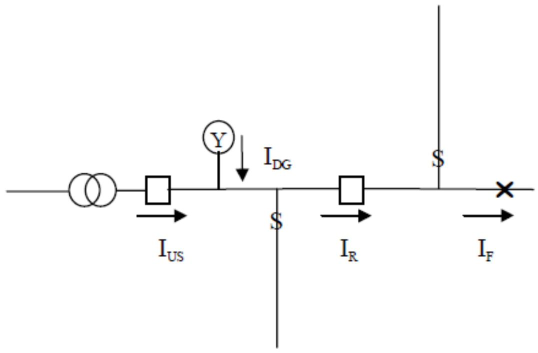


Figure 2.1: Typical feeder with the addition of DG up line of recloser and fault at end of line

Notice that without the DG connected ($I_{DG} = 0$),

$$I_F = I_{US} = I_R \quad (2.1)$$

However, with the DG connected,

$$I_F = I_{US} + I_{DG} \quad (2.2)$$

$$I_R = I_F \quad (1.3)$$

But

$$I_R \neq I_{US}$$

With the DG connected the fault current seen by the recloser (I_R) will be greater than without the DG connected. This would normally not cause a problem with the recloser size as long as the greater I_R does not exceed the recloser maximum interrupting rating. However, it is very likely that coordination between the recloser and any down line fuses will be lost. Because both the recloser and fuses operate faster at higher fault currents, the required margins between the recloser fast curve and the fuse minimum melt curve could be reduced enough to lose coordination.

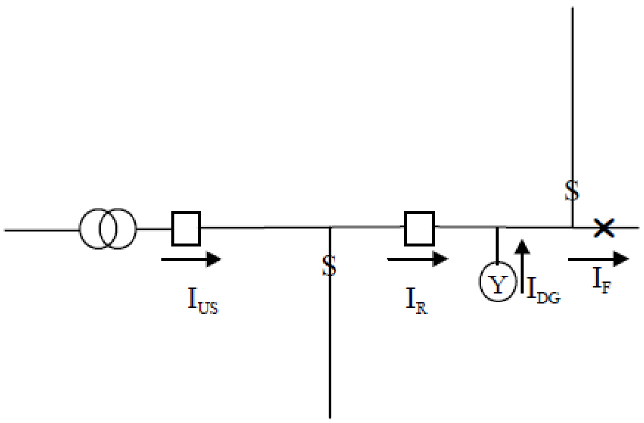


Figure 2.2: Typical feeder with the addition of DG down line of recloser and fault at end of line

Without DG connected,

$$I_F = I_{US} = I_R$$

However, with the DG connected,

$$I_R = I_{US}$$

$$I_R \neq I_F$$

In this case, the fault current seen by the recloser with DG connected will be less than without the DG connected. This lower fault current makes the recloser less sensitive in its ability to see the fault and result in longer recloser tripping times.

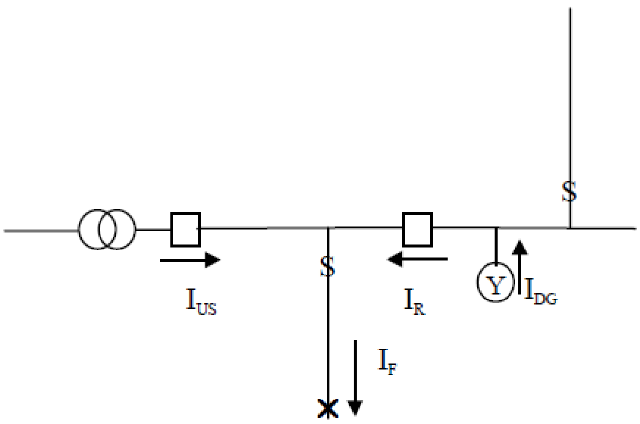


Figure2.3: Typical feeder with the addition of DG down line of recloser and fault up-line of recloser

Notice that without the DG connected ($I_{DG} = 0$),

$$I_F = I_{US}$$
$$I_R = 0 \qquad (2.1)$$

However, with the DG connected,

$$I_R = I_{DG}$$

But

$$I_R \neq I_F$$

Under this condition, the recloser could trip for a fault up-line, which of course is unacceptable. If I_R exceeds the minimum tripping value of the recloser, tripping of the recloser will occur.

2.2.3 Problem related to islanding protection of DG in distribution network. [8]

These papers discuss the problem related to the islanding detection in distribution network with DG. DG units are typically not design for feeding the public the public network alone. So DG units maintaining the voltage in a part of the network result in severe consequences. First is safety hazard to network personnel as the feeder is assumed to be dead when open the breaker at the substation. Secondly is failing autoreclosings by maintaining the voltage and thus the arc at the fault point. In addition, the DG unit is not capable to maintain the power quality in the network which may cause disturbances and equipment damage.

One of the islanding detection methods is passive methods. This refers to measuring different electrical values at DG unit's point of common coupling. Rates of change of frequency (ROCOF), which based on continuously calculating the gradient of frequency. The gradient is calculated over a few cycle and compared with its defined threshold. Another new method is called vector shift (VS). VS relay is based on measuring and comparing the cycle durations. By measuring the duration with the previous one, the islanding situation can be detected.

Active methods of islanding detection also discuss in this paper. Active methods are typically implemented in inverter applications, as the inverter is suitable for introducing small changes. But active methods are not allowed in all networks as they are thought to disturb the network and to result in reduces power quality.

The third type of islanding detection methods is system based on communication. The idea is based on feeding continuous high frequency carrier signal to the substation's bus bar. This signal will propagate on all feeders fed by the substation. The DG unit located in the network considers the signal as a guard signal which enables the generation. As the feeder opens, the connection to the substation is lost and the signal will disappear.

2.2.4 A new adaptive current protection scheme of distribution network with distributed generation. [7]

Adaptive current directional protection algorithm adopts module value of fault current as fault criterion, uses fault component calculating system composite impedance, and adds directional relay. The new relay based on this algorithms can automatically adjust its setting according to operation mode of distribution network and fault state. This method is suitable for DG connecting with grid at or near the bus bar.

$$I_{DZ}=\frac{K_d K_K E}{Z_s + Z_{L1}} \tag{2.1}$$

where

K_d = Fault type coefficient

K_k= reliable coefficient

E = phase voltage, V

Z_{L1} = line impedance

Z_s=composite impedance

K_d is set according to the fault type. When it is three phase short circuit, K_d = 1, in two phase short circuit fault, $K_d = \frac{\sqrt{2}}{3}$. The fault component of negative sequence current or phase current can be used to distinguish two phase or three phase short circuit fault. The calculation formula of Z_s is as follow:

$$Zs = \frac{-U_{mg}}{U_{mg}} \tag{2.2}$$

where

U_{mg} = fault component of voltage of protection

I_{mg} = fault component of current of protection

Z_s=composite impedance

When the system impedance is known, the system equivalent phase voltage can be calculated through follow equation:

$$E = U_m + I_m Z_s \tag{2.3}$$

where

U_m = voltage of protection when fault occur

I_m =current of protection when fault occur

$$Z_{L1} = K_{L1}\ Z_L \tag{2.4}$$

where

Z_L = line impedance

K_{L1} =line decrease current compensation coefficient

The coefficient will be 1 if DG is not connected to distribution network.

$$K_{L1} = 1 + \frac{Z_s}{Z_g} \tag{2.5}$$

The criterion of the adaptive current directional protection is $I \geq I_{DZ}$ where I is the fault current flows through the protection. When the protection is upstream of DG, the line decrease current compensation coefficient K_{L1} will decrease the setting of the protection, which compensates the reduced current by DG. When the protection is downstream of DG, the adaptive algorithm will compensate the enhanced current by DG by calculating Z_s in real time, and K_{L1}=1. When they is no DG connected to the network, the coefficient will be 1, and there is no change of the setting of protection.

This protection technique is independent on the fault type. It is depended on the system impedance and line compensation coefficient. This method can automatically alter its operating parameter in response to the change of the network conditions in order to maintain optimal performance.

2.2.5 Development of adaptive protection scheme for distribution system with high penetration of distributed generation. [1]

This paper offer a comprehensive system –independent adaptive protection scheme for distribution network with high penetration of DG that would not undermine the system reliability after connecting DG.

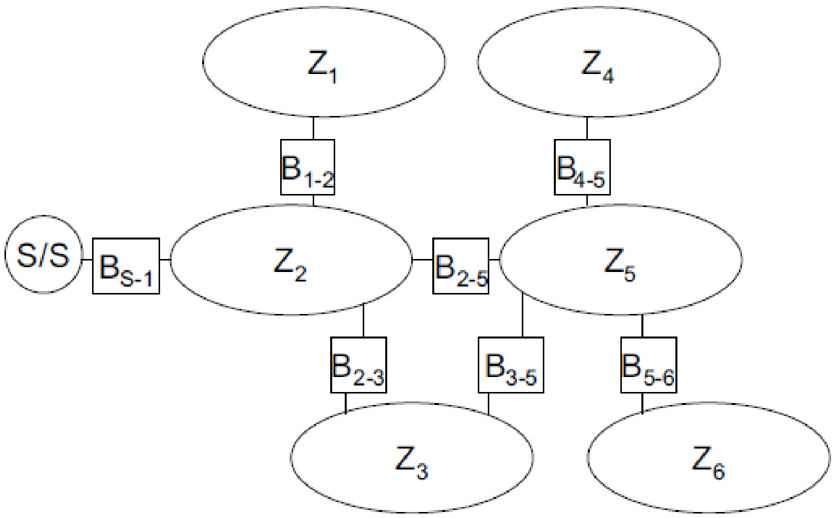


Figure 2.4: Distribution systems that divide in breaker separated zones

The proposed scheme is to divide the system into zones as shown in figure 1. A zone is formed such that it has a reasonable balance load and DG, DG capacity being little more than the load. As shown in figure 1, each zones is separated by a breakers. The breaker should be capable to repeatedly open and close on receiving a signal from a main relay located in the substation.

The first requirement for protection scheme is the actuating input. This comes through measurement. This paper recommends continuous measurement on synchronized current vectors for all three phase from DG in the system and from the main source. A signal indicated current direction in every zone forming breaker.

This method requires a load flow study and a complete short circuit analysis for all type of faults involving different phase. In additional, the fault current contribution of each DG and main source should be found out.

