“I hereby declare that I have read through this report entitle “Load Shedding Scheme for Radial Distribution System” and found that it has comply the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)”

Signature	: …………………………….
Supervisor’s Name	: …………………………….
Date	: …………………………….

LOAD SHEDDING SCHEME FOR RADIAL DISTRIBUTION SYSTEM

ONG BENG TAI

A report submitted in partial fulfillment of the requirements for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

MAY 2017

I declare that this report entitle “Load Shedding Scheme for Radial Distribution System” is the result of my own research except as cited in references. This report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature	: …………………………….
Name	: …………………………….
Date	: …………………………….

Specially dedicated to

My beloved father and mother,

To my family and friends

Thanks for all the encouragement and support

ACKNOWLEDGEMENT

First and foremost, I would like to express my greatest gratitude to my respected supervisor, Dr Aziah Binti Khamis for her humble guidance, encouragement, patient, enthusiasm, invaluable support and motivation throughout the whole completion of this project. This project would not be succeeded without her continuous support and precious time.

Secondly, I would like to drop my sincere appreciation to thank all my friends who have been recognized for their continual support and encouragement. My sincere appreciation also extends to my entire course mates and other who have provided assistance at various occasions. Their views and supports are useful indeed.

My appreciation also goes to my family who has been so tolerant and supports me. Thanks for their guidance, encouragement, advice and emotional supports that they had given to me along my way to prepare this project. I would like to express my heartiest appreciation to my parents and family. I had learnt a lot, not just theoretically but also practically for the entire project.

Last but not least, I would like to express my heartiest appreciation to my supervisor, parents, and friends, who are always there when it matters most. They taught me all the knowledge and I have gained in completion of this project. The knowledge and guidance that I have acquired from them are very priceless and useful in this project and my future life. Thank you so much.

ABSTRACT

In general, the growth of electricity demand and nature interruption of power system network may cause the failure of grid system and lead to power shortage. Several technical issues should be resolved when the power system network integrated with dispersed generation (DG) is disconnects from external grid and form an islanded system. During power system experiences an islanding state, load-generation mismatch and voltage instability may lead to the system collapse. One of the most effective solution to maintain the system stability is load shedding scheme. The aim of this study is to develop an optimal load shedding scheme in order to maintain system stability and minimize amount of loads to shed when the power system network experiences unintentional islanding. In order to handle this optimization issue, a constrain of multi-objective function that consider linear static Voltage Stability Margin (VSM) and amount of load (active and reactive) curtailment was formulated. The Backtracking Search Algorithm (BSA) was proposed in this study as an optimization tool for determining optimum mount of load curtailment based on proposed objective function. Besides that, the load shedding scheme also involved with load priority case. The performance of proposed load shedding scheme was evaluated and conducted based on IEEE 33-bus radial distribution system integrated with four units DG using MATLAB® software. The performance of power mismatch is analyzed based on daily load demand and power generation. After using optimization process based on BSA, the power mismatch of active and reactive load was curtailed from 33-bus system without cutting substantial loads in the system. Moreover, the voltage profile for each buses are improved and complies with IEEE Standard 18-2002. The obtained findings proved that the proposed load shedding scheme based BSA is more effective in obtaining amount of optimal of loads to be shed without disconnects substantial load in islanding condition compared to optimization technique of Genetic Algorithm (GA).

