LOAD SHEDDING SCHEME FOR RADIAL DISTRIBUTION SYSTEM

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

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“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 : ……………………………

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

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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).

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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

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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.

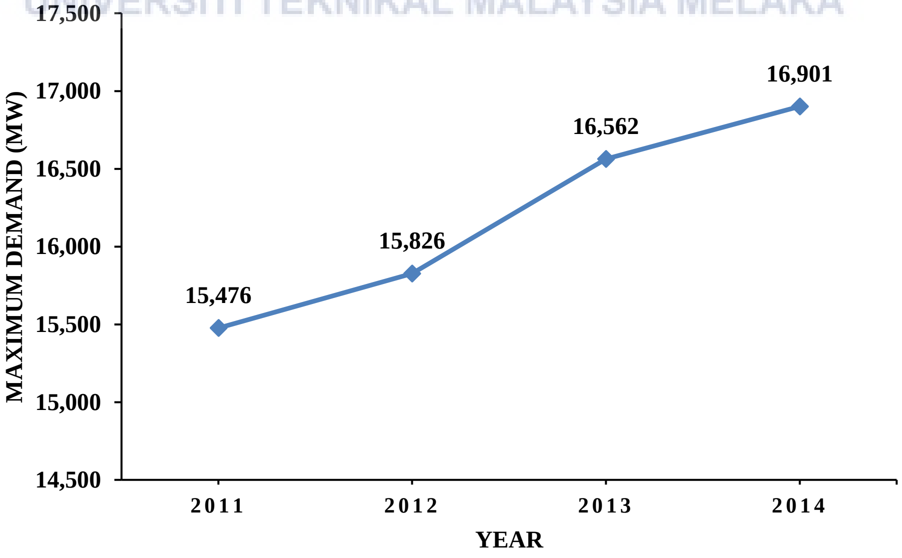


Figure 1.1: Maximum demand in Peninsular Malaysia [1]

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.

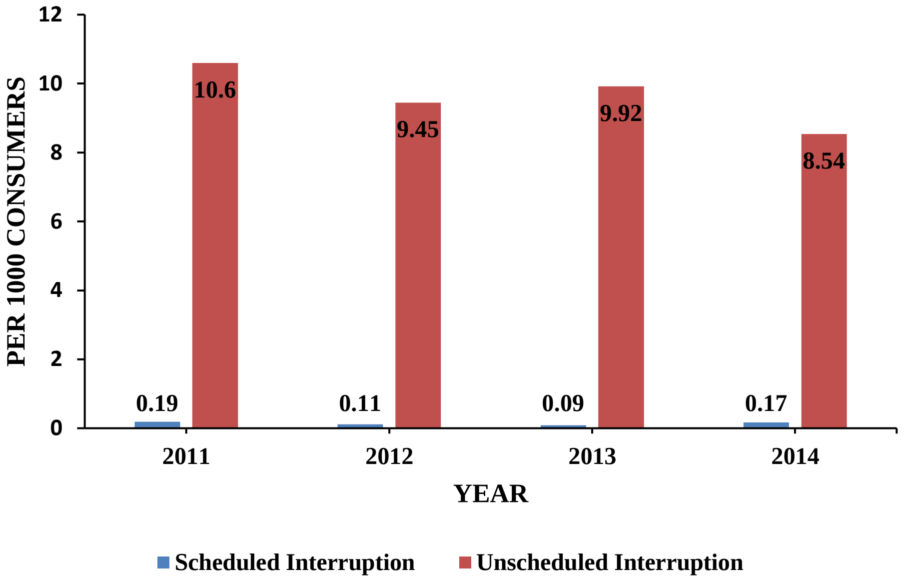


Figure 1.2: Electricity supply interruption in Peninsular Malaysia [1]

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

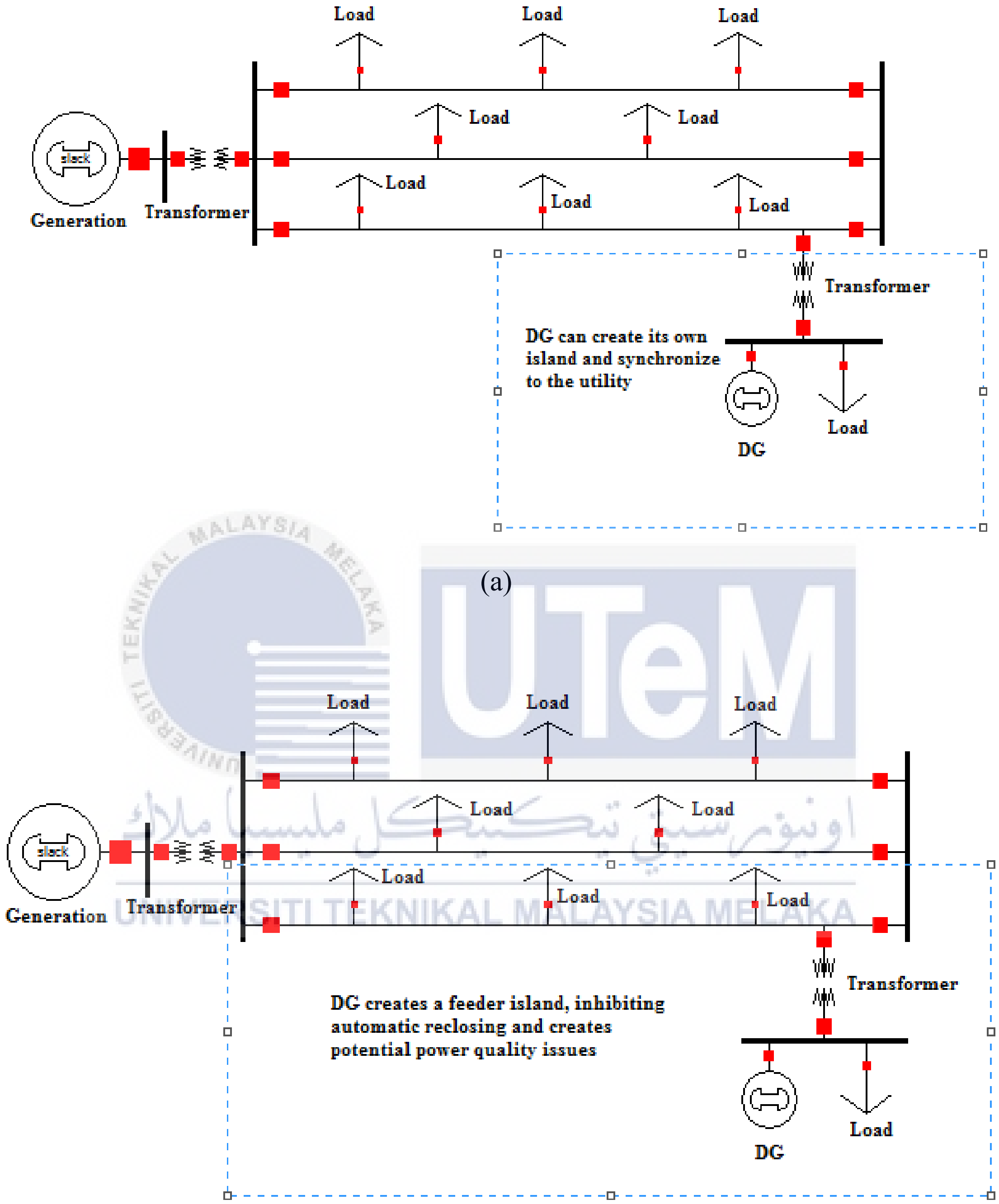
2.1 Dispersed Generation

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 active technique is detection of impedance at specific frequency which is more focuses in harmonic detection method. In presence of utility in power system, the harmonic current will flow into grid system if the load impedance is lower than utility impedance. Thus, no abnormal voltage is detected in network system. During absence of utility, harmonic current will flow along the loads which will cause the load to generate harmonic voltage. Thus, abnormal voltage is detected in network system. However, this method will lead to nuisance trip problem in multiplex inverter case [25].

Meanwhile, hybrid islanding detection technique involve the combination of active and passive techniques. The combination of active and passive technique is effectual even when the close mismatch occurs in between the DG power generation and power consumed by loads. In hybrid detection technique, active technique only will inject disturbances to system when islanding is detected by passive technique [26]. The first parameters are measured at PCC and compared with comparator. When imbalance measured PCC voltage is within threshold limits, disturbance signal is subjected to system to clarify more preciously the islanding condition [27]. It provides better performance in term of misclassification and detection time. The detection time of islanding faster than active and passive method based on IEEE 1547-2003 [28]. However, this technique may unsuccessful to detect islanding for perfect match of demand and generation in islanded system. Any subsequent change in power mismatch of islanded system may lead to change in voltage and islanding being detected [29].

Table 2.1 summarizes the comparison of islanding detection technique in power system.

Table 2.1: Comparison of islanding detection technique

Islanding Detection Technique	**Advantages**	**Limitation**
Passive	- Protection relay able to cut off the operation of DG when utility is isolated. - Easy to implement.	- Complicated process of setting for relays. - Wide non detection zone. - Slow detection of abnormal condition.
Active	- Involve feedback technique. - Improve harmonic distortion.	- Lead to nuisance trip problem in multiplex inverter case. - Poor power quality and system stability due to positive feedback.
Hybrid	- Power quality improved. - Better performance in misclassification and detection time. - Detection time faster than active and passive method based on IEEE 1547-2003.	- Longer detection time for small power mismatch.