Current phasors from the main source and all DG are continuously available. In normal condition, the sum of these phasors would be equal to the total load on system. In case of fault on any part of the system, this sum would exceed the total load substantially. This is how the relay senses a fault in the distribution system. The monitored zones is here is the distribution system itself. When there is a fault anywhere in the system, the sum if the current contributions from all sources would equal to the fault current. On the other hand, if there is a fault in a DG, since the DG is outside the monitoring zone, the sum would be zero.

Once the fault in the system is sensed, total fault current in each phase can be determined using the following equation:

$$I_{Fabc} = \sum_{i=1}^{n} (I_{Fabc})_{sourcei} \quad (2.6)$$

where

I_{Fabc} = total fault current (phasors)

$(I_{Fabc})_{sourcei}$ = fault current contribution in the phases from sources i

n= total number of sources

Total fault current is the sum of fault contributions from all sources in the system. From the fault point, every source can be represented as a voltage source behind Thevnin impedance. If the fault shifts from one bus to adjoining bus, for a given type of fault, Thevnin impedance to a given source can either increase or decrease. Thus as shown in figure 2, if the fault point shifts over a section from bus I to bus j, for a given type fault, the fault current contribution from any given source can wither continuously increase (IFMIN to IFMAX) or continuously decrease (IFMAX' to IFMIN'). Thus, the fault contribution from source "k" for a given type of fault occurring at any point between bus i and bus j will always lie between the contributions from source "k" to type same type of fault on bus I and bus j. This means that for a given type of fault on some section, the fault contribution from each source must lie between contributions from that source for same type of fault on buses connected to this section. Fault current contribution from each source for every type of fault for all buses is already known from short circuit analysis. The fault location can be identify as the section for which the measured fault contribution from each source is between the calculated fault contributions at the 2 buses connected to this section from that source for a given type of fault.

Once the fault section is identified, the relay would send a trip signal to isolate the fault zone and DG in this zone.

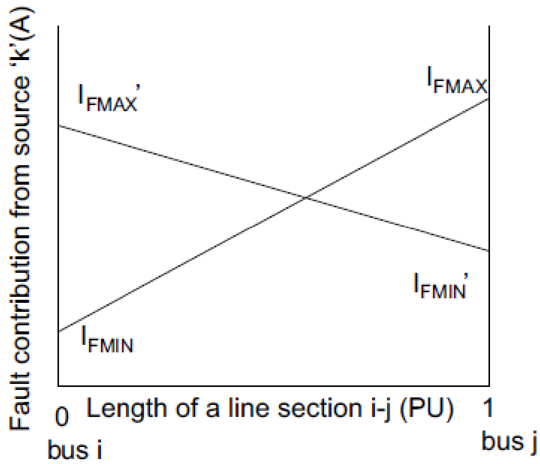


Figure 2.5: Nature of fault contribution from source k to a given type of fault on a line section between bus i and j

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss about the method use to study on network behaviour use as reference for the protection scheme for the distribution network with high level of distributed generation (DG). In this project, the distributed generation used is Photovoltaic (PV). First of all, the operation of the relay will be discussed. 2 type of relay will be use in the project, which is MR13-Digital multifunctional relay for overcurrent protection and MRU3-2 Voltage relay with evaluation of Symmetrical components. Besides that, a load bank had been built for this project. In addition, the batteries bank also built for the storage purpose. PSCAD software is use to simulate the actual situation and data collection. Experiment also conducted in the lab to observe the behaviour of the distribution network with different DG level, loading and so on. Finally, the setting of the overcurrent, overvoltage and undervoltage relay had been set.

3.2 Hardware description

3.2.1 MR1-3 Overcurrent Protection Relay

The MR13 digital multifunction will be used as the overcurrent protection in the project. It is a universal time overcurrent and earth fault protection device intended for use in medium voltage system, either with an isolated/compensated neutral point for network with a solidly earthed/resistance-earthed neutral point.

The protective functions of MR13 which are implemented in only one device are summarized as follows:

1. Independent (definite) time overcurrent relay,
2. Inverse time overcurrent relay with selectable characteristic,
3. Integrated determination of fault directon for application to doubly indeeded lines or meshed system,
4. Two-element (low and high set) earth fault protection with definite or inverse time characteristic,
5. Integrated determination of earth fault direction for application to power system networks with isolated or arc suppressing coil neutral earth.
6. Integrated determination of earth short-circuits fault direction in systems with solidly-earthed neutral point or in resistance-earthed system.

Furthermore, the relay MR13 can be employed as a backup protection and differential protective relays.

3.2.1.1 Operation and Setting

First of all, the relay is supply by 24V DC. After the power on, the screen is display “SEG”. After the push button <SELECT/RESET> has been pressed, always the next measuring is indicated. The operating value are indicated and then the setting parameters. By pressing the <ENTER> push button, the setting values can directly be called up and changes. Before parameter setting can be started, the relevant password must be entering. The password for this relay is:

<+>, <->, <SELECT/RESET>, <ENTER>

Pick up current for phase overcurrent element, I>. The setting value of this parameter appears on the display is related to the nominal current I_N of the relay. When the LED at I> light up, we can set the overcurrent setting by <+> or <->, then press enter. Password may required, after input the password, press enter for 3 second. The overcurrent setting has been set.

Trip delay or time factor for phase overcurrent element, tI>. By setting the trip relay, the actual set value for forward faults appears in the display first and the LED under the arrows is a light green, it can be changed with push button <+> or <->, and then stored with push button <ENTER>. After that the actual trip delay for backward fault appears on the display by pressing push button <SELECT> and the LED under the arrows is alighting red. Usually this value should set longer than the one forward, so that the relay obtains its selectivity during forward fault. If the delays are set equally for both forward and backward faults, they relay trips in both cases with the same time delay, namely without directional feature.

3.2.1.2 Blocking the protection functions

Setting procedure for blocking the protection function:

1. Press the <ENTER> and <TRIP> together or simultaneously, the display shows the text “PR_B” (the protection stages are blocked) or “TR_B” (the tripping stages are blocked).
2. The setting can be changed by actuating the keys <+> or <->. In this procedure, the LEDs I>; I>>; IE>; IE>> are simultaneously alight in case of protective blocking “PR-B” and tI>; tI>>; tIE>; tIE>> are simultaneously emit light case of trip blocking “TR_B”.

3. Actuation of the <ENTER> key with a onetime entry of the password will store the set function.
4. The display will show the text “BLOC” (Blocked) or “NO_B” (no blocked).
5. Actuation of the <ENTER> will store the set function.
6. By pressing the <SELECT/RESET>, all further protective function that can be blocked is called one after the other.

After selection if the last blocking renewed pressing <SELECT/RESET> pushbutton switches to the assignment mode of the output relays.

3.2.1.3 Assignment of the output relay

Unit MR13 has five output relay show in figure 3.1. The fifth output relay is provided as permanent alarm relay for self supervision is normally on. Output relays 1-4 are normally off and can be assigned as alarm or tripping relays to the current functions. The output relay can only be set in the assignment mode. The assignment mode can be reached only via blocking mode. By pressing push button <SELECT/RESET> in blocking mode again, the assignment is selected. The relays are assigned as follows, LEDs I>, I>>, IE>, IE>> are two colored and light up green when the output relays are assigned as alarms relay and red as tripping relays.

After assignment mode have been activated, first LED I> light up green. Now one or the four output relays can be assigned to current element I> as alarm relays. At the same time the selected alarm relays for frequency element 1 are indicated on the display. Indication”1_ _ _” means that output relay is assigned to this current element. The assignment of output relay 1-4 to the current elements can be changed by pressing <+> and <-> push buttons. The selected assignment can be stored by pressing push button<ENTER> and subsequent input of the password. Relays 1-4 are selected in the same ways as described before.

Alarm relay are active at pickup. Tripping relays are only activated after elapse of the tripping relay.

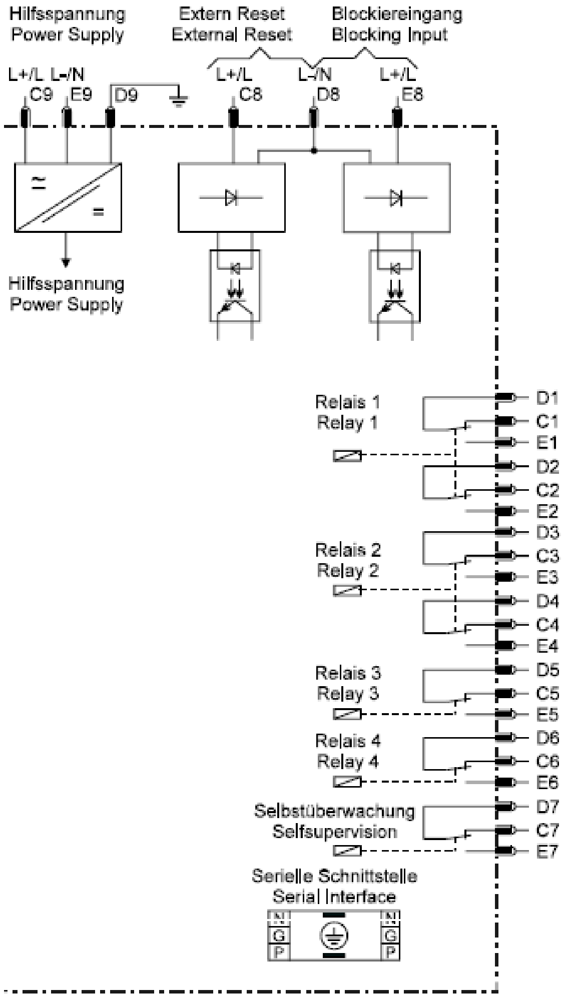


Figure 3.1: Relay output contact

3.2.2 MRU24D Voltage Protection

The MRU3-2 relay is the voltage relay used in the project for overvoltage and under voltage protection. This relay protects the three phase network against voltage unbalance or earth fault in isolated networks. Besides the pure rms value measurement of the line voltage, the MRU3-2 evaluates the symmetrical components (positive and zero sequence system). By evaluating these components, this relay can detect the phase sequence, voltage unbalance and earth faults.