ABSTRAK

Secara umum, pertumbuhan permintaan elektrik dan gangguan semula jadi terhadap rangkaian pengagihan akan mengakibatkan kegagalan grid utama berfungsi dan gangguan bekalan elektrik. Beberapa isu teknikal perlu diselesaikan apabila rangkaian pengagihan yang berhubung dengan penjana teragih (PT) diputuskan dari grid utama dan membentuk sistem kepulauan. Apabila rangkaian pengagihan mengalami situasi kepulauan, ketidaksepadanan generasi-beban dan ketidakstabilan voltan akan mengakibatkan ketidakseimbangan dalam sistem. Oleh yang demikian, cara penyelesaian yang terbaik adalah penyisihan beberapa beban tertentu dengan menggunakan skim penyisihan beban optimum. Tujuan kajian ini dijalankan adalah untuk memperkenalkan skim penyisihan beban optimum untuk mengekalkan kestabilan sistem dan mengurangkan kadar beban yang disisihkan apabila rangkaian pengagihan mengalami situasi kepulauan. Dalam usaha untuk mengendalikan skim pengoptimuman ini, fungsi pelbagai objektif dengan mempertimbangkan Kestabilan Jidar Voltan statik (KJV) dan jumlah beban (aktif and reaktif) yang perlu disisihkan telah digunakan. Pengenalan Algoritma Carian Jejak Balik (ACJB) dalam proses pengoptimuman adalah untuk mengenalpasti jumlah beban yang perlu digugurkan secara optimum. Selain itu, skim peyisihan beban ini juga terlibat dengan kes keutamaan beban. Prestasi pengoptimuman bagi skim tapisan beban ini dinilai melalui beberapa kepulauan sistem kuasa yang telah diwujubkan berdasarkan sistem agihan jejari IEEE 33 bas dengan 4 unit PT menggunakan perisian MATLAB. Analisis prestasi ketidaksepadanan kuasa telah dijalankan berdasarkan permintaan beban harian and generasi. Setelah proses pengoptimuman ACJB, ketidaksepadanan aktif dan reaktif beban telah disisihkan dari 33 bas tanpa mengugurkan beban secara besaran dari sistem. Tambahan pula, profil voltan untuk setiap bus telah diperbaiki dan memenuhi Standard IEEE 18-2002. Hasil kajian bagi skim pengotimuman ini menunjukkan bahawa cadangan kaedah ACJB adalah lebih berkesan dalam menentukan jumlah optimum beban yang perlu disisihkan dalam sistem kepulauan berbanding dengan skim pengoptimiman Algoritma Genetik (AG).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

DG	-	Distribution Generation
VSM	-	Voltage Stability Margin
ST	-	Suruhanjaya Tenaga
PSO	-	Particle Swarm Optimization
FLLSC	-	Fuzzy Logic Load Shedding Controller
ANN	-	Artificial Neutral Network
GA	-	Genetic Algorithm
AHP	-	Analytic Hierarchy Process
QIEP	-	Quantum-Inspired Evolutionary Programming
BSA	-	Backtracking Search Optimization
PCC	-	Point of Common Coupling
PJD	-	Phase Jump Detection
CSI	-	Current Source Inverter
VSI	-	Voltage Source Inverter
PLL	-	Phase Locked Loop
UVLS	-	Under Voltage Load Shedding
UFLS	-	Under Frequency Load Shedding

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Figure 1.1 shows the maximum demand of Peninsular Malaysia which provided from Suruhanjaya Tenaga (ST) in Malaysia Energy Statistic Handbook 2015 [1]. According to the line chart, the demand of electric power in Peninsular Malaysia was increasing from year 2011 to 2014 with increases of 2.23% from year 2011 to 2012, followed by 4.65% from year 2012 to 2013 and 2.05% from year 2013 to 2014. The maximum demand in Peninsular Malaysia was increased 9.21% in past 4 years. The increasing of power demand in recent year state that the power utilities cannot longer fully feed them from generation system. Therefore, the dispersed generation (DG) is introduced in order to overcome the increasing of power demand.

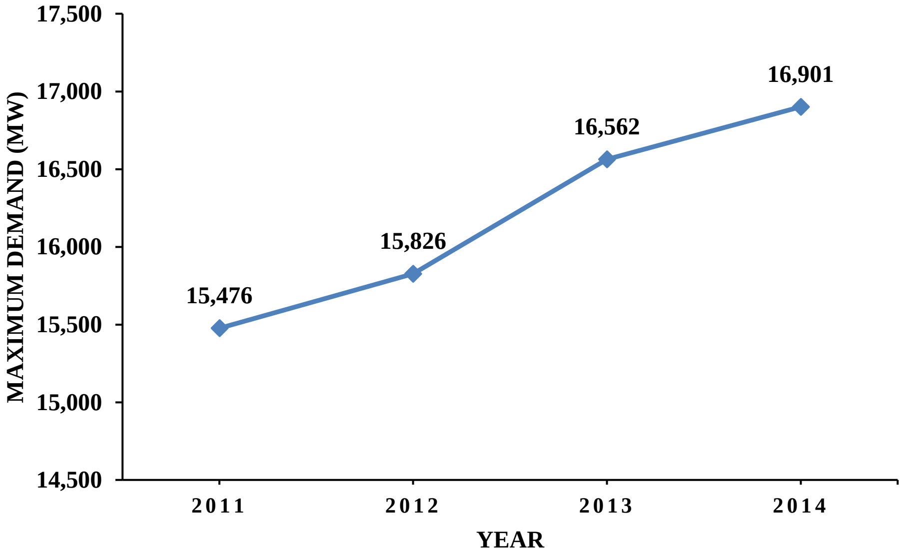


Figure 1.1: Maximum demand in Peninsular Malaysia [1]

Generally, DG used to supply power to consumer in generation and transmission capacities in order to meet the load demand requirements. The rapid growth of DG into distribution network based on renewable energy such as solar, hydro and biomass contribute to the increased of generation capacity. Through the implementation of islanding, DG is used to improve the reliability of supply and stability in power system [2].