2.3 Load Shedding

Noting that several power outages occurred recently around the world, voltage stability becoming important criteria in power system due to intensive use of transmission network. Voltage stability can be defined as the capability of system to maintain the acceptable bus voltage in normal and abnormal condition of power system. The performance of voltage stability can be improved by rescheduling the active and reactive power control variables. When power system is fully loaded and operates near to collapse point, active and reactive power control variable will be exhausted [8]. Voltage stability margin is the key to overcome voltage collapse in power system and stability margin can be considered for power system is 5% or 6% [30]. H. Omidi proposed a study of improving stability margin by application of shunt capacitors, active and reactive power management technique. The study was implemented into IEEE 30-bus system which contains of two shunt capacitors that can generate more reactive power. For management of active and reactive power injection, some generator requires more active and reactive power to improve voltage stability margin, while others require less to obtain desirable stability margin [30]. Besides that, the additional way to save the power system from being collapse is load shedding. Load shedding used to describe the deliberate switching off of electrical power supply to part of power system network, then to consumers. It is an important part of emergency management of all electrical power system network. Load shedding in power system network may cause loss of electric power to consumers, but it is possible to keep and maintain other equipment or devices which are more preference. Once the abnormal condition is solved, the power system network will operate in normal state [31]. Load shedding scheme used to shed some loads to keep system running at reduced capacity due to variation of frequency and voltage during islanding condition. If load shedding scheme is not applied, the large variation of frequency and voltage during islanding may lead power collapse due to imbalance between generation and load demand [32].

Generally, there are two types of automatic load shedding scheme which are under-voltage load shedding (UVLS) and under-frequency load shedding (UFLS). UVLS is designed to protect system where voltage collapse occurs and expected to lead blackout in power system. This scheme is used to avoid wide area voltage collapse when protection mechanism in power system network is exhausted. UVLS will operate by shedding selected loads when there is system disturbance or voltage drop below preselected level for specific time [33].

In contrast, UFLS is designed to rebalance load and generation within island when abnormal or fault occur in power system network [34]. The most common type of UFLS technique for under frequency control is load shedding through frequency relay. Through this technique, the under frequency relay will be triggered when system frequency drops below threshold. However, UFLS is ineffective in load shedding scheme when instability or voltage collapse occur during islanded [32], [34]. Moreover, UFLS unable to ensure system security and reliability which the loads are not accurately estimated before shed.

2.4 Optimal Load Shedding

Nowadays, the researchers are more focusing on the development of computational intelligence in load shedding scheme. Usually, the computational intelligent is utilized to identify energy planning under uncertainty condition, decision of location and sizing of reactive power sources, deciding dispatch scenarios, analysis combined active and reactive power dispatch, load shedding and optimization of cost [35]. Therefore, the intelligent computational load shedding scheme was proposed which includes Fuzzy Logic Load Shedding Controller (FLLSC), Particle Swarm Optimization (PSO), Artificial Neural Network (ANN), Genetic Algorithm (GA), Analytic Hierarchy Process (AHP) and Quantum-Inspired Evolutionary Programming (QIEP).

For instance, a qualitative study by J.A. Laghari described FLLSC as strategy to stabilize the system frequency by sheds optimum loads in islanded. At first, FLLSC investigates the type of load disturbance and estimate power imbalance. Then the detected signal will send to load shed controller module (LSCM) for shedding the estimated loads based to load priority. This proposed method can avoid the frequency drop and maintain system stability by shedding optimal load. At the same time, this technique may improve and increase the system frequency response [15]. However, A.A. Sallam reports that FLLSC technique must applied correctly and a proper procedure to ensure result obtained is correct [14].

Meanwhile, T.N. Le points out that the combining Fuzzy Analytical Hierarchy Process algorithm (Fuzzy-AHP) with fuzzy logic for load profile in order to draw out the most capable control strategy of load shedding during power outage. This method will determine the size of load nodes of power system and choose a strategy control method when power system operate in various load level condition. This proposed method was tested through the experiment of IEEE 37 bus system in PowerWorld simulation software. The implementation of this method shows that the recovery time of this method is longer but the system processing speed is increased and proved has lower capacity of load have been shed [36].

Analysis for an optimal load shedding technique with combination of modal analysis and PSO was carried out by S. Jalilzadeh. This technique used to minimize load to be shed as well as maintain the system stability and voltage profile. Modal analysis is a technique to analyse system voltage stability and measurement of system parameters such as active/reactive load in buses and active/reactive power of generator. Firstly, Modal analysis is applied to investigate system's weak point, then PSO based multi objective optimization problem used to calculate the voltage profile and stability margin [37]. However, Y. Wang declared that PSO has limitation in term of computation time which may lead to non-optimal load shedding. Further research should be carry on to speed up the execution time in large scale of power system [13]. Besides that, T. Kerdphol examines the extent the implementation of PSO to determine the optimal size of Battery Energy Storage System (BESS) with load shedding scheme during disconnection of power in microgrid. Optimal BESS is to smoothen the power system with solar energy and compensating power outage due disconnection of gird. This paper proved that the time taken to stabilize the magnitude of frequency deviation for BESS-PSO is shorter than BESS based analytic algorithm. Other than that, proposed algorithm improved the performance of load frequency control and provide more secure system stability from faulty state to normal state [38]. However, Z. Li point out, PSO-based wireless network mapping has been shown to result in which the computation time for this algorithm is a little bit longer thus requires more time complexity and resources [39].

A longitudinal study of ANN as optimal load shedding scheme by M. Moazzami reports that the scheme is more effective in load shedding due to the fact that the loads changes in network system are very fast. This high speed ANN scheme able to provide the optimal load shedding in transient states and maintain the frequency range in steady state condition. Thus, the system stability may be maintained when islanded after load shedding scheme is applied [40]. C. Hsu presents the design of load shedding scheme by using ANN model and transient stability analysis for a cogeneration system. Various algorithms are applied and interconnected for feed-forward neutral network with back-propagation for determine the most effective algorithm to derive ANN. Thus, ANN model can minimize load shedding to maintain system stability and avoid power outage in cogeneration system [41]. M.S Kang proposed an adaptive load shedding strategy by using ANN as optimal load shedding scheme in Taiwan Power Company (Taipower). This proposed method was demonstrated in Taiwan by comparing the simulation result with the present load-shedding scheme in Taipower. From proposed ANN methodology, it provides effective load shedding to maintain system stability and prevent excessive load shedding that will cause unnecessary power outage to consumers [42]. Besides that, A.M. Khafaga makes the case for ANN technique as a controller to control voltage instability problem in power system. Voltage stability can be controlled by applying load shedding scheme and estimate the reactive power required to control power sources in power system. From the study, controller based ANN is extremely powerful provided high quality results and high processing speed compared to other conventional methods. However, this algorithm requires longer processing time when come to large neutral network, which will increase the computation time [43].

GA is an optimal load shedding scheme which was first invented by John Holland at University of Michigan in 1975. In power system, GA provide the solution for reactive power dispatch and over current relay coordination [12]. M. Guichon states that GA is used to protect the electrical power equipment by calculating amount of load to be shed and disconnect it from network system [44]. A study by R. Yuan involved Standing Phase Angle (SPA) reduction based GA optimization in power system restoration. During system dispatch, SPA is a phenomenon when the voltages on both sizes of circuit breaker has constant phase angle difference. The GA optimization proposed used to minimize the adjustment of active power generation and load shedding. Thus, proposed paper claimed that the computation time for adjustment was shortened and then the power restoration process was faster [45].

M. Eghbal presented optimization technique of GA as application of metaheuristic methods to Reactive Power Planning (RPP) of power system under different conditions. RPP used to deal with economy and security by determining optimal combination of speed control for load shedding and new installation of reactive power load. Proposed paper claimed that GA leads a better solutions and minimize any divergence problem. However, GA technique leads to limitation of application in power system especially during real time operation due to excessive time consumption [46]. The study demonstrated GA is designed to determine the optimal load shedding and minimize amount of load to be shed, thus lower down the impact of disturbance in power system network. However, optimization technique of GA has limitation in pre-mature convergence, which may cause optimization of loads will converge too early and lead to non-optimal load shedding [29].

A systematic study of AHP as optimization technique to select the optimized route of large scale cargo transportation was presented by K. Jun-tao. The classification steps of AHP optimization algorithm in mathematical modelling are making hierarchical structure model, founding comparison judgment matrix, sorted under single criterion, and optimization. The proposed study proved that the AHP in decision making of optimal transit route selection for large scale cargo transportation is stable and effective [47]. In a follow-up study, Zhiping Ding found that load shedding based AHP able to maximize numeral system benefits and minimize the load curtailment. AHP is a multi-objective decision making to address complex decision which was first developed by Saaty. The proposed optimization technique is applied to a typical islanded power system which is shipboard power system (SPS). This algorithm is illustrated and tested on a 10-load zone of SPS and aims to optimize the number of CB switching actions during islanded. From the proposed result, this optimization tool able provide a quick restoration process after optimal load shedding. At the same time, it also able to provide priority load decision making which loads with higher active power and reactive power are tend to be shed first [48].