3.2.2.1 Parameter setting

The relay is supply by 24V DV. The password for this relay is:

<SELECT/RESET>, <+>, <->, <ENTER>

Table 3.1: System parameters and protection parameter

U_{Prim} / U_{Sek}	Primary or secondary measured value of the voltage transformer
D/Y	Selection of the switching group
LED-Flash	Suppression of LED flashing after activation
f_N	Rated frequency
P2/FR	Parameter switch/external trigger for the fault recorder
1/3	1 phase or 3 phase
U<	Pickup value for under voltage
$t_u<$	Trip value for under voltage low set element
U<<	Pickup value for under voltage
$t_u<<$	Trip value for under voltage high set element
U>	Pickup value for over voltage
$t_u>$	Trip value for over voltage low set element
U>>	Pickup value for over voltage
$t_u>>$	Trip value for over voltage high set element
U1<	Pickup value for under voltage in positive-phase sequence system
$t_{u1}<$	Trip value for under voltage low set element in positive-phase sequence system
U1>	Pickup value for over voltage in positive-phase sequence system
$t_{u1}>$	Trip value for over voltage low set element in positive-phase sequence system
U2>	Pickup value for over voltage in negative-phase sequence system
$t_{u2}>$	Trip value for over voltage low set element in negative-phase sequence system
U0>	Pickup value for over voltage in zero-phase sequence system
$t_{u0}>$	Trip value for over voltage low set element in zero-phase sequence system

3.2.2.2 Assignment of output relay

The assignment of MRU24 is the same as the MR13 over current relay. Please refer to page 17 for detail.

3.2.3 Load Bank

The load bank schematic diagram is design as figure 3.2. The function of the load bank is to emulate the loading condition at customer side. The load bank consists of 15 resistors, with each of the value of 288Ω. Each phase have 5 resistors connected in parallel. 9 Volt batteries is used to trigger the solid state relay. If 5 resistors in one phase are turned on, it consumes 1000W power.

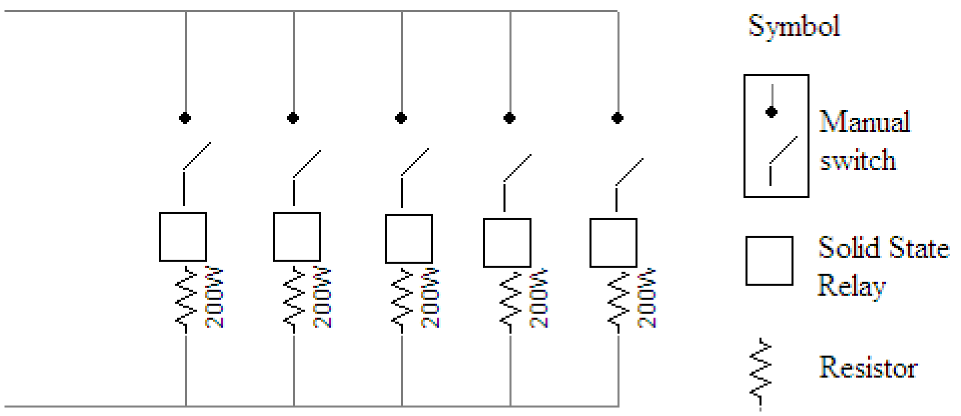


Figure 3.2: Load Bank schematic diagram of single phase

Figure 3.3: Connection of solid state relay to each phase

Figure 3.4: Load Bank

3.2.3.1 Solid state relay

RX ThyRex 1-Phase ZS, Fully Pluggable is use to protect the load bank and also act as a switches. It is an extremely compact solid state relay that is fully pluggable to make the installation and servicing easy.

General Specification:

Input control voltage range: 4 to 32VDC.

Pick up voltage: 3.5 VDC.

Response time pick up :< 10ms.

Operational voltage range: 24 to 265 VA.

Blocking voltage : >650V

Zero voltage turn-on: <10V

3.2.4 Batteries bank

Batteries bank is used to replace the PV panel for PV inverter to generate electricity. The advantages of using batteries bank instead of PV panel is that it can be used at any time without depending on the weather. If the weather is cloudy, we may not be able to run the experiment.

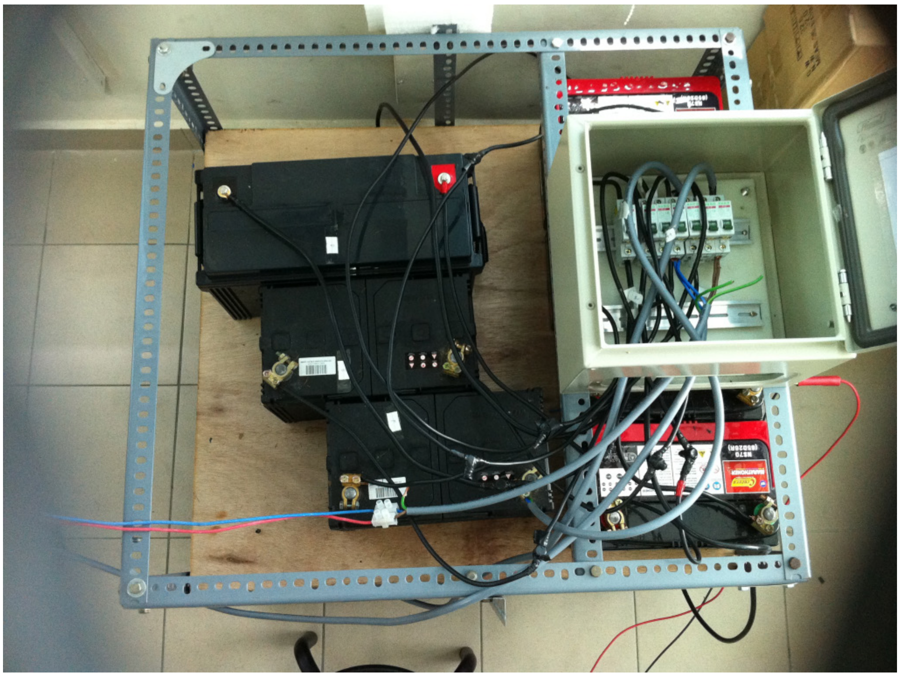


Figure 3.5: Batteries bank used for PV inverter

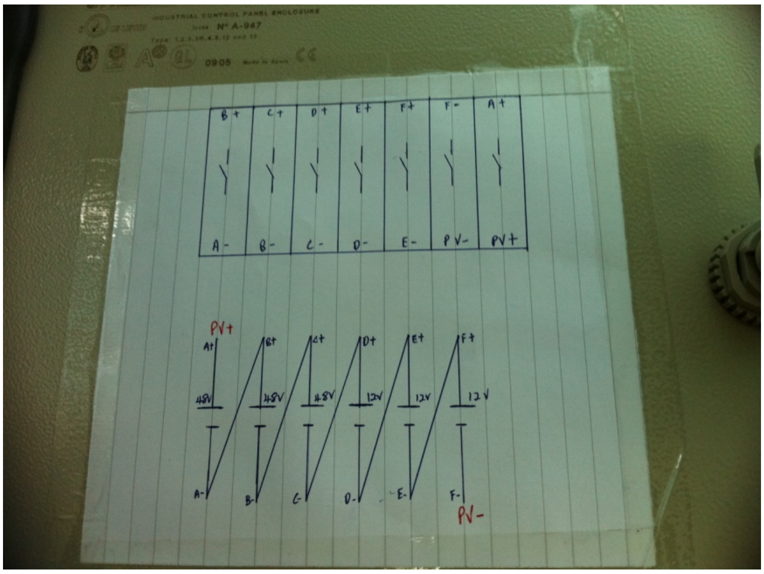


Figure 3.6: Schematic diagram of the batteries bank

The batteries bank consists of:

1. 15 piece of 12V battery.
    a) 8 x GP free Rechargeable Sealed Lead Acid Battery, 12V 100AH.
    b) 4 x Century Marathoner NS70 (65D26R)
    c) 2 x Yokohama 12V,75AH
    d) 1 x PowerBatt Sealed Lead Ascid Battery, 12V 120AH.
2. 2 piece Super-Lite Battery Charger STM-1205
3. 6 piece Circuit Breaker as switches
4. Control Box

3.2.5 PV inverter

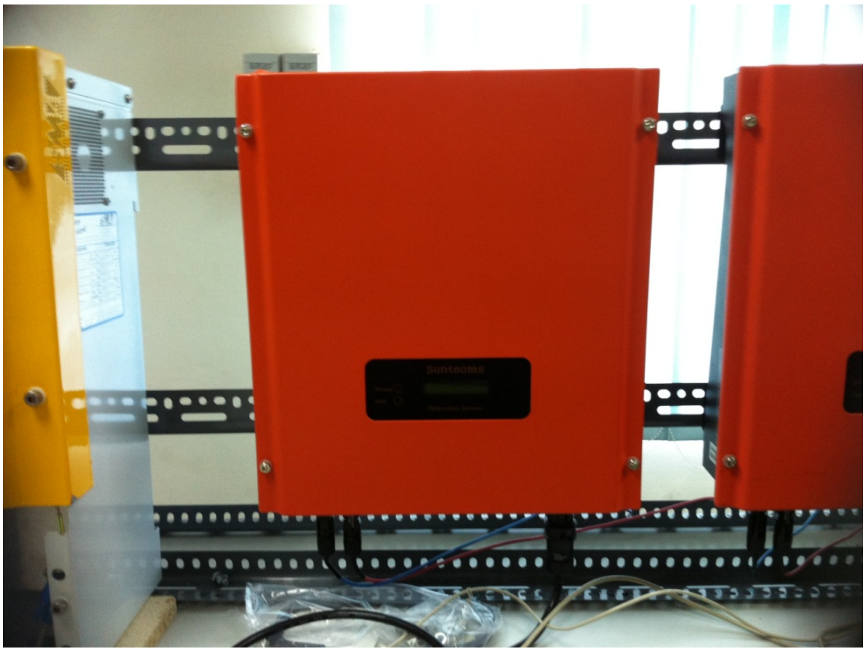


Figure 3.7: Single Phase Power Inverter.