Islanding in power system can be defined as several parts of distribution system is disconnected from main supply or grid collapsing condition and the loads is fully supplied from DG. The loss of main supply and fault occurs in distribution system is main factor of the islanding condition in power system. During system experiences an unintentional islanding state, a sudden change in generation over loads and voltage instability may lead to the system collapse [2]. The load and generation trapped within it at the time of islanding is the essential property of sustained island and the necessary application to overcome the islanding condition is the load shedding [3].

Load shedding in power system analysis can be defined as a number of load that immediately be removed from a power system to maintain the system stability and able to provide enough power to critical load [4]. Critical load includes hospitals, water pump station and infrastructures that correlative to basic human needs. The load to be shed is response to disturbance that results in generation deficiency condition and the most common disturbances that cause of this condition are loss of generation, switching error, natural cause (lighting strike) and fault [5].

In a large interconnected power system, the power system will be suddenly disconnected and form an islanding condition under certain possibility. Some of island will face a large number of power deficit, which may cause system collapse and voltage instability [6]. The impact of sudden power outage of generation due to certain abnormal fault such as generator fault or line tripping will disturb the balance between generation and loads which may cause the system collapse [7].

Notifying that amount of power outage or blackout have happened recently around the world, voltage stability become major problem in power system due to intensive use of transmission networks. Voltage stability is measured with its capability of power system to maintain bus voltages under normal (without disturbance) and abnormal (with disturbance) operating conditions [8]. Voltage stability in power system is one of main factor that dominate the maximum permissible loading of transmission or distribution system. Voltage stability also known as load stability because the load playing an important role in voltage stability analysis [9].

Power system instability can be measured in the form of angle, frequency and voltage instability. Voltage instability consequent from inability of combined transmission and generation system to transmit the power required by active and reactive loads. Load response to voltage changes is the dynamic phenomenon of voltage instability. Therefore, load shedding is an effective solution to overcome voltage instability in power system, especially when the system withstand an initial voltage drop that is too difficult to be corrected by generator voltages [10].

1.2 Problem Statement

Every year power outage happen in Malaysia was reported due to several reasons such as natural causes (weather related), equipment's failure, overload, construction accidents, maintenance from utilities and occasional human error. Figure 1.2 shows the electricity supply interruption in Peninsular Malaysia as reported in Malaysia Energy Statistic Handbook 2015 [1]. The line chart shows the scheduled and unscheduled electricity supply interruptions from year 2011 to 2014. For past four years, the average unscheduled interruption is 9.63 per 1000 consumers while scheduled interruption is 0.14 per 1000 consumers. For unscheduled interruptions, the statistic shows that decrement of 1.15, 0.68 and 2.06 in year 2012 ,2013 and 2014 compared to year 2011. While for scheduled interruption, there is decrement of 0.08 in year 2012, 0.1 in year 2013, and 0.02 in year 2014 compared to year 2011. The statistic shows that the number of unscheduled interruptions is higher than scheduled interruptions in past 4 years.