The study of structural behaviour of new technique determination of optimal load shedding namely QIEP based on multi-objective function was first carried out by Z.M. Yasin. QIEP is developed to investigate critical location of load and decide amount of load to be shed. This optimization technique is referring to the conception of quantum mechanics in Evolutionary Programming (EP) optimization algorithm. The implementation of Quantum-Inspired can improve the speed of computation time in EP optimization algorithm. This proposed technique able to detect amount of optimal under-voltage load shedding and maintain the voltage stability in distribution network during islanding [49]. Due to QIEP is a new load shedding scheme for distribution network, this algorithm is only tested on IEEE 33 bus, 69 bus and 141 bus. Further study should be developed by considering solution quality and convergence speed of optimization algorithm. Table 2.2 summarizes the advantages and disadvantages of computational intelligent technique for load shedding applications in power system.

Table 2.2: Comparison of optimization technique

Algorithms	Advantages	Limitation
Fuzzy Logic Load Shedding Controller (FLLSC)	-Higher processing speed. -May improve system response.	- Require longer time of recovery process and computation. -Require proper procedure.
Particle Swarm Optimization (PSO)	-Convergence speed is faster than GA. -Easy to implement.	-Limitation in term of computation time.
Artificial Neural Network (ANN),	-Higher processing speed and converge faster than PSO.	- Requires higher processing time for large neutral network.
Genetic Algorithm (GA)	-Faster computation time lead to restoration process faster.	-Pre-mature convergence. -Limitation in real time operation.
Analytic Hierarchy Process (AHP)	-Decision making consideration -Fast restoration time	-Required longer elapsed time for decision making
Quantum-Inspired Evolutionary Programming (QIEP)	-Speed of computation time is faster -Easy to implement.	-Require further study due to new technique of optimal load shedding

2.5 Backtracking Search Algorithm (BSA)

BSA optimization algorithm is a population-based evolutionary algorithm (EA), which designed as global minimizer and applied for solving complex mathematic numerical optimization problem. Basically, BSA uses selection, mutation and crossover as genetic operator to produce trial population. This optimization technique is a population based algorithm and can be classified into 5 functions: initialization, selection-I, mutation, crossover and selection-II [50].

The study by V. Gupta offers probably the most comprehensive empirical analysis of BSA optimization technique on various load models in design the optimal placement and sizing of DG in distributed system. The implementation of BSA is applied on IEEE-69 bus system thus the comparative study found that the optimal location and sizing of DGs are improved voltage profile of loads, reliability and line losses are reduced in distribution network [51].

Drawing on an extensive range of sources, A. Nathset set out the different ways in which the implementation of BSA as multi objective optimization technique into Automatic Generation Control (AGC) by determine the optimal frequency and power for interconnected power system in year 2005. The result of proposed technique is compared in term of computational time with PSO optimization technique based controller for a similar interconnected power system. The result obtained from BSA in AGC interconnected system have superior solution quality and better convergence property. Hence, the optimal control of frequency and power will maintain the system stability in interconnected power system [52].

K. Dasgupta presented BSA as optimization tool for Economic Load Dispatch (ELD) in power system operation and control. EDL in power system can define as allocation of power among generation by maintaining load demand and minimize the generating cost. This proposed study of BSA optimization technique is compared with PSO in fifteen and forty units of generating system. The test result proved that BSA optimization technique converge to optimal generating fuel cost and can be concluded that BSA has better convergence characteristic than PSO [53].

A recent study by Jamal Abd Ali involved BSA as optimization tools for adaptive Proportional-integral(PI) controller to improve indirect field oriented control (IFOC) of three-phase induction motor. The BSA based IFOC used to minimize mean absolute error in order to improve the performance of induction motor in term of speed response. The proposed result was verified with PSO based controller and clearly proved that BSA technique offer better of result quality in term of speed response (overshoot, steady-state error, settling time), damping capability and transient response for three-phase induction motor [54].

2.6 Conclusion

Literature review shows that there are many researches and developments on the optimal load shedding scheme. For past 3 years, researches have been proposed profound development based on load shedding scheme where the most applicable technique of load shedding schemes are using computational intelligence techniques such as FLLSC, PSO, ANN, GA, AHP and QIEP. However, some of these proposed techniques have limitation in term computation time, processing speed and pre-mature convergence. Therefore, an effective optimization algorithm named Backtracking Search Algorithm (BSA) is proposed as computational intelligence technique for load shedding during islanding in power system.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the development and implementation of proposed load shedding scheme for islanded power system network. **Section 3.2** describes the various tools and methods that have been used in this proposed paper which is voltage stability margin (VSM) and Backtracking Search Algorithm (BSA). VSM is used as an indicator or index to evaluate the closeness of power system to voltage collapse. Besides that, BSA is an optimization algorithm that have been applied in this study for optimal load shedding scheme. Both methodologies are detailed explained in this section. Meanwhile, **Section 3.3** presented the fitness function and operational constrains of system when optimization process. The applications of BSA and performance of evaluation GA in optimal load shedding scheme for this study are presented in this section.

3.2 Tools and Methods Used in Proposed Method

This section describes the overview of numerals tools and procedures that have been applied in implementation of load shedding scheme for islanded 33-bus radial distribution power system. Tools and methods that used to develop for load shedding scheme is VSM. **Section 3.2.1** describes about the main concept of VSM. The VSM is simulated using the MATPOWER Newton-Rapson based power flow algorithm in MATLAB software. Meanwhile, **Section 3.2.2** describes the development of proposed optimization load shedding scheme based on BSA.

3.2.1 Voltage Stability Margin (VSM)

For this study, VSM is used to determine the optimal load shedding scheme of IEEE-33 bus radial distribution system and estimate the distance to voltage collapse. VSM index was first proposed and implemented by M.H Haque which derived from typical radial feeder of a distribution system as shown in Figure 3.1. Consider that “Branch *i*” is connected between bus k and bus m. Provided the complex (magnitude and angle) of radial bus voltages, the loading index (L_i) of “Branch *i*” can be expressed as follows [55],

$$L_i = \left(2\frac{V_m}{V_k}cos\delta_{km} - 1\right)^2 \tag{3.1}$$

where V_m represents voltage at bus m, V_k represents voltage at bus k and δ_{km} represents angle between bus k and bus m.

Figure 3.1: Typical radial feeder of distribution system [55]

M.H Haque states that L_i index as shown in Equation (3.1) able to estimates the maximum load level of a single line section and capable to be utilized to represent the voltage stability at any loading level due to its linear relationship. Same to other voltage stability indexes, L_i also varies between unity (no load) and zero (voltage collapse point) [55]. By knowing the complex (magnitude and angle) of bus voltage profile, VSM of multiple feeder system can be expressed as the product of loading indices of all branches of the feeder as shown in Equation (3.2),

$$VSM = \prod_{i\varepsilon\Omega} L_i \tag{3.2}$$

where Ω is a set of branches constituting the feeder (from source bus p to end bus q).

Generally, a practical distribution system may consist of more than one feeder. The feeder that has lowers value VSM indicated that that feeder as the weakest feeder in system and lead to voltage collapse. Thus, voltage stability of a multiple feeder system (VSM_{sys}) can be expressed as [9],

$$VSM_{sys} = min(VSM_1, VSM_2, \dots \dots VSM_K) \tag{3.3}$$

where, k is the number of feeders in the system.

The procedures for implementing and understanding the VSM in proposed method are described as below:

i. Input system parameter such as line (resistance and reactance), nominal load (active and reactive loads) and bus data.
ii. Define the set of branches based on the test system model.
iii. Input load multiplier factor from zero to a critical value (where system collapse) into active and reactive loads of all feeders.
iv. Run MATPOWER Newton-Raphson-based power flow algorithm in MATLAB ® to obtain power losses and voltage deviation.
v. Evaluate VSM_{SYS} by using Equation (3.1), (3.2) and (3.3).
vi. Repeat the procedure (iii) to (iv) until system is defined as collapse (VSM_{SYS} drop monotonically).
vii. Record the data result and present result in graph.

Figure 3.2 illustrates a schematic of the procedure involved in analyzed and understanding the VSM scheme.