Table 3.2: Specifications of the Sunteams 1500 PV inverter

Specifications	Sunteams 1500
Input Data	
Max.DC power	1.75KW
Max. DC voltage	450V
PV voltage range MPPT	110V-430V
Full load voltage range	200V-430V
Max. input current	9A
DC voltage ripple	< 5%
Max. number of strings	1
Ground fault monitoring	Yes
Reverse polarity protection	Short circuit diode
Output data	
Max.AC power	1.65KW
Nominal AC output	1.5KW
THD of AC current	< 3%
Grid voltage range	230V
Grid frequency range	50Hz
Power factor	1
Short-circuit proofing	Yes
Efficiency	
Max. efficiency	95.50%
Euro ETA	94.50%
Protection	IP/65

3.3 Software Description

3.3.1 PV inverter

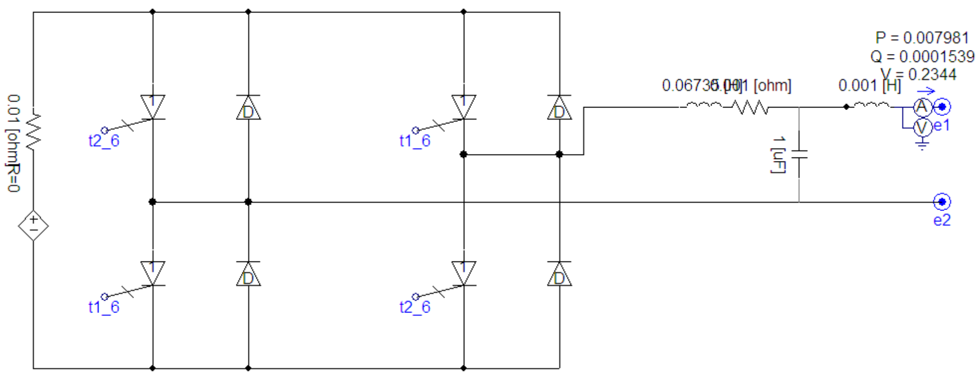


Figure 3.71: Schematic diagram of PV inverter design in PSCAD

Power inverter is use to convert direct current (DC) from the batteries to alternating current (AC) which use in the distribution network. This inverter is design using four gate-turn-off (GTO) thyristor to perform a H-bridge inverter. GTO is control by pulse width modulation (PWM) signal which generate by compare between the triangle waveform and sine wave.

Capacitor and inductors are used as a low pass filter. Low pass filter are applied to allow the fundamental component of the waveform to pass to the output while limiting the passage of the harmonic component. By this the output can be regulated and reduce voltage ripple.

Since most loads contain inductance, feedback rectifier or anti-parallel diodes are connected across the GTO to provide a path for the peak inductive load current when the GTO is turn off. By this, the switches are protected.

3.3.2 PWM generator

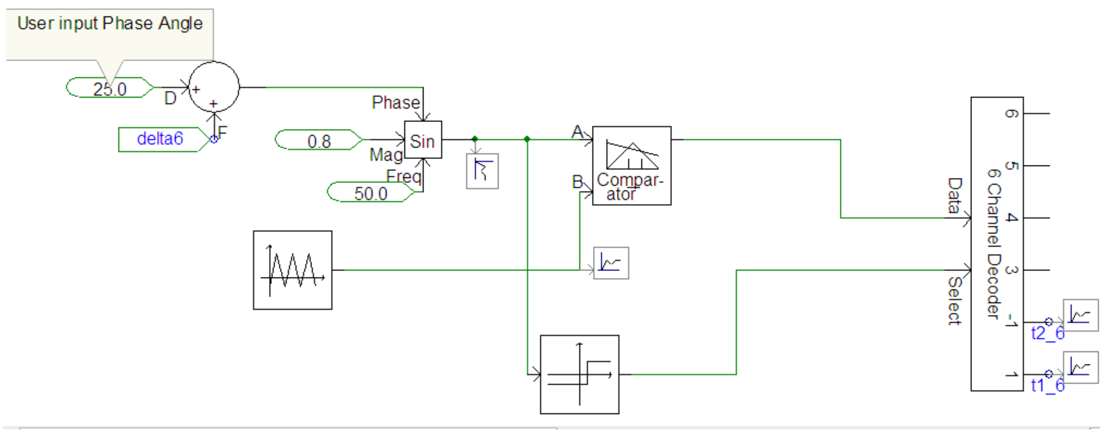


Figure 3.8 PWM generator circuit

PWM signal controlled the switch on or off of the GTO in H-bridge. The average value of voltage output fed to the load can be controlled by turning the GTO between supply and load on and off at a fast speed. The main advantage for using PWM signal to control the GTO is that the power loss in switching devices is very low compare to the device use in linear region.

Delta 6 is the phase from grid network. Use input phase angle to control the output power. Adder will add two phase angle together and send to sine wave generator. A 0.8 amplitude and 50Hz sine wave will be generated. After that, the sine wave is compare with the triangle signal, and finally PWM signal is generated.

3.3.3 Voltage Protection Design

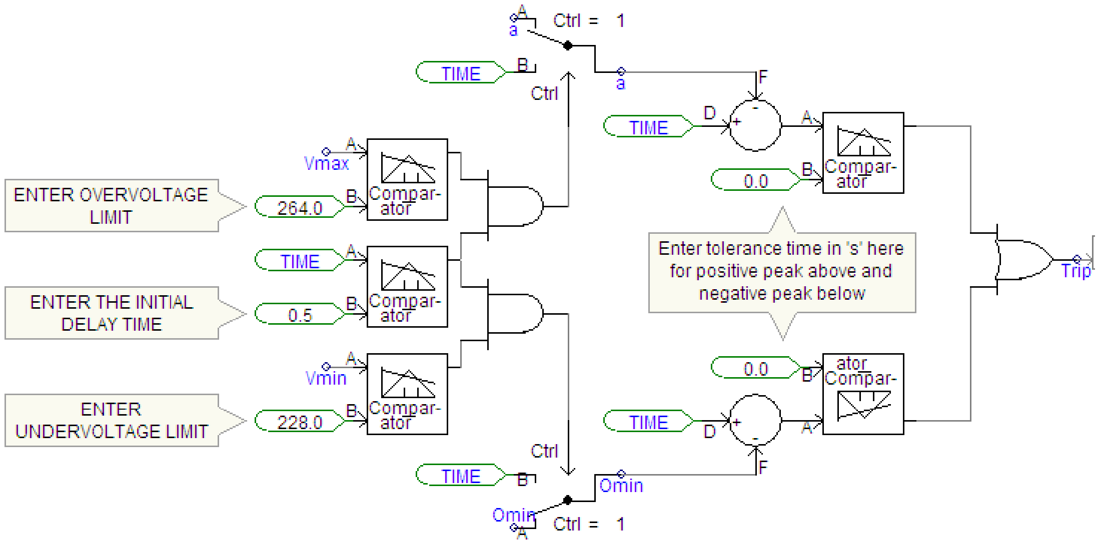


Figure 3.9: Voltage Protection Circuit

This design is base on the supply voltage of 240Vwith tolerance of +10% to -5%. To keep the network within the tolerance, the overvoltage is set to 265V and undervoltage set to 228V. The delay time of 0.5s is needed to wait the voltage rise until the stable stage. If not, the relays will always undervoltage because at the initial the voltage is below the undervoltage setting.

The function of the tolerance is to let user to enter the sensitivity of the relay. For example, if the setting is 3s, and the overvoltage occurs only for 2 second, the relay will not trip. The relay will only trip if the abnormal condition occurs more than the time setting. By this, the electricity interrupt can be minimizing if the fault is just for a while and fault is clear automatically within the time setting.

3.3.4 Voltage Unbalance Mitigation

From the data that collected in the experiment, the voltage unbalance can be mitigated by limit the upper voltage and lower voltage level of the network. For example, if the voltages unbalance factor need to be below 1%, from the studied, the voltage level at where the voltage unbalance is 1% can be found. So, by the help of voltage relay, the overvoltage and under voltage is set so that the relay trip when the voltage level is not within the allowed zone.

Figure 3.10: The phase voltage of Phase A, B and C that monitor by the relay.

Figure 3.11: The tripping of the relay due to the under voltage.

3.3.5 Current Protection Design

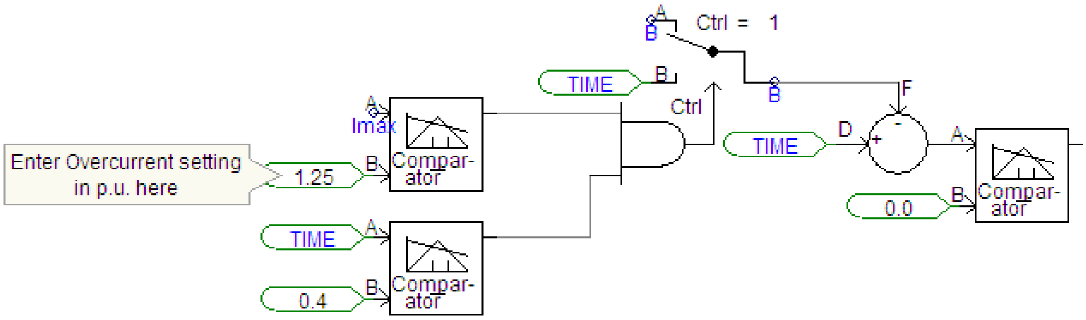


Figure 3.12: Current Protection Circuit

In electricity supply, overcurrent is a situation where very large amount of current through the conductor in the abnormal condition. This may lead to excessive generation of heat, the risk of fire, damage to equipments and also the insulation of the conductor. So overcurrent is vital important to prevent unnecessary damage, repairing cost, and also make sure the safety of the human being.

The overcurrent setting is set to the 125% of the maximum loading. In the cases of fault occurs, the current is much bigger than the maximum load. 25% overload is acceptable in normal condition. For example every utility customer at one housing area celebrates particular festival, many electrical devices in used that cause the loading increase. When short circuit, fault or overloading, this overcurrent protection circuit will detect this abnormal condition and send signal to breaker to trip.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

This chapter discusses the results obtained from simulations and experiments. The study of the network's voltage and current provides reference for the future network with high penetration of distributed generation (DG).

4.2 Voltage Unbalance without DG

In this section, the issue of voltage unbalance in the network without DG connection is studied. The purpose is to identify the inherent network voltage unbalance factor. In order to emulate the actual power demand in the real low voltage distribution network, various network scenarios were considered for both the simulation and the experiment. The loading condition in the three phase network will be represented in the matrix form as [A B C], where A, B and C are the load values. Several symbols are used as a short form for the loading conditions.

Table 4.1: Illustrates the abbreviation of the symbols used for the following discussion.

Abbreviation	Meaning
VL	Variable load from zero to maximum load
ML	Maximum load (1KW)
VL+DG	Variable load with distributed generation
ML+DG	Maximum load with distributed generation
0	No load

4.2.1 Simulation for network without DG

Figure 4.2.1 shows the voltage unbalance factor (VUF) versus the variable load for difference load conditions.