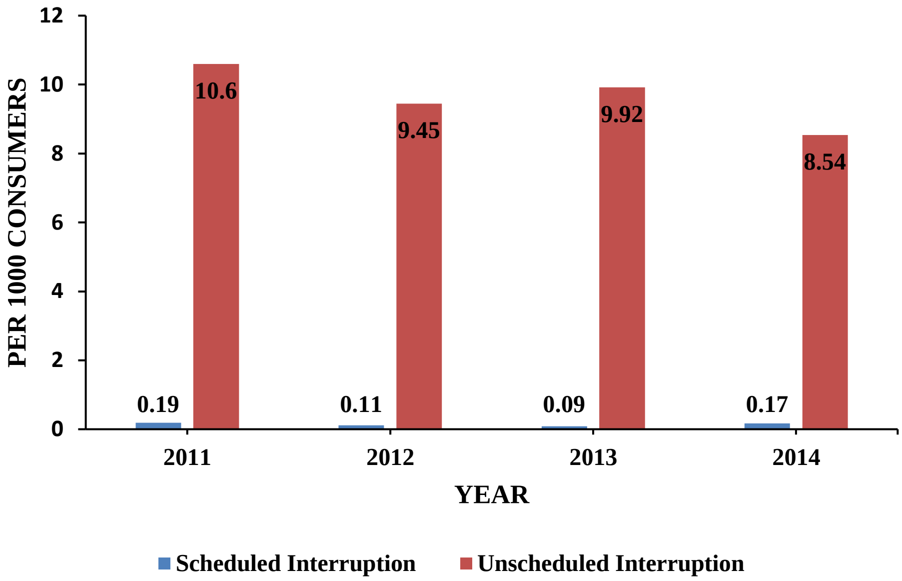


Figure 1.2: Electricity supply interruption in Peninsular Malaysia [1]

When power outage occurs in a DG integrated distribution system, some technical issue should resolve by electricity supply industry if grid system disconnected and form an islanding condition. During islanding condition, several loads should be rejected through load shedding scheme in order to maintain stability of islanded system. Different type of loads such as ZIP loads (constant resistance load, constant current load, constant power load) and induction motor has different active and reactive power. These active and reactive loads will may lead the system voltage collapse due to lack of active and reactive power supply. During islanding condition, induction motor may lead to critical oscillation and voltage collapse due to insufficient of reactive power supply while ZIP load will tend to cause the dropping of frequency due to lacking of active power supply [11]. Therefore, optimal load shedding scheme on active and reactive load is needed during islanding condition to prevent system collapse.

Generally, several types of load shedding scheme of previous research have been proposed. These techniques include the implantation of particle swarm optimization (PSO), Fuzzy Logic Load Shedding Controller (FLLSC), artificial neutral network (ANN), genetic algorithm (GA), and Quantum-Inspired Evolutionary Programming (QIEP). These techniques are used to determine the optimal amount of load to shed. However, the implementation of GA and PSO techniques proposed in previous paper have limitation of computation time and pre-mature convergence which optimization of loads will converge too early that may cause non-optimal load shedding [12], [13]. Besides that, FLLSC technique which used to stabilize the system frequency required a proper procedure and apply correctly in order to obtain the correct result [14].

1.3 Objectives

1. To develop an optimal load shedding scheme after system experiences unintentional islanding condition.
2. To maintain the voltage stability due to load-generation mismatch in islanding condition.
3. To minimize the amount of active and reactive load to shed without disconnects substantial load in islanding condition.

1.4 Scope of Work

The main purpose of this thesis is the development of optimal load shedding scheme for radial distribution system after the system experiences an unintentional islanding condition. A systematic approach of optimal load shedding scheme is developed to investigate the priority based on the impact of power system state. Therefore, this thesis will focus on the analysis of power outage in a DG integrated distribution system. Voltage stability margin (VSM) is proposed in order to evaluate critical active and reactive loads of radial distribution system in an islanded condition by applying system voltage profile. An optimization technique known as backtracking search optimization algorithm (BSA) with higher feasibility, solution quality and convergence speed is used by comparing the performance with genetic algorithm (GA) technique. The optimization technique is applied to IEEE 33 bus radial distribution system with four DGs units. The MATPOWER Newton-Raphson-based power flow algorithm in MATLAB® is used to evaluate the formulated multi-objective function that considered VSM and amount of load curtailment.

1.5 Summary

This report consists of five chapters. **Chapter 1** highlights the research background, problem statement, objectives and scope for this project. **Chapter 2** describes the literature review of this project. This chapter will highlight all the theories and overviews of load shedding scheme in power system. This section also included with previous research studies. **Chapter 3** explains the procedure and approach applied for this project. It covers the methodology of VSM, BSA and GA that have been applied as technique for load shedding scheme. **Chapter 4** describes the results, data analysis and discussion that obtained from experimental data. The obtained result shows the VSM value of each feeder in 33-bus system. The percentage of power mismatch between load demand and power generation are presented in this section, followed by amount of optimal load needed to curtailed during islanding. The findings of convergence characteristic, load demand after optimization and voltage profile of 33-bus system are presented in this section. Lastly, **Chapter 5** presents the conclusion and outcomes from the study that have been implemented by MATLAB software.