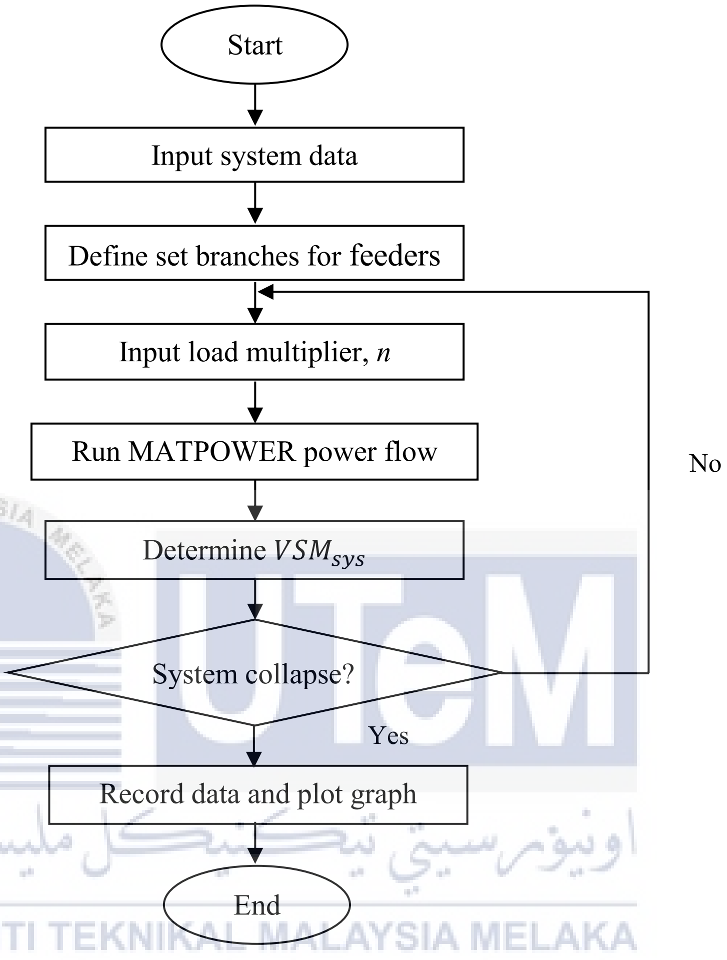


Figure 3.2: Process involved in VSM scheme

3.2.2 Backtracking Search Algorithm (BSA)

BSA is the new evolutionary algorithm (EA) and one of the most popular method for optimization technique. BSA is fit up with, solution quality, higher feasibility and convergence speed with other optimization techniques such as GA, PSO and ANN algorithm. Generally, BSA have five main processes namely initialization, selection-*I*, mutation, crossover, and selection-*II*. Basically, BSA uses three basic genetic operators (selections, mutation and crossover) to generate trial individuals. The development of BSA is based on random mutation strategy, which choose randomly the direction of individual from individuals of randomly chosen in previous generation as shown in Figure 3.3[56].

Firstly, BSA initiate the individual parameters to be optimized. The initialization process is same with other optimization technique which expressed as below:

$$P_{ij} \sim U(low_j, up_j) \tag{3.4}$$

where P_{ij} is the j^{th} individual element in the problem dimension D that fall in i^{th} position in a population dimension N, *U* represents the uniform distribution, while *up* and *low* represent the upper and lower boundaries.

The second process is selection-*I*. In this stage, the process is used to investigate the search direction based on historical population *oldP*. The initial *oldP* can be expressed as below:

$$oldP\_ij \sim U(low_j, up_j) \tag{3.5}$$

However, *oldP* will be re-updated using Equation (3.6) in each literation at the beginning through the if-then rule as shown below:

$$if\ a < b\ \ then\ \ oldP := P | a, b \sim U(0,1) \tag{3.6}$$

where *a* and *b* behave as a random number between 0 and 1, while := represent the update operation.

The update of *oldP* is then completed by randomly changing the order of individual in *oldP* as shown in Equation (3.7). The updated *oldP* will act as memory and stored in BSA as the guide to search direction.

$$oldP := permuting(oldP) \tag{3.7}$$

After *oldP* is updated, a trial population, T is subsequently generated through mutation and it is expressed as below:

$$Mutant = P + F(oldP - P) \tag{3.8}$$

where F is an algorithm-dependent parameter used to control the amplitude of the search direction. For this study, the standard Brownian walk is applied at the mutant stage, and it is given by *F=3. rand*, where *rand* represents the random value determined from a standard normal distribution.

Besides, the final form of T is produced at the crossover stage which involves two major steps. The primary step is to produce a binary integer-value matrix (*map*) of size NxD using the same if-then rule adopted for the update of *oldP*. At the following stage, the individuals of T are controlled by using corresponding individuals in P as expressed in Equation (3.9).

$$if \quad map_{i,j} = 1 \ then \quad T_{i,j} \coloneqq P_{i,j} \tag{3.9}$$

After that, the boundary condition of trial population, T is subsequently examined and revised by using the following expression

$$T_{ij} = rand.\left(up_j - low_j\right) + low_j \tag{3.10}$$

The final stage of BSA technique is selection-*II*. At this stage, the fitness of trial population T is evaluated and original population P is updated using greedy selection.

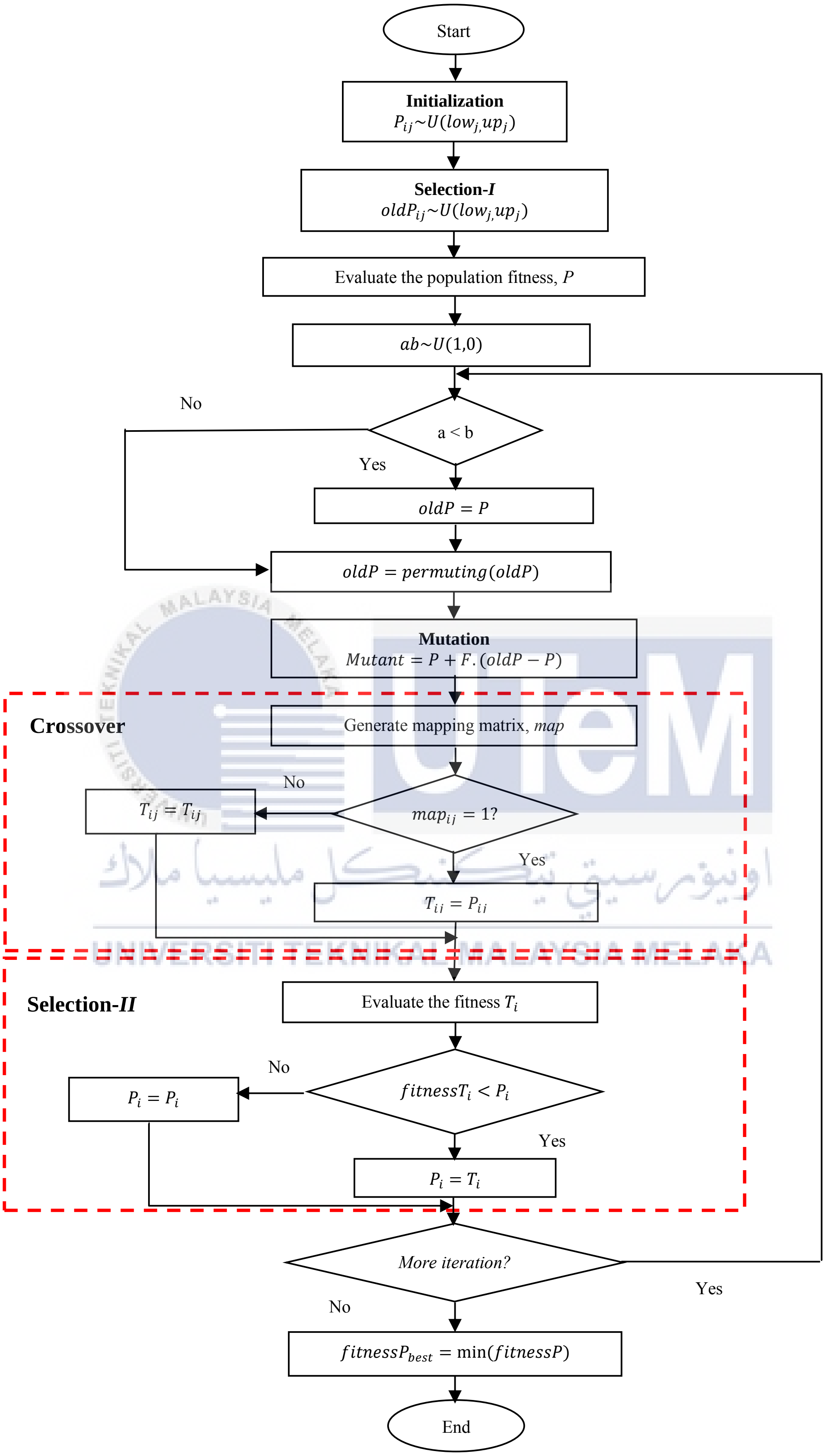


Figure 3.3: General flowchart of BSA [56]

3.3 Problem Formulation

A static voltage stability margin as multi-objective function is applied in obtaining the optimal load shedding in islanded system. **Section 3.3.1** and **Section 3.3.2** present the operational constrains and fitness functions, respectively of this optimization scheme. Other than that, the application of BSA and GA is summarized in S**ection 3.3.3** and **Section 3.3.4**, respectively.