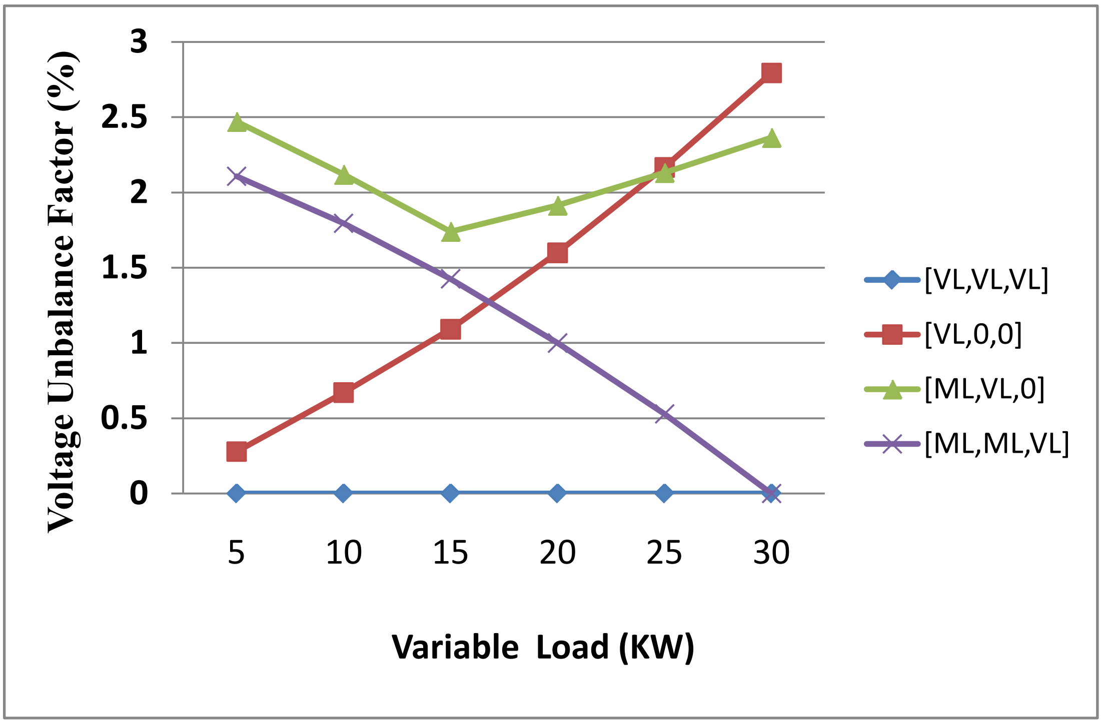


Figure 4.2.1: VUF% at the different load combination from simulation

For the balance load condition, [VL VL VL], the voltage unbalance fator is zero. This is justifiable to the theory where all the loads at each phase are the same. For the load condition [VL 0 0], where the load increase from zero to 30 kW while the laod at phase B and phase C are zero, the voltage unbalance factor increase linearly with the increment of load. For the load condition, [ML,VL,0], the voltage unbalance decrease until 10KW and begin to rise after this point. This is because when the load at phase B increases, it reduces the overall deviation between each phases. When the load reaches 10KW, the voltage deviation start increases. For the load condition, [ML,ML,0],the voltage unbalance factor decrease linearly. This is because increment of load on phase C decreases the voltage deviation between each phases.

4.2.2 Experimental for network without DG

Figure 4.2.2 shows the experimental voltage unbalance factor (VUF %) versus the variable load for difference load conditions. From this experiment, the actual behaviour of the voltage unbalance without distributed generation (DG) in the existing network can be studied.

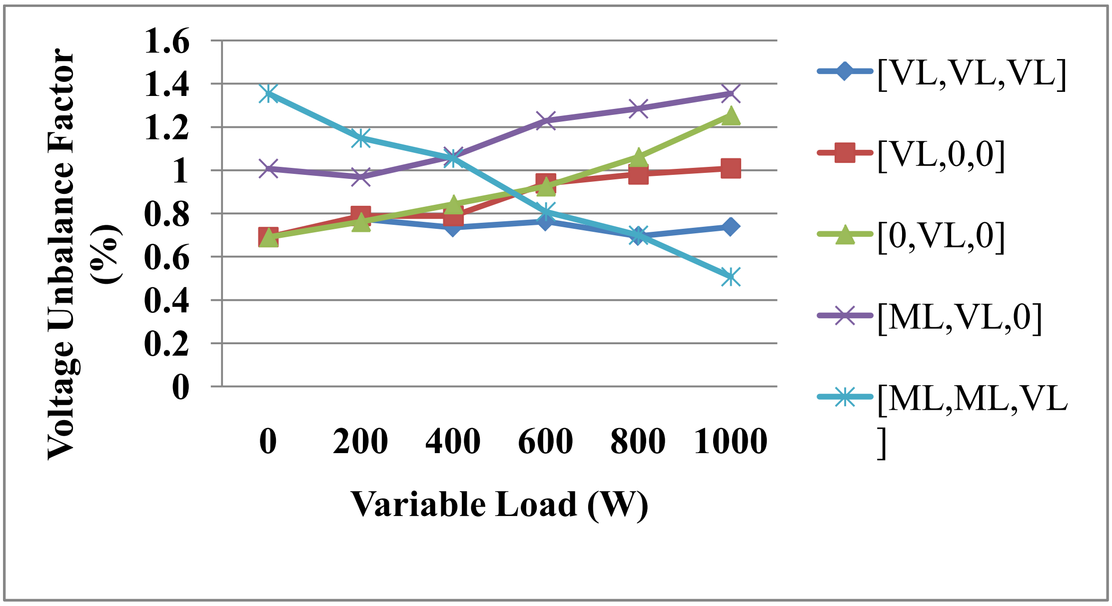


Figure 4.2.2 : VUF% at the different load combination from experiment

The experiment result showed in the graph above look different from the simulated results. This is due to the inherent unbalance in the network. From the graph, the voltage unbalance fator when there is no load in the network is 0.7%. This is still within the statutory limit set by Malaysia. For the balance case, [VL VL VL], the VUF varied between 0.7 % to 0.8 %. For the case where [VL 0 0], the VUF fall between 0.7% to 1%, increasing as the load increase. For [0 VL 0] the VUF increase from approximately 0.7% when 200W load to sligthly more than 1.2% when the loas is 1KW. For the unbalance case [ML VL 0], the VUF is the higher varied between 1% to 1.4%. For the [ML ML VL] , the VUF drop linerly from 1.4% to 0.5% as the increasing in load decrease the variation energy consume by the load.

4.3 Voltage Unbalance with DG connected

In this section, the voltage unbalance factor of the distribution network with the DG connected. The maximum load is set to 10% of 1MVA transformer. DG penetration level is referring to how much percentage to the maximum load. 10% of 1 MVA equal to 100KVA or approximately 30KVA per phase. For example 50% of DG means 15KVA of DG injected into the network. . The experiment and also simulation have been conducted with various conditions. After this, theoretical (simulation) and practical (experimental) result can be comparing.

4.3.1 Network with DG and balance load [VL+ DG, VL, VL]

Figure 4.3.1 shows the voltage unbalance versus variable load condition with DG connected from PSCAD simulation, while Figure 4.3.2 show the result form experiment. In this section, the DG in connected in Phase A, and balance load for all three phase. The DG power output level is change varying by the input DC voltage of the power inverter.

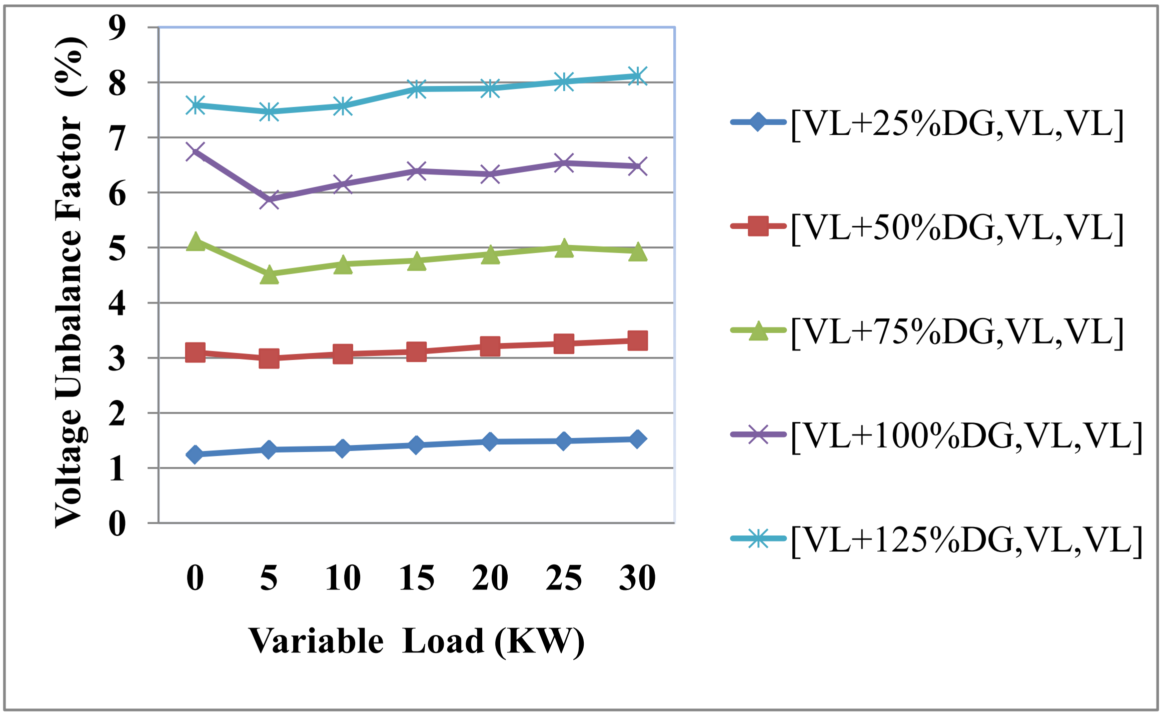


Figure 4.3.11: VUF% of balance load with various level of distributed generation conected from simulation

For the load condition [VL+25%DG,VL,VL], the voltage unbalance almost constant while the loading is increasing. Same thing happen with other load condition. The increasing of load have not much influence on the voltage unbalance. This is due to the balance load for all three phases. But, when the distributed generation generated level increase, the voltage unbalance also increase. this is because when the current pass through the phase with DG connected will be higher than the other phase. This cause the variation between the three phase become larger. Hence the voltage unbalance increase when DG power increase.