CHAPTER 2

LITERATURE REVIEW

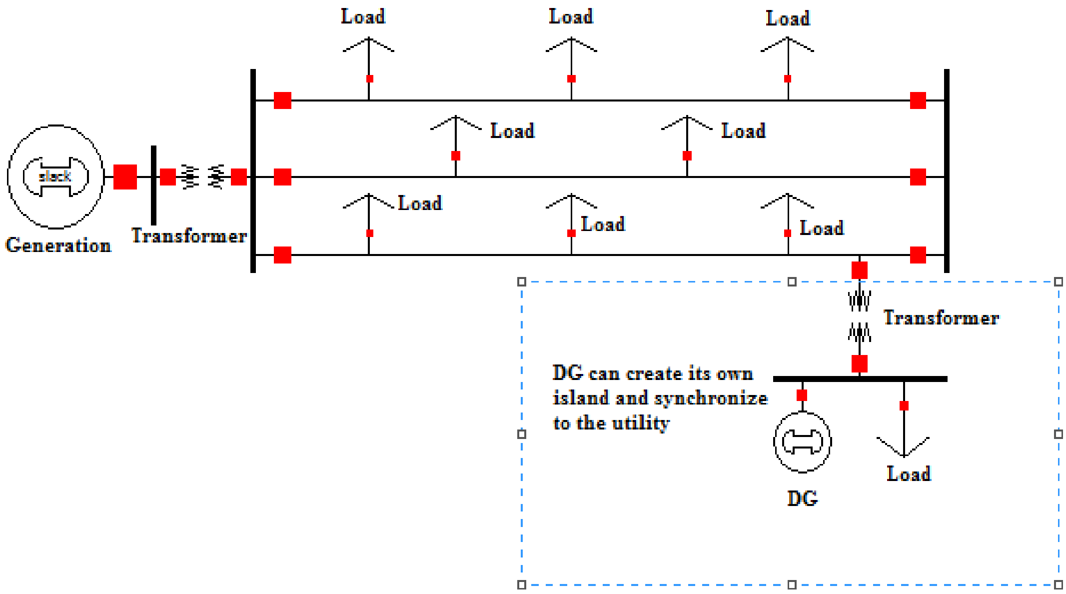
2.1 Dispersed Generation

Distribution generation in power system, also known as dispersed generation (DG), which generate a small amount of power being used to meet the increasing of power demand in distribution network. Generally, conventional power plant resources such as fossil-fuel, nuclear, thermal and hydro are known as centralized generation (large scale generation). In contrast, DG resources are decentralized, which installed nearby the load centers or close to customer. DG commonly uses renewable resources for power generation such as solar, wind, photovoltaic and biomass. The integration of DG with power plant in distribution network diverse several advantages. It can reduce the consumption of reactive power in power network which may improve the system stability in term of voltage stability. Besides that, integration of DG in distribution network can reduce the active power losses and reactive power losses. In power system network, active power losses are caused by resistance of lines while reactive power losses occur due to reactive loads installed. A proper allocation of DG in distribution network can reduce these active power and reactive power losses [15]. At present, power system network with DG operated are in passive way that only generate active power and constant reactive power Q, which normally set to Q=0. Thus, it cannot involve in power factor correction and voltage control [16]. However, reactive power compensation which using switched or shunt capacitor, playing an important role for future power system network with DG penetration. Integrating of shunt capacitor with DG in distribution network may help reducing of power losses, improving power factor and maintain high voltage quality [17]. Several technologies have been adopted to supply reactive power to DG which is small generator, capacitor banks, synchronous condensers, full cells and micro turbines [18].