3.3.1 Operation Constraints

The optimal load shedding scheme during islanded condition aims to maximize the voltage stability margin and voltage profile of power system network. Thus, the several constraints should be considered as below:

a) *Power flow balance:* The total power demands must be equal to total power generation during optimization:

$$\Sigma P_{gi} - \Sigma P_{di} - \Sigma P_{loss} = 0 \tag{3.11}$$

$$\Sigma Q_{gi} - \Sigma Q_{di} - \Sigma Q_{loss} = 0 \tag{3.12}$$

where P_{gi} and Q_{gi} are the generated active and reactive powers, respectively, and P_{di} and Q_{di} are the active and reactive power consumed by load, respectively. Meanwhile, P_{loss} and Q_{loss} are the active and reactive power losses in power system network, respectively.

b) *Power flow limit:* In steady-state operation, the apparent power S_l that transmitted through branch *l* should not more than the maximum thermal limit of apparent power S_{l-max} . These limits can be expressed in inequality function as below:

$$S_l \leq S_{l-\max} \tag{3.13}$$

c) *Bus voltage stability:* The bus voltage at each bus *i* must be maintained around tis normal value V_i , specified as $[V_{i-\min}, V_{i-max}]$ in order to avoid the voltage instability of power system network.

$$V_{i-\min} \leq V_i \leq V_{i-max} \tag{3.14}$$

where $V_{i-\min}$ is the minimum allowable voltage at bus i while $V_{i-\max}$ is the maximum allowable voltage at bus i. Generally, this deviation can reach up until 10% of its nominal voltage value.

d) *Load shed limit:* The allowable value of load that can be shed in system is limited and control by load priority limit. The minimum amount of load that should be remained and maintained for each load is stored in load priority list. Therefore, the load should be maintained throughout the process in obtaining the optimum load shedding scheme. These limit can be expressed in equality function as below:

$$S_{priority} \leq S_{l-i} \leq S_l \tag{3.15}$$

where S_{l-i} is the remaining load apparent power, while S_l is the load at bus i before load shedding scheme is applied, and $S_{priority}$ is the load priority limit.

e) *Voltage stability margin limit:* The VSM_{sys} must be maintained at certain permissible limit in order to maintain the voltage profile of system within the nominal value by using Equation (3.14). The limit of VSM_{sys} can be given as:

$$0 \leq VSM\_sys \leq 1 \tag{3.16}$$

f) *Power generator limit:* The generator active power P_{gen} and reactive power Q_{gen} must be maintained at its maximum value is order to supply all available power to fulfil the load requirement in power system network. The limit of P_{gen} can be given by:

$$P_{gen} = P_{max} \tag{3.17}$$

$$Q_{gen} = Q_{max} \tag{3.18}$$

3.3.2 Fitness Function

The objective of fitness function is to evaluate optimal load shedding scheme in islanded system. In order to obtain the best fitness function value, the constraints of problem must be fulfilled during evaluation. Therefore, the overall fitness function can be formulated as:

$$f = \max(VSM_{SYS} + P_{remaining\ load} + Q_{remaining\ load}) \tag{3.19}$$

where f is the fitness function, VSM_{sys} is the overall system voltage stability margin, $P_{remaining\ load}$ is the total remaining active power load and $Q_{remaining\ load}$ is the total remaining reactive power load.

In this study, BSA is applied to determine the optimal load shedding scheme in islanded power system network. Load shedding (L_{factor}) is utilized as the solution set in this optimization technique. In L_{factor} vector, it contains amount of load that permitted to be shed for each bus in islanded system, while dimension of L_{factor} vector is corresponding to the amount number of busses in islanded system under study. The variation of range for L_{factor} is between unity and zero while L_{factor} vector should be in the range of $[S_{priority}, S_l]$. This optimization processes are repeated for several times until the maximum f is obtained and selected as the best fitness value. The load shedding scheme that corresponds to maximum f obtained from repeated optimization processes will generate the optimal amount of remaining loads at particular hour.

The VSM_{sys} element in Equation (3.19) maintains the load shedding scheme, in which the constraints in Equation (3.14) and Equation (3.16) must be followed in order to prevent the system collapse in islanded power system network. Besides, this element is used to evaluate the critical load in islanded system by using the system voltage profile. Meanwhile, the $P_{remaining\ load}$ and $Q_{remaining\ load}$ elements in Equation (3.19) are utilized to make sure all the remaining load is maximum such that it has the lowest amount of load to be shed in the islanded system in order to fulfil the constraints Equation (3.17) and Equation (3.18).

3.3.3 Application of BSA for Optimal Load Shedding Scheme

The BSA is applied as an optimization tools with MATPOWER Newton-Raphson-based power flow algorithm in MATLAB® to determine the optimal load shedding scheme in islanded power system network as illustrated in Figure 3.4. The procedures for implementing the proposed optimal load shedding scheme are described as below:

i) Input system data such as line (resistance and reactance), load (active and reactive) and generator data.
ii) Randomly generate the initial population for 50 individuals. The initial population is created using Equation (3.4), and the historical population $oldP$ is created using Equation (3.5).
iii) Run MATPOWER power flow to obtain power loss and voltage deviation. Determine VSM_{sys} using Equation (3.3).
iv) Evaluate the fitness function using Equation (3.19).
v) Run MATPOWER power flow to obtain power loss and voltage deviation. Determine VSM_{sys} using Equation (3.3).
vi) Perform Mutation and Crossover and generate the trial population.
vii) Evaluate the fitness function of trial population using Equation (3.19).
viii) Update the population and redefine the $oldP$ using Equation (3.6) and Equation (3.19).
ix) Repeat processes (v) to (viii) until criterion is achieved and best solution is obtained.

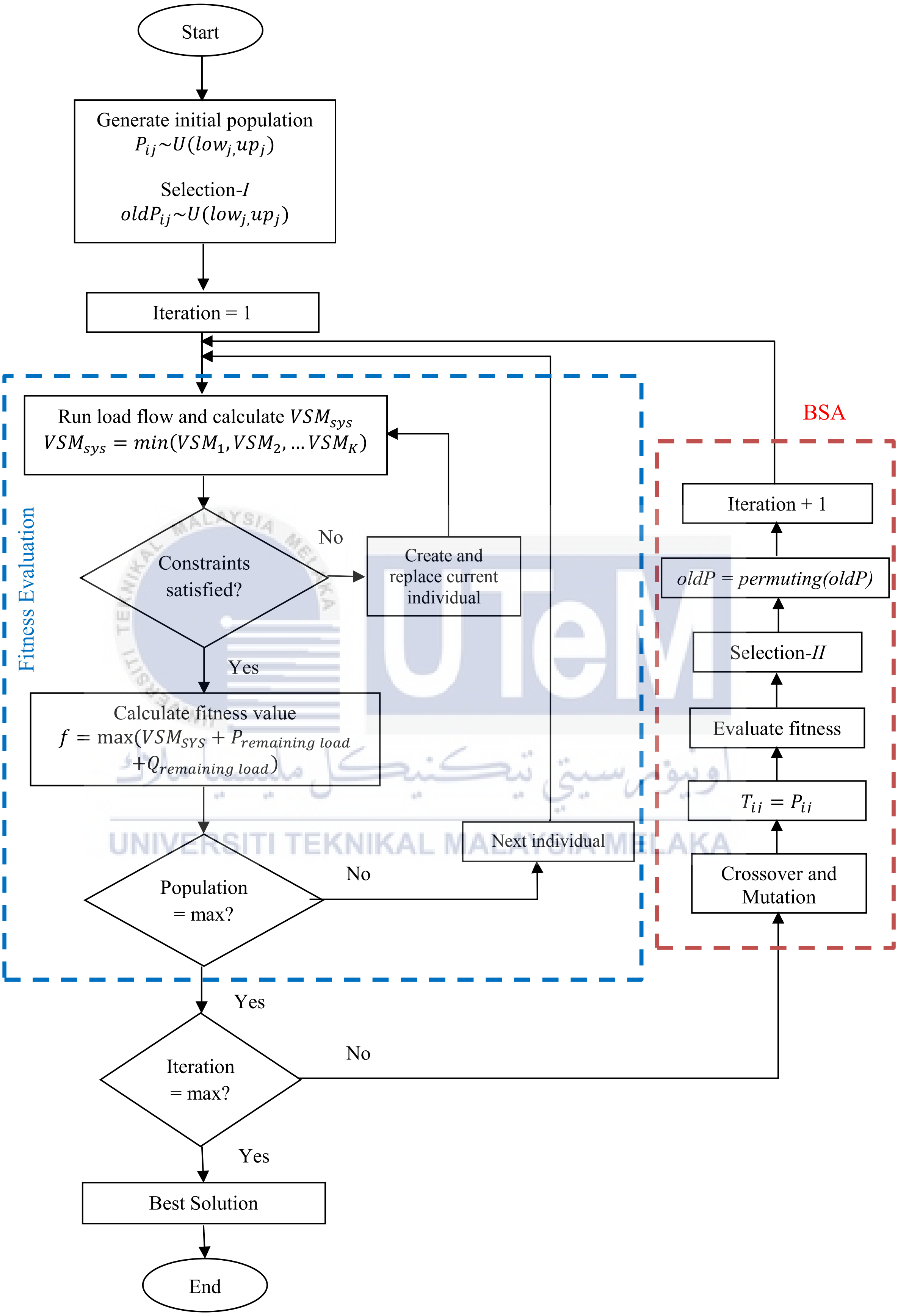


Figure 3.4: Optimal load shedding scheme using BSA

3.3.4 Performance Evaluation with Conventional GA Method

The procedures for implementing the GA for determining optimal load shedding scheme are described as below and illustrated in Figure 3.5:

i) Input system data such as line (resistance and reactance), load (active and reactive) and generator data.

ii) Randomly generate the initial population for 50 individuals. The initial population is created using Equation (3.4).

iii) Run MATPOWER power flow to obtain power loss and voltage deviation. Determine VSM_{sys} using Equation (3.3).

iv) Evaluate the fitness function using Equation (3.19).

v) Select parent chromosome: Evaluate the best individuals by fitness function are selected as parents to reproduce new population.

vi) Perform Mutation and Crossover.

vii) Update the population.

viii) Repeat processes (v) to (viii) until criterion is achieved and best solution is obtained.