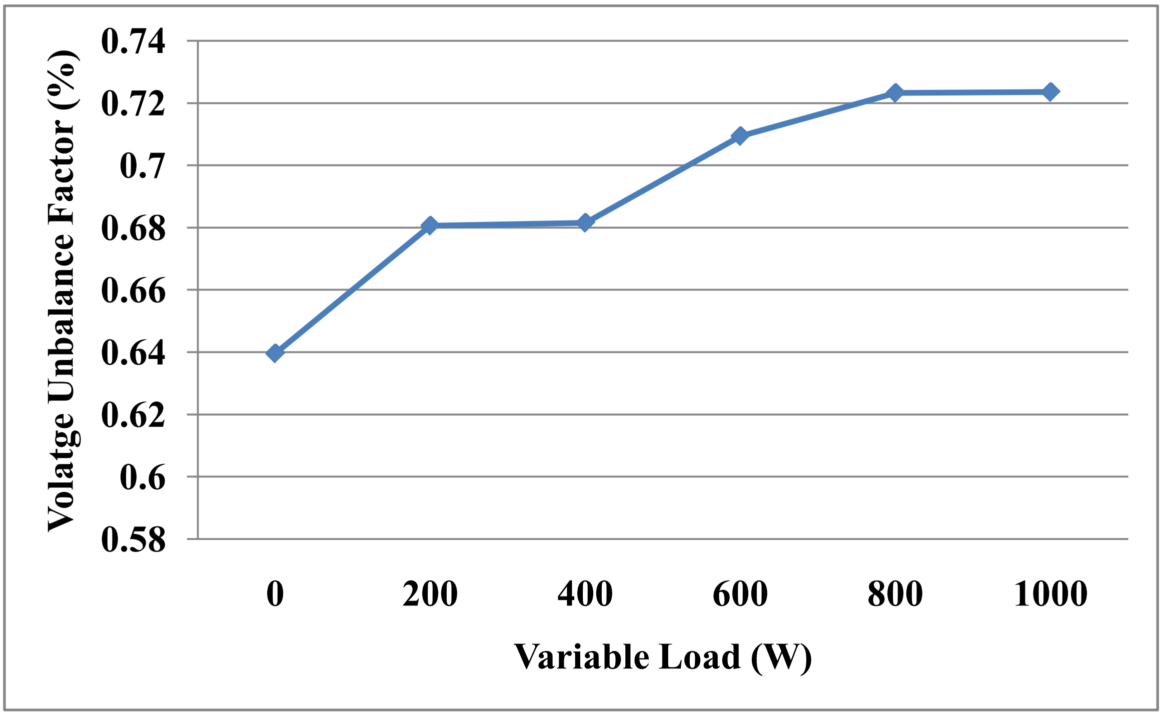


Figure 4.3.12 : VUF% of balance load with distributed generation (1.2KW) connected from experiment

From the figure 4.3.12, when the distributed generation power inject into the distribution netwrok with balance load, the voltage unbalance slightly increase when the increase of the load. This is because the phase injected by the DG power will have higher voltage compare to other phase. So, when the loading increase, the variation of voltage between three phase increase and hence increase the voltage unbalance factor.

4.3.2 With DG and Unbalance Load [VL+ DG, 0, 0]

Figure 4.3.21 shows the voltage unbalance factor versus the different load condition in the PSCAD simulation. Figure 4.3.22 show the relationship between the voltage unbalance factor and the load in experiment. In this section, DG is connected in Phase A, and zero loads at Phase B and Phase C. The DG output power is vary in simulation to see the influence of different penetration level to the voltage unbalance. In experiment, DG power injected into the network is around 1200W.

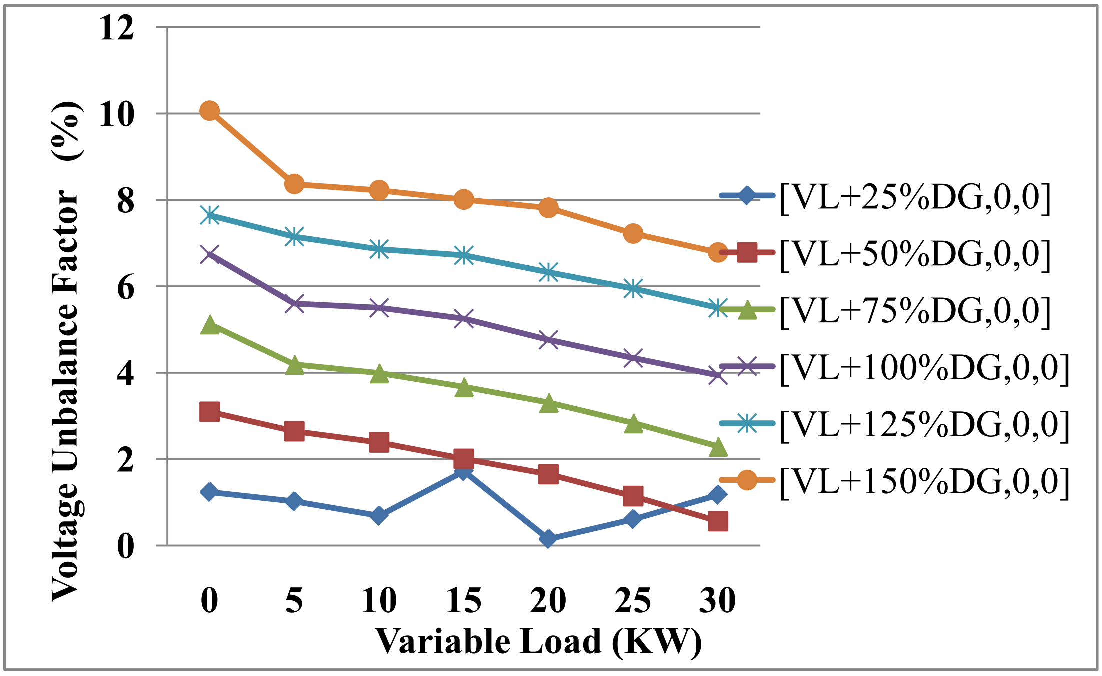


Figure 4.3.21 : VUF% of unbalance load with various level of distributed generation connected from simulation

For each load conditions in the Figure 4.3.21, the voltage unbalance decrease when the load increase. This is because when DG power injected into Phase A, and the load is low or zero, the variation voltage of Phase A is large compare to other two phase, hence result in high voltage unbalance. As the load increase, the power injected by the DG consumed by the load and hence reduce the voltage variation. This show that if the DG power injected into the network and consumed by the customer, it will not cause much influence to the network power quality.

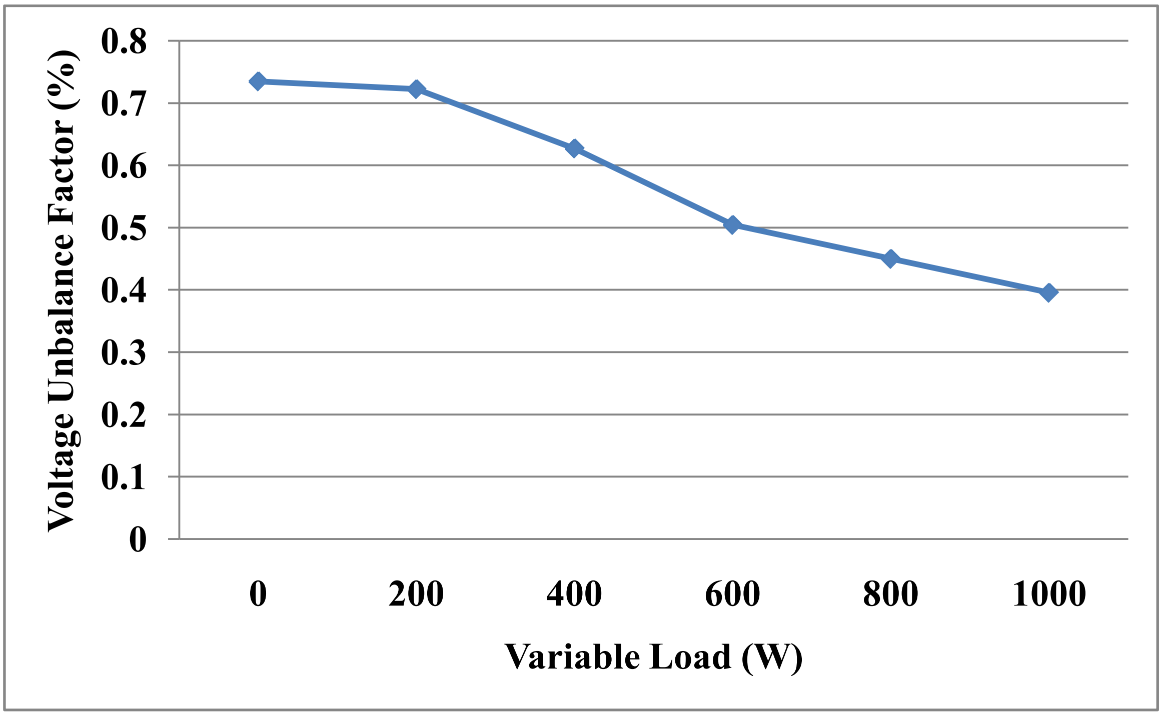


Figure 4.3.22 : VUF% of variable load at Phase A, with distributed generation (1.2KW) connected and zero load at Phase B&C from experiment

From the Figure 4.3.22, the voltage unbalance is inversely proportional to the load. When the load increase, the voltage unbalance decrease. The trend of the graph same with the simulation, so it is acceptable pratical result. As long as the injected DG power consumed by the utility customer, it will reduce the effect of the voltage unbalance problem. So proper study on the customer demand needed before connect DG into the grid to minimize the voltage unbalance issues.

4.3.3 With DG and Unbalance Load [DG, VL, 0]

Figure 4.3.31 shows the voltage unbalance factor versus variable in simulation. While the Figure 4.3.32 shows the voltage unbalance factor versus variable loading in the experiment. In this section, DG is connected in Phase A, zero load on Phase A and Phase C, variable load at Phase B is increasing. By this combination, DG power is not consumed. The simulation and experiment result are obtained for comparison.