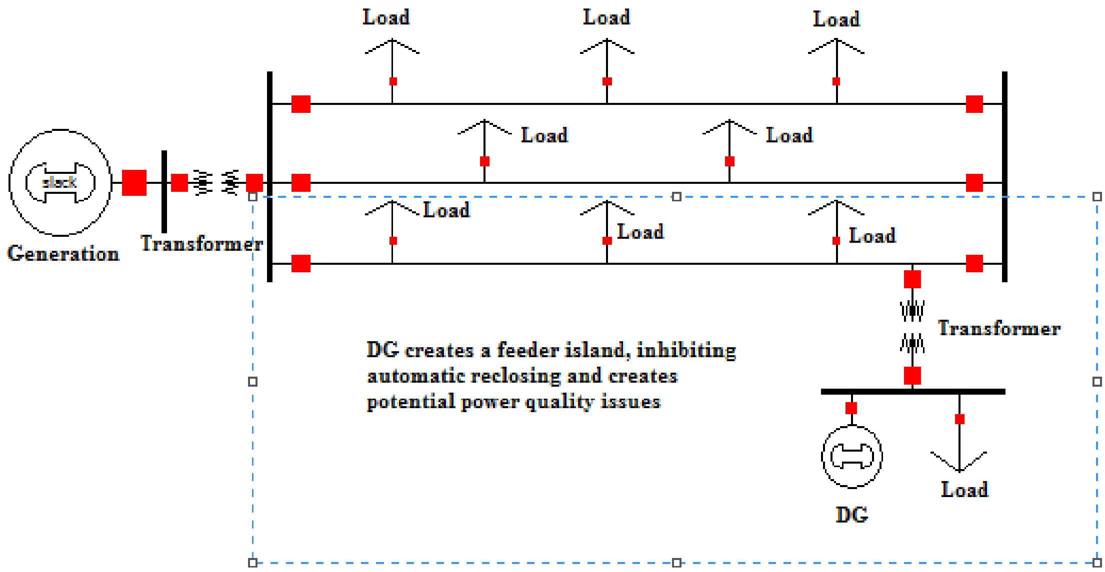
2.2 Islanding

Islanding condition taking place when the distribution network is fully energized by DG connected after the distribution system turns to electrically isolated from power supply. Generally, the distribution system doesn't consume any electrical power during islanding condition due to any fault occur in transmission line but with appearance of DG in distribution network, this presumption in no longer valid [19]. Currently, DG is required to be disconnected once the distribution system is islanded. Based on IEEE 929-1988 standard, DG required to be disconnected once the system is islanded, while IEEE 1547-2003 requires the DG be disconnected once islanding is detected at maximum delay of 2 seconds. The Danish code avoided the operation of distribution network up to 25MW in islanded condition [19], [20].

Theoretically, DG cannot be islanded with utility loads external to DG zone when it separates from power system, which may create the restoration problem and power quality problem for utility loads [21]. Reclosing the restoration of network is much difficult and synchronizing equipment is required. At the same time, DG also incapable to maintain voltage, frequency and harmonic in utility loads external to DG zone. However, DGs are suitable islanded with local loads at DG zone where the load is consumed enough of power generation from DG as shown in Figure 2.1(a) [22]. Meanwhile, Figure2.1(b) shows the not allowed islanding operation of DG with utility system.



(a)



(b)

Figure 2.1: (a) Allowed DG islanding operation, (b) Not allowed DG islanding operation

Islanding in power system can be classified into intentional islanding and unintentional islanding. Intentional islanding can be defined as scheduled islanding which caused by opening the protective breaker located at the point of common coupling (PCC). This islanding will create the power "island" when power system experiences disturbances or faults. Intentional islanding can prevent the loads in power network being damaged due to variation of voltage or frequency in PCC [23]. In contrast, unintentional islanding can be defined as unplanned islanding. This unplanned islanding will cause several problems to power system network in term of power quality, voltage and frequency stability. Thus, unintentional islanding of DG must be avoided to prevent unnecessary loss of generation especially for the loads are sensitive to high quality power supply. Besides that, the variation of voltage and frequency which beyond limits specified by state regulation can cause the damage of consumer's equipment [23], [24].

Generally, there are three types of islanding detection techniques which are passive techniques, active techniques and hybrid techniques. In passive techniques, under/over voltage and under/over frequency is the oldest method adopted. This method placing the under/over voltage and under/over frequency protective relay for several types of abnormal condition. During islanding, the relay must cut off the operation of DG when utility is isolated. However, the disadvantages of this method is complicated process of setting for these relays, wide non detection zone and slow detection of abnormal condition [25].

The other method that involving passive technique is Phase Jump Detection (PJD). For current source inverter (CSI), it controlling the phase different between output current of inverter and voltages at PCC. While for voltage source inverter (VSI), it measuring the phase different between output voltage of inverter and current at PCC. Thus, an analogue or digital phase locked loop (PLL) is used for synchronize the waveform of inverter output current and voltage at PCC. This method is easy to implement but will give some nuisance tripping problem due to setting of threshold is complicated [25].

In active technique, it involves feedback technique or control mechanism that used to investigate the changes in frequency or voltage in PCC. Several parameters in PCC is applied with disturbance noise so that the islanding condition can be detected. One of the