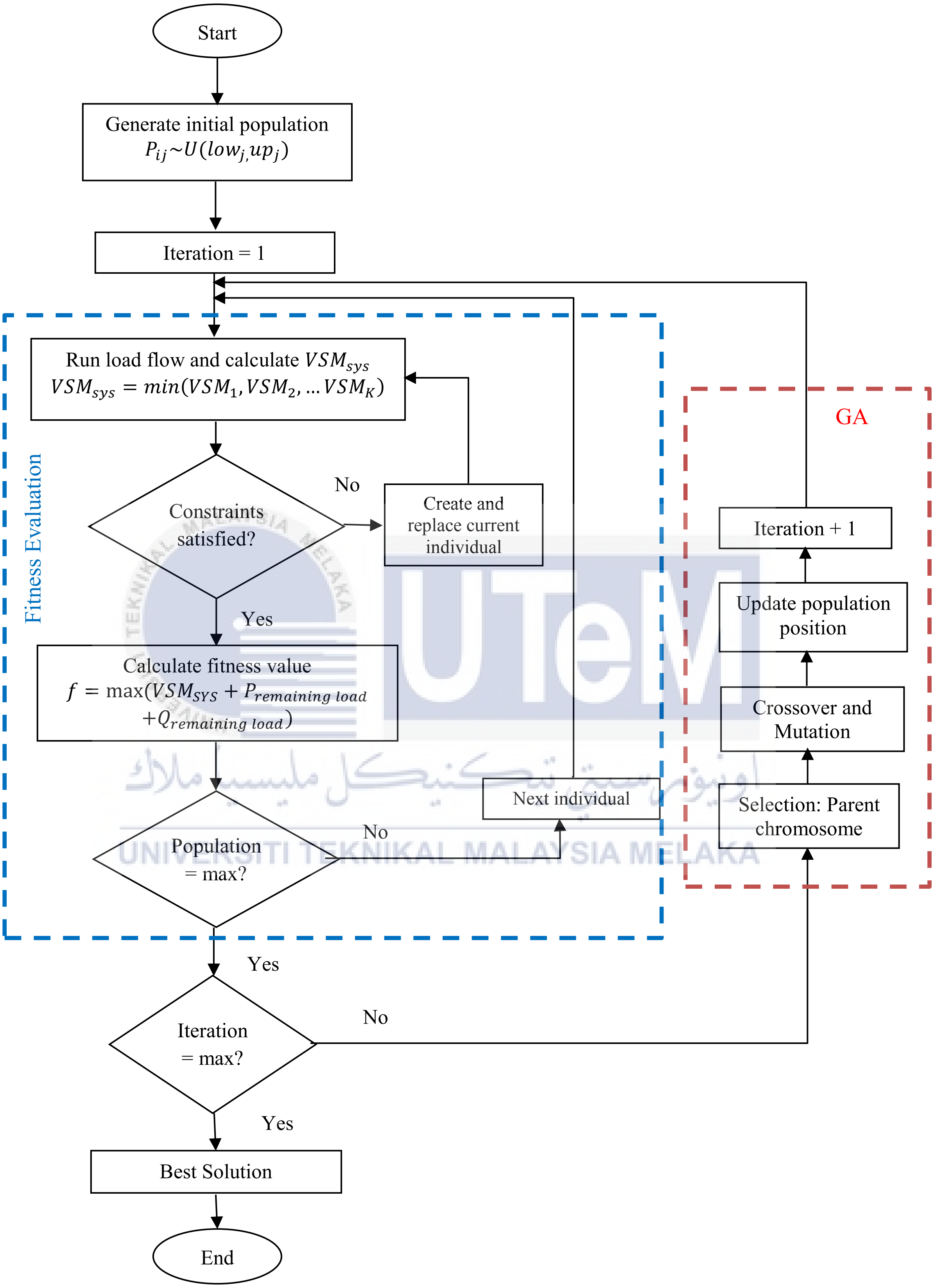


Figure 3.5: Optimal load shedding scheme using GA

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discussed and explained the obtained results for the optimal load shedding scheme using BSA in different scenarios of islanded system. **Section 4.2** highlights the test system description, which explained the parameter of modeled four units DG in power system and load priority limits in 33-bus system. The overall load demand and available power generation from DG for islanded system are presented in this section. **Section 4.3** and **Section 4.4** highlight the case study of VSM for 33-bus system and power mismatch performance. The percentage of power mismatch and optimal load needed to be curtailed from 33-bus system are presented in this section. Meanwhile, **Section 4.5** presented the optimal load shedding scheme using BSA and **Section 4.6** discussed the optimal load shedding scheme using GA for power island A. These findings are related in considering the benefits and limitations for both techniques for load shedding. Besides that, **Section 4.7** presented the optimal load shedding scheme for other scenarios islanded system namely, island B, island C, and island D.

4.2 Test System Description

The modified system of IEEE 33-bus radial distribution system with four units DG are being utilized in validating the proposed load shedding scheme as shown in Figure 4.1. The test system is a balanced three phase system that consists of 4 feeders, 33 busses, and 32 branches, which operating at 11 kV. The power system network consists of 32 loads with total nominal loads of 3.715 MW and 2.29 MVar, active and reactive power respectively. The initial base load of 33-bus radial distribution system studied is adopted from M. M. Hamada [57]. The base case bus, line, and load data of 33-bus radial distribution system are listed in Appendix A. Consider that the power supply to 33-bus is fed from main substation and connected to bus one.

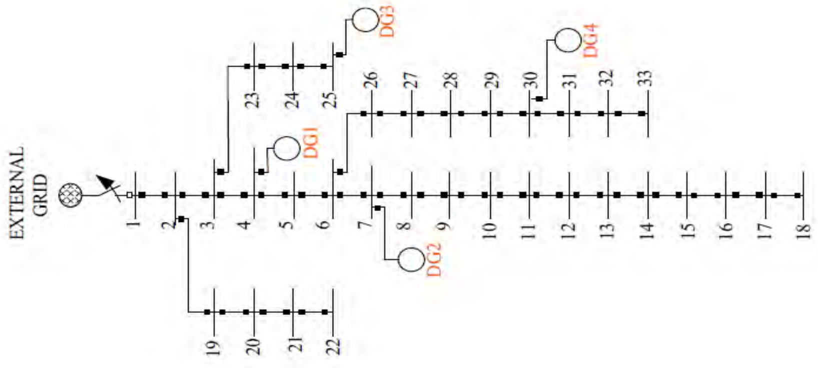


Figure 4.1: Single line diagram of the 33-bus system

In this study, four DG units are modeled as constant power sources where rating of power injection for various DGs are depend of type and hour of the day and rating of capacitor bank. Table 4.1 shows the type of DG, maximum active and reactive power rating of each DG [17], [34]. The four DGs are placed at buses 4, 7, 25 and 30 (as shown in Figure 4.1). The total amount of power generated from four DGs are 1.83 MW and 1.154 MVar, active and reactive power respectively. Meanwhile, the overall maximum amount of load demands and available supply from DGs for each islanded system is presented in Table 4.2.

Table 4.1: Rated maximum power of DGs

DG	DG types	Maximum active power rating (MW)	Maximum reactive power rating (MVar)
1	PV + Shunt capacitor	0.03	0.284
2	Constant power generator + Shunt capacitor	0.80	0.080
3	PV + Shunt capacitor	0.60	0.700
4	Constant power generator + Shunt capacitor	0.40	0.090

Table 4.2: Overall load demand and DG supply in islanded system

Island	**Maximum amount of load demand (MVA)**	**Available DG**	**Maximum amount of DG supply (MVA)**
A	3.715 + j 2.29	ALL DG	1.83 + j 1.154
B	1.405 + j 0.68	DG1, DG2	0.83 + j 0.364
C	2.335 + j 1.13	DG1, DG2, DG3	1.43 + j 1.064
D	2.325 + j 1.63	DG1, DG2, DG4	1.23 + j 0.454

The effectiveness of the proposed BSA optimization technique is then validated with GA optimization technique by comparing the performance of the optimal load shedding scheme. Table 4.3 shows the optimization parameter settings for MATLAB simulation for this study.

Table 4.3: BSA and GA parameter settings

Parameter	**BSA**	**GA**
Population size	50	50
Maximum iteration	1000	1000
Cross Probability	0.96	-
Mutation rate	0.08	-

Figure 4.2 and Figure 4.3 show the daily load profile for individual loads and daily DGs power production, respectively for load shedding study[17], [34]. In Figure 4.2, the 100% load level at hour 15:00 shows that the base case bus power value which acquired from original IEEE 33-bus radial distribution system integrated with four units DG. Meanwhile in Figure 4.3, the highest power produced from DG 1 is 0.03 MW at hour 12:00 and 0.2193 MVar at hour 16:00 (Figure 4.3a), while DG 3 is 0.60 MW and 0.2248 MVar at hour 14:00 (Figure 4.3b).