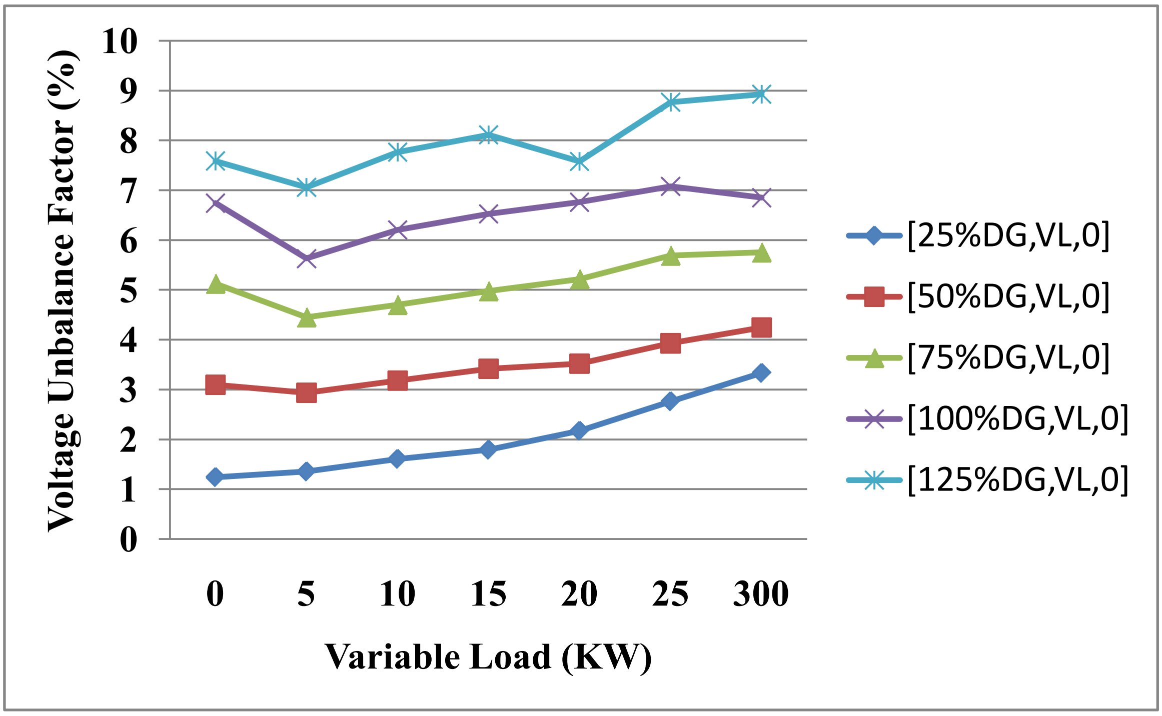


Figure 4.3.31: VUF% of unbalance load with various level of distributed generation connected from simulation

From the Figure 4.3.31, when the load increase, it will followed by the increasing of the voltage unbalance. This is due to the DG connected in Phase A will increase the voltage level, so the voltage unbalance factor increase. Besides this, the increasing of unbalance load on phse B cause the variation of current in the phase B compare to other phase. This result in the increasing of the voltage unbalance of the network. By comparing the graph to graph in figure 4.3.11, the voltage unbalance is higher in this section. So the efffect of the injected DG power is not consumed by the customer will decrease the power quality.

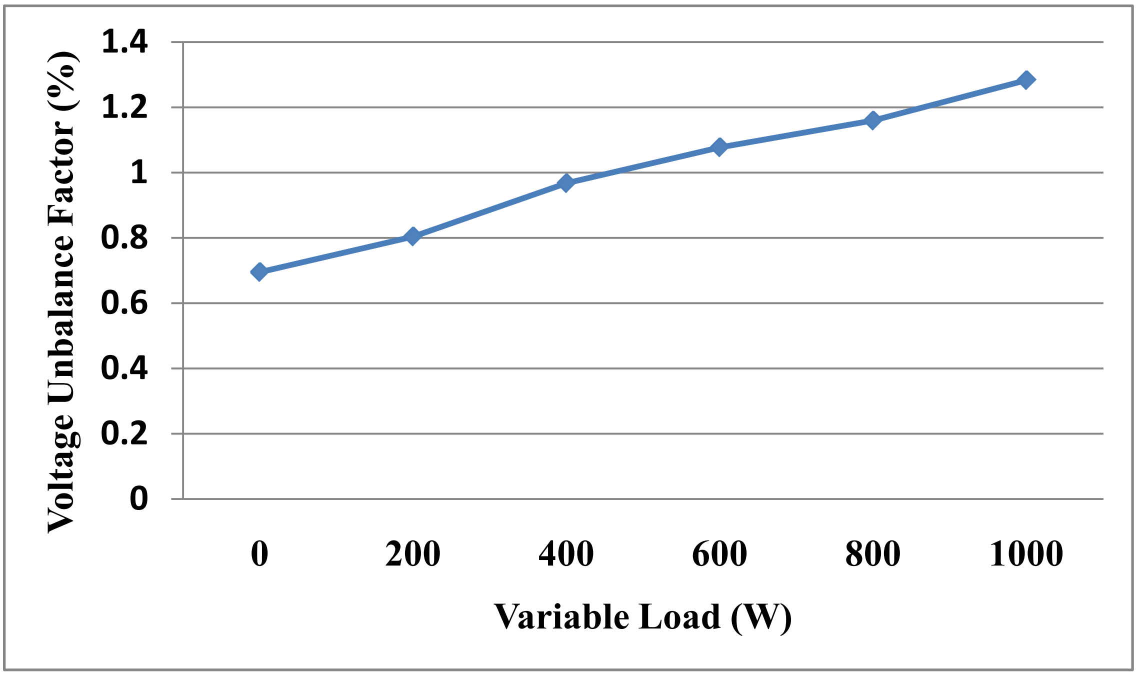


Figure 4.3.32: VUF% of unbalance load with distributed generation (1.2KW) connected from experiment

From Figure 4.3.32, we found that the trend of the graph is same as the simulation. This prove that our experiment result is correct. The voltage unbalance factor is directly propotional to the load. As the load increase, the voltage unbalance increase also. This is because DG injected into the network increase the voltage level of that phase. So the variation of voltage between the phase with DG and without DG become larger. To reduce the voltage unbalance, the DG should be connected in the phase which have the higher load demand. In additional , the demand of each phase should be divided equally when planning to avoid the voltage unbalance even without DG connected.

4.3.4 With DG and Unbalance Load [ML+DG, VL, 0]

In this section, The DG is connected in Phase A, maximum load of 30KW in Phase A, variable load at Phase B and zero load at Phase C.

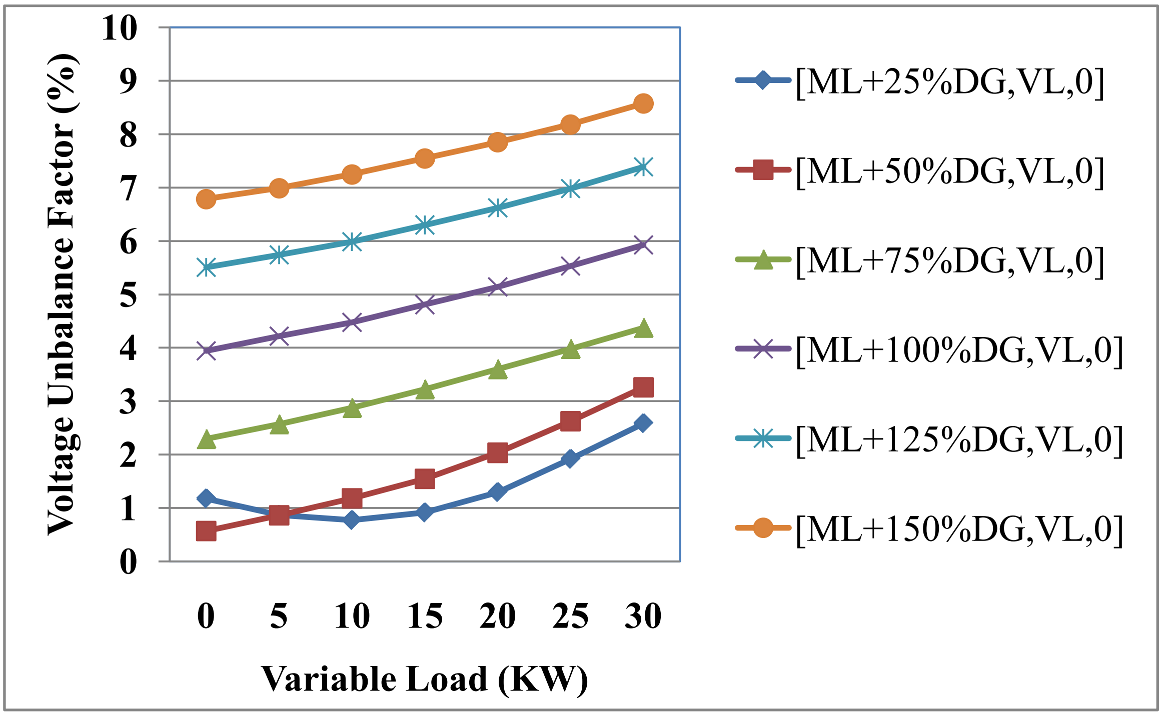


Figure 4.3.41: VUF% of unbalance load with various level of distributed generation connected from simulation

From the graph, noticed that the voltage unbalance factor increase linearly with the variable load. This is due to the unbalance load at Phase B. The increasing demand cause the current variation between three phase increase and hence the voltage unbalance increase. As the DG power increase, the voltage unbalance also increase. But if compare this graph to the graph in figure 4.3.31, the voltage unbalance with the same level of DG is much more lower in this section. This is due to the power injected by the DG consumed the the maximum load at Phase A.