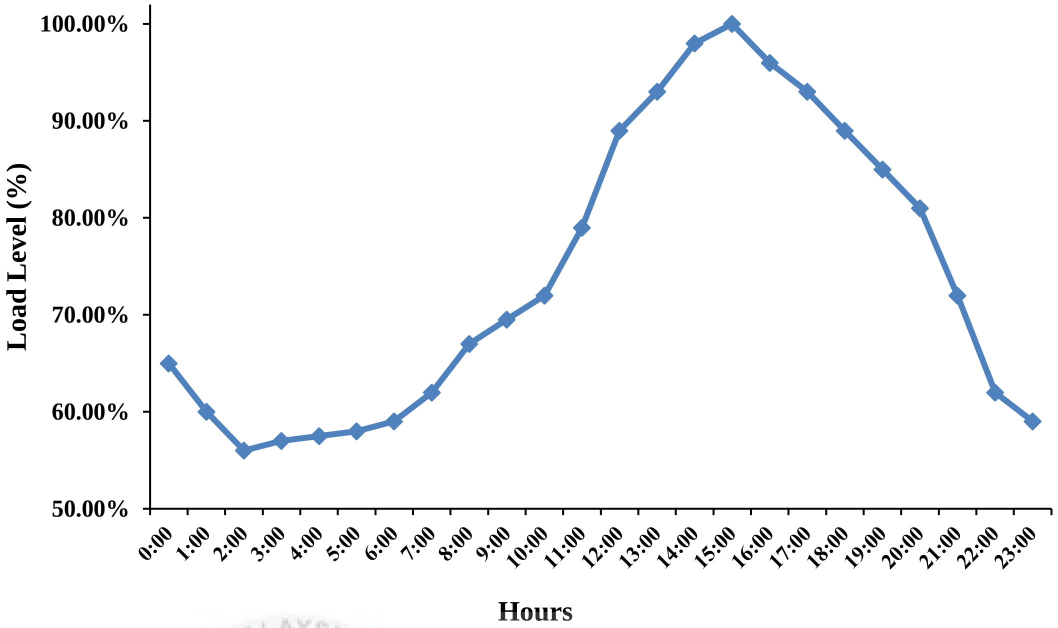
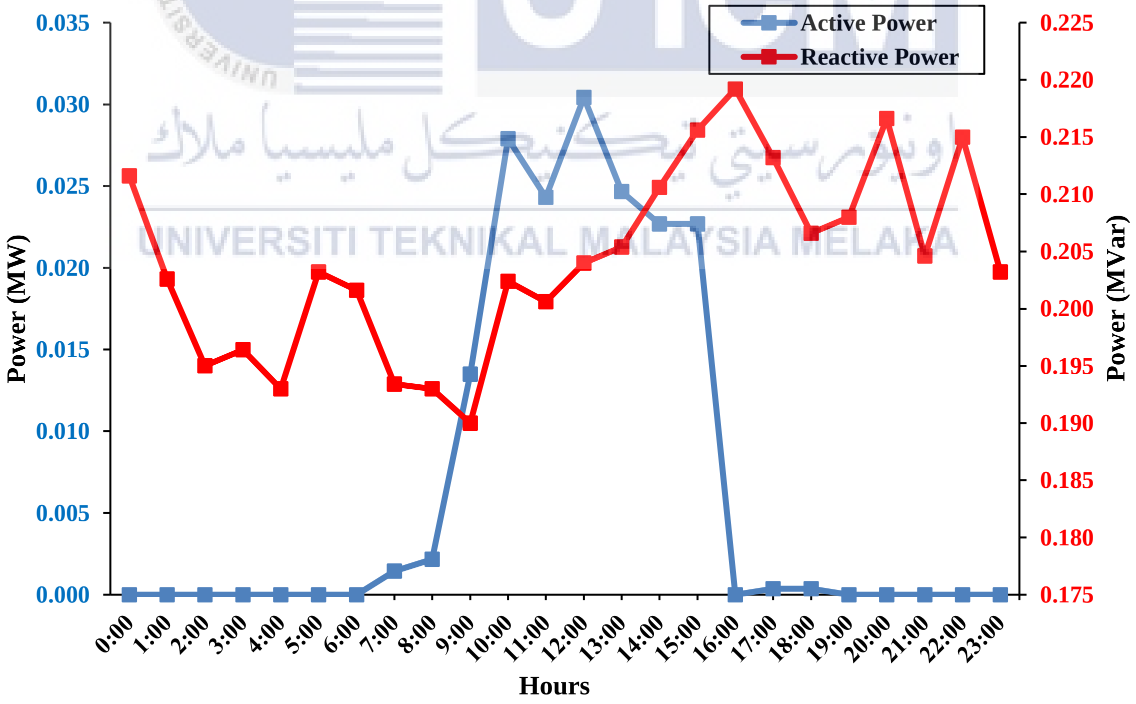
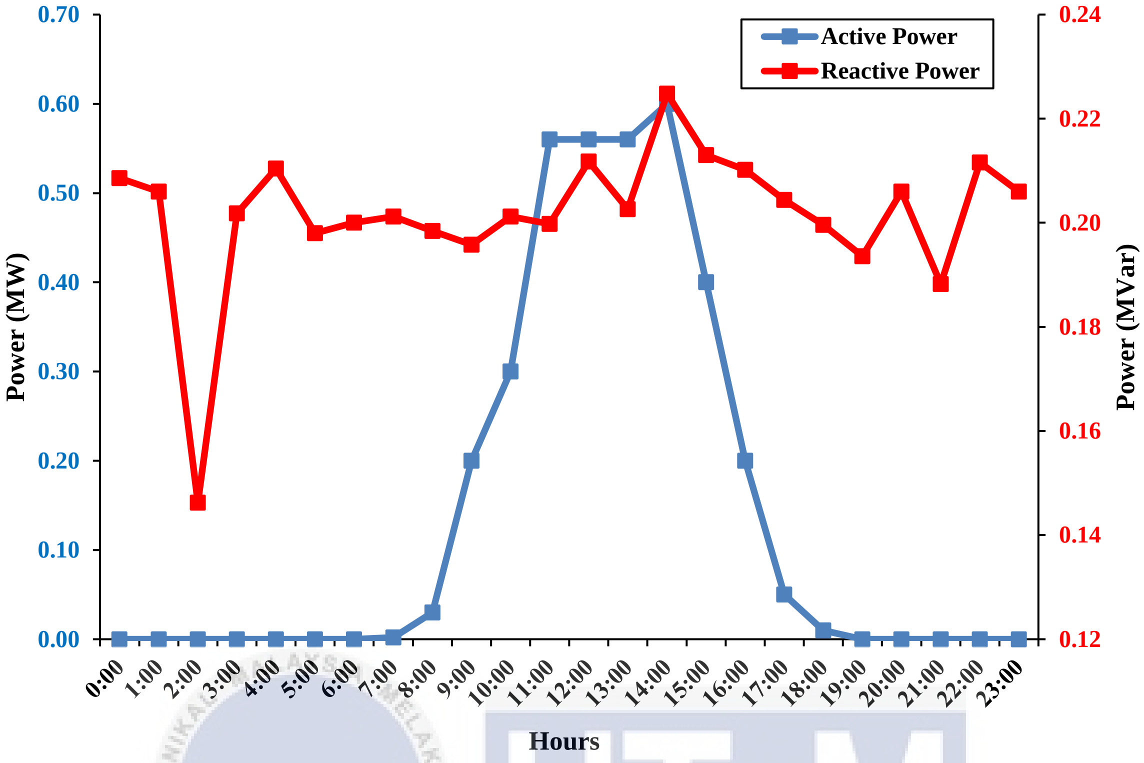


Figure 4.2: Hourly load profile for individual loads



(a)



(b)

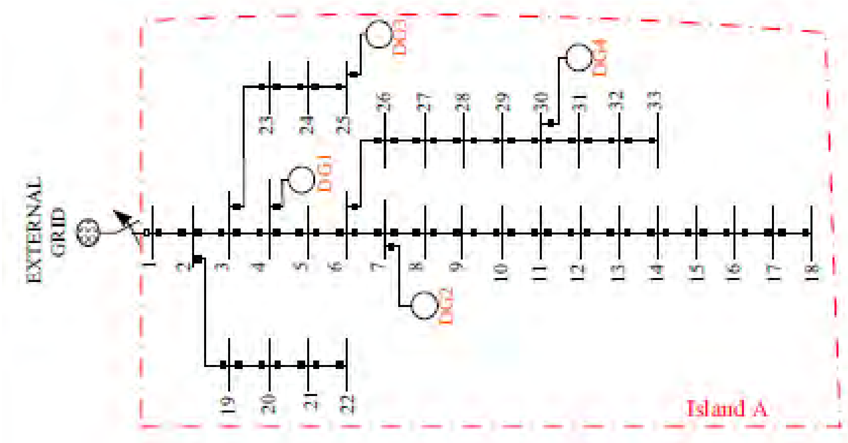
Figure 4.3: Daily DGs power production: (a) DG1 and (b) DG3

To prevent system collapse, several loads should be shed by applying load shedding scheme. Thus, the priority load limit for each bus in IEEE 33-bus radial distribution system is used to ensure obtained power demand is remained and maintained for load shedding scheme. The load priority list that indicates the minimum power that expressed in percentage is presented in Table 4.4 [34]. From the table, any priority load with 100% limit cannot be curtailed while priority load with 0% limit can be curtailed from bus.

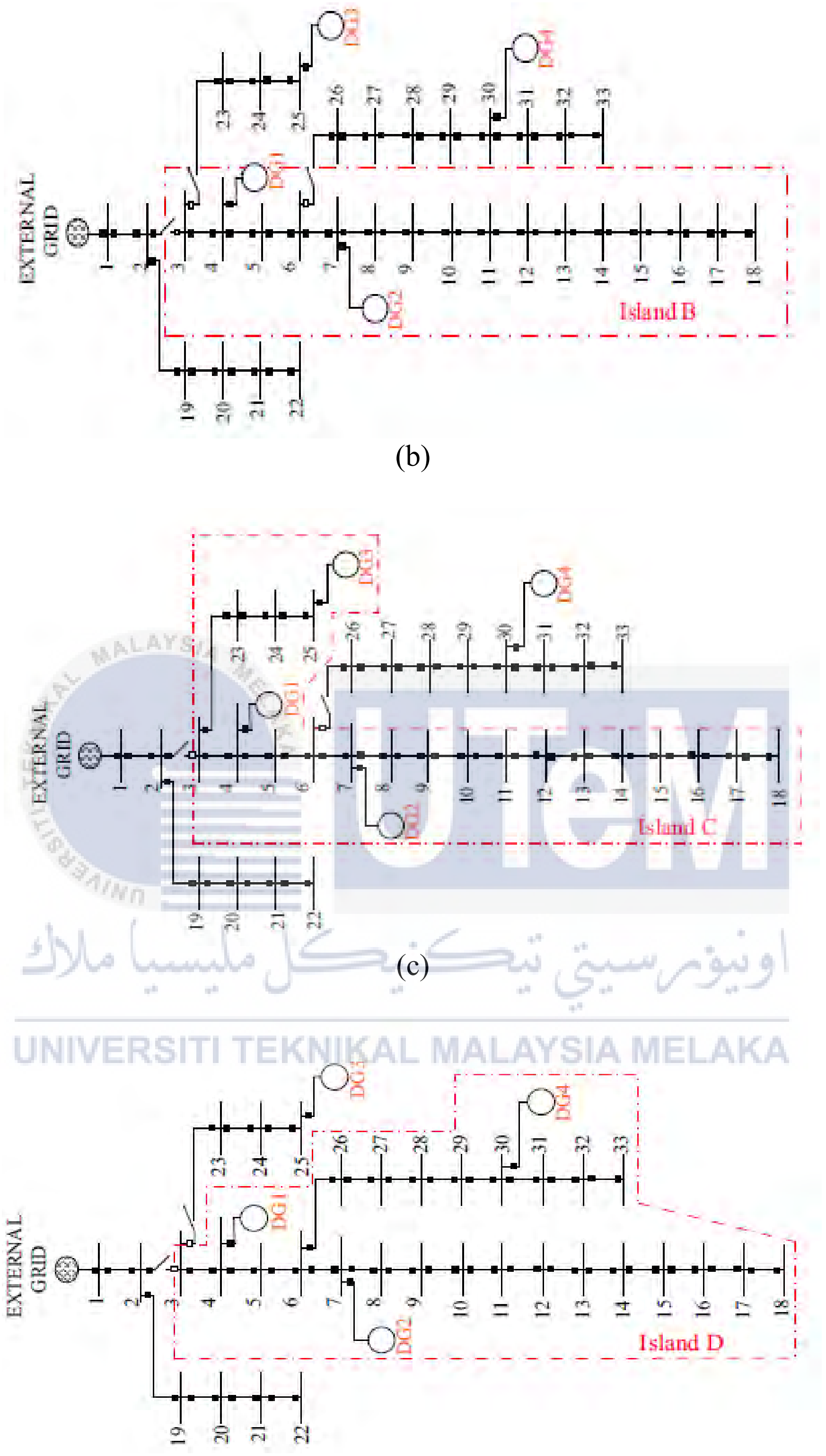
Table 4.4: Percentage load priority limits for the IEEE 33-bus radial distribution system

Bus Number	**Percentage (%)**	**Bus Number**	**Percentage (%)**
1	*0*	18	34
2	34	19	60
3	23	20	53
4	64	21	20
5	15	22	50
6	43	23	4
7	*35*	24	15
8	21	25	10
9	5	26	59
10	21	27	2
11	0	28	28
12	52	29	15
13	11	30	55
14	47	31	25
15	57	32	30
16	61	33	3
17	37		

The simulations of this study are based on possible island scenarios as shown in Figure 4.4, which four possible islanded systems can be formed for IEEE 33-bus radial distribution system with four DGs integrated system.



(a)



(b)

(c)

(d)

Figure 4.4 Single line diagram of islanded systems,

(a) A, (b) B, (c) C, (d) D

4.3 Case Study: Voltage Stability Margin (VSM)

IEEE 33 bus radial distribution system can be classified into 4 feeders. The single line diagram in Figure 4.5 shows that the power system network has four radial feeders (one main feeder and three sub-feeders). The set of branches (Ω) between busses in each feeder (starting from source bus to end of last bus) is given as below:

Feeder 1: Ω_1= [1-2-3-4-5-6-7-8-9-10-11-12-13-14-15-16-17-18]

Feeder 2: Ω_2= [1-2-19-20-21-22]

Feeder 3: Ω_3= [1-2-3-23-24-25]

Feeder 4: Ω_4= [1-2-3-4-5-6-26-27-28-29-30-31-32-33]

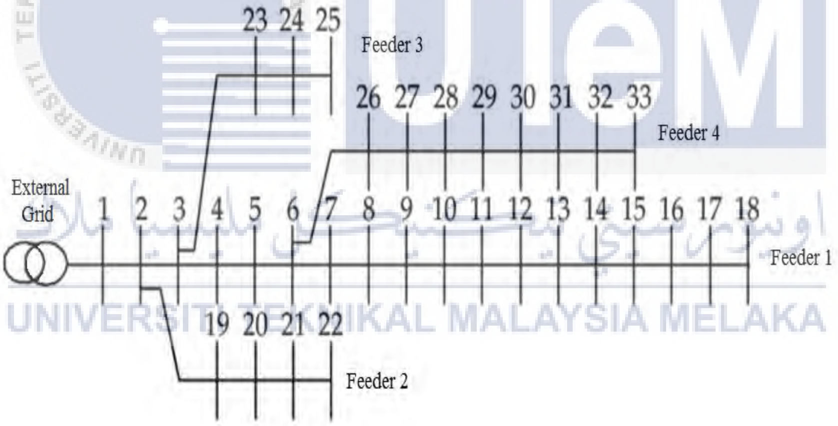


Figure 4.5: Single line diagram of the 33-bus system

The nominal loads for Feeder 1, Feeder 2, Feeder 3 and Feeder 4 are (1505 +j740) kVA, (360 + j160) kVA, (930 + j450) kVA, and (920 + j950) kVA, active and reactive power respectively. Thus, the nominal loads of Feeder 1 is the highest among Feeder 2, Feeder 3 and Feeder 4.

Figure 4.6 shows the VSM of all feeders of 33-bus system which evaluated by using Equation (3.2). From the figure, Feeder 1 with VSM of 0.8124 (when load multiplier factor = 2), indicates that has the lowest voltage stability margin compared to other feeders. This is because Feeder 1 has larger number of load busses compared to Feeder2, Feeder3 and

Feeder 4. The larger number of load busses in feeder will consume more power compared to feeder that contain lesser number of load busses. Thus, Feeder 1 can be considered as the weakest feeder or heavily loaded feeder in 33-bus system and prone to voltage collapse. The second lowest VSM of this power network is Feeder 4, followed by Feeder 2 and Feeder 3.

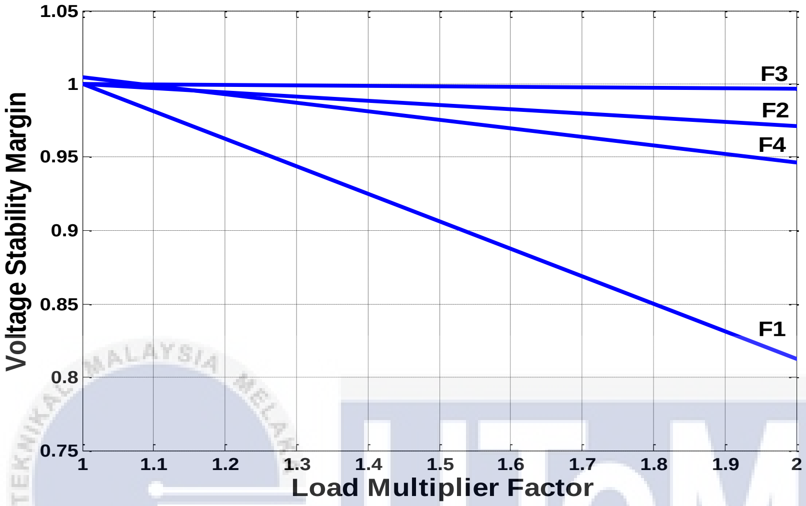