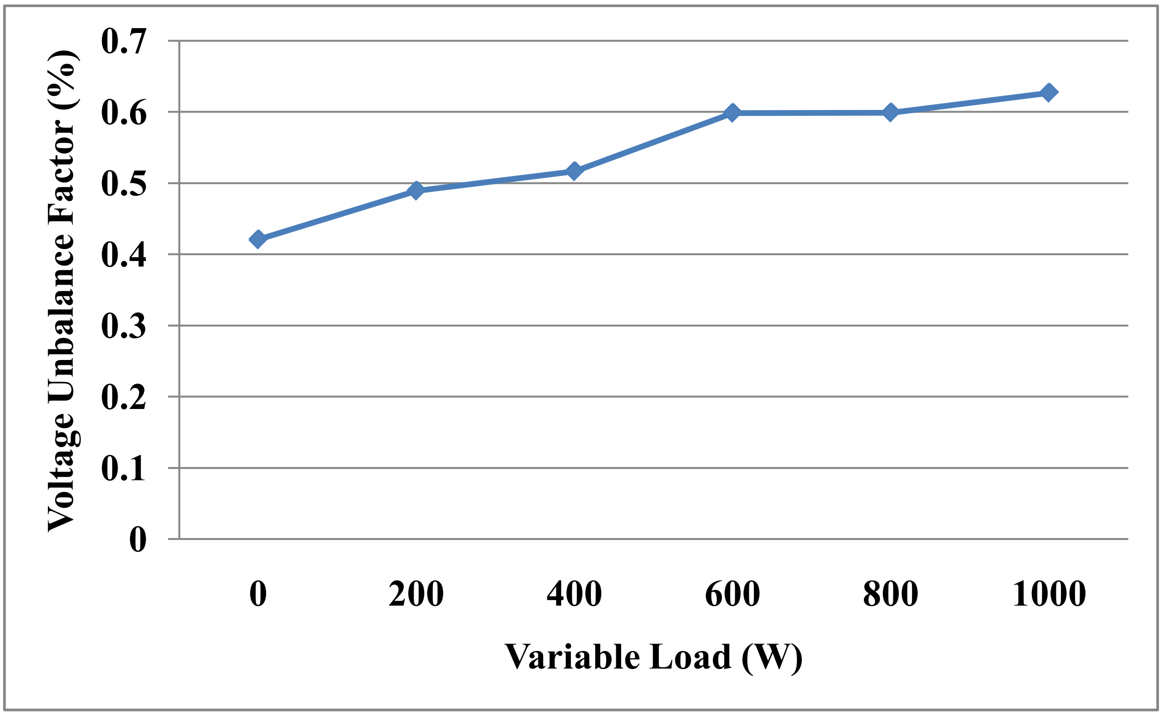


Figure 4.3.42: VUF% of unbalance load with distributed generation of 1.2KW connected

The trend of the graph in Figure 4.3.42 is also the same compare to the simulation result. When compare this graph to the graph in figure 4.3.32, the voltage unbalance factor in the section is much more lower, only 0.4% to 0.65%. This prove that the DG power injected to the netwrok must be used by the utility customer to reduce the effect of voltage unbalance cause by the high penetration of DG.

4.4 Voltage Unbalance with Distributed generation (DG) Connected and Network Resistance

In this section, when the DG is connected in Phase A, and network resistance is applied in between the network and the load. By this, the voltage drop due to the network resistance can be investigated. The voltage at point A and point B are measured as the following diagram.

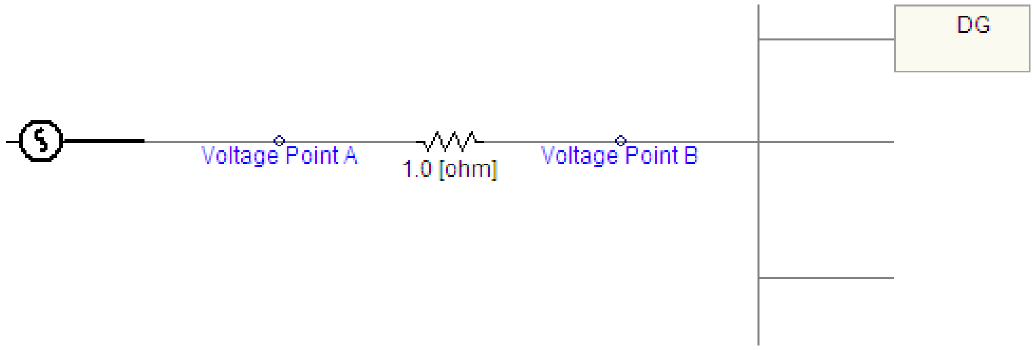


Figure 4.4.10: The single line diagram of the network with DG connected and network resistance.

4.4.1 [VL+DG 0 0] with 1 ohm network resistance

In this section we injected DG power of 1.2KW to the Phase A, zero loads at Phase B and Phase C. The network resistance is set to 1Ω.

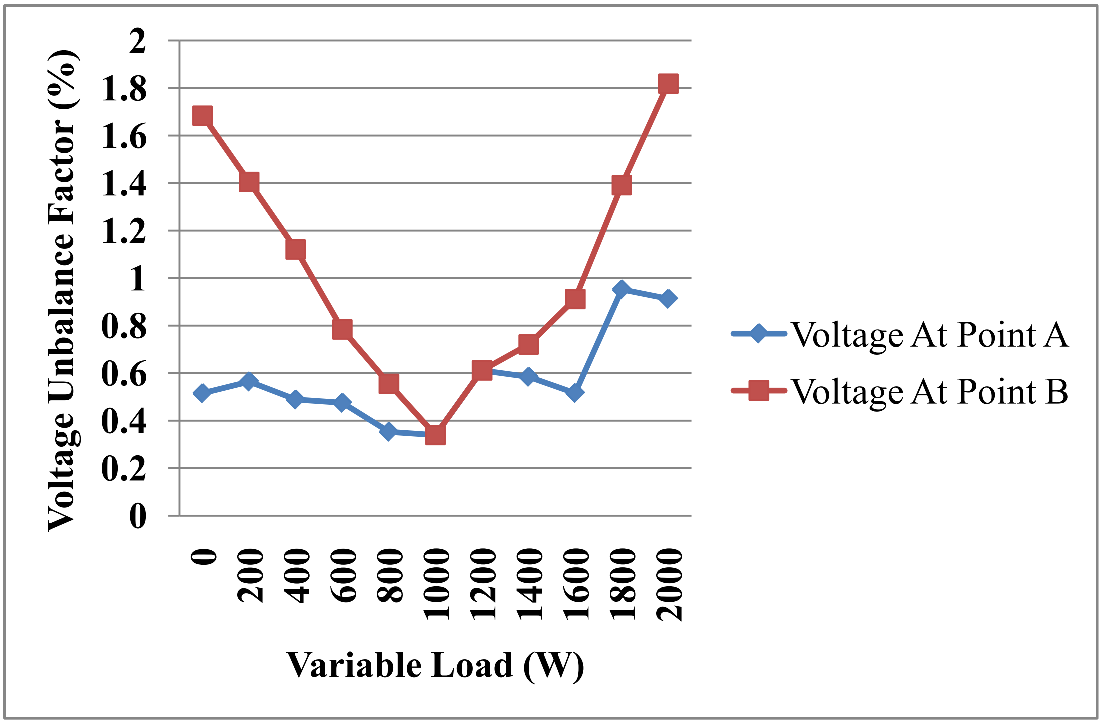


Figure 4.4.11 : The voltage unbalance factor when different load is applied

For the Figure 4.4.11, the voltage unbalance decreasing from 1.7% to 0.4% when load increase from 0 W to 1000W. After this the voltage unbalance factor increase from 0.4 % to 1.8 % when the load increase from 1000W ro 2000W. The voltage unbalance deceasing before 1000W because the injected DG power causing the rising of the voltage, while the loading reduce the voltage level. By this, the voltage variation reduce as the load increase, so voltage unbalance decrease. The voltage unbalance increase after this.The output power from the DG finish consumed by the load, we can say that it reached a balance point, at which the injected power fully used by the load. Any futher increase in the load will cause the voltage to drop and increase the voltage variation between Phase A and other two phase, so increase the voltage unbalance.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this chapter, the overall conclusion of this project will be made. The objective, challenges, system design, voltage unbalance study, data collected and result will be summarizing in this chapter. In addition, some recommendation to improve this project will also be discuss.

With increasing environmental concerns and rising oil process, governments across the world have been forced to look for alternative sources of the energy which are sustainable and environmentally friendly. The implementation of the Small Renewable Energy Program promotes small power plants, utilizing renewable energy; to sell electricity to the state owns electricity utility. This program applies to all type of renewable energy, including biomass, biogas, municipal waste, solar, mini-hydro and wind. The penetration of the distributed generation in the distribution network will increase and thus, proper planning and control needed to ensure continuity of the electricity supply. Existing protection scheme may need to improve in order to support the network that is no radial in nature, high penetration of distributed generation, multiple sources and so on.

The distributed generation using in this project is Photovoltaic inverter connected the 12 V batteries in the batteries bank. The power inverter convert the DC current to the AC power before injected the power into the distribution network. The network is protected by the overcurrent, undervoltage and also overvoltage by the relay and existing circuit breaker.

In order to control the various loads demand in the network for research purpose, a load bank is built. The load bank consists of 5 pieces of 288ohm resistor per phase that can consume up to 1000W of power. The voltage unbalance with various load condition and fixed distributed generation output are study experimentally. Besides that, the voltage unbalance with various load condition and various level of distributed generation also study by simulation in the PSCAD. The influences of network resistance to the voltage unbalance factor also study experimentally.

In conclusion, the voltage unbalance in the network affect by various load condition. The minimal voltage unbalance occurs when the phase injected with the DG power is consumed by the load in that phase. The injected DG power will cause the voltage rises to the higher level thus increase the voltage unbalance. The network resistance also increases the voltage unbalance factor when DG injected into the network. In other words, if the DG is connected for a long transmission lines, the voltage unbalance problem will be more significant.

5.2 Recommendations

There are many other issues can cause the existing protection scheme do not work probably beside voltage unbalance. In order to design the suitable protection scheme for future network, the issues of connecting the DG into the existing network need to be justified.

The voltage unbalance already exists in the three phase network due to the various loading demand. So the actual voltage unbalance causing by the DG connected into the network only can be obtained if the particular feeder only use for research in the lab, without other loading.

The load bank consists of resistive load only. But in the actual network, inductive and capacitive load also appear. So we can improve the load bank by include the capacitive and inductive load. By this, the data and result will be more accurate and reliable.

Lastly, a suitable fast charging device can be included in the battery bank. The charger will automatically stop charging when the battery is fully charged. By this, the batteries are always being ready for experiment.

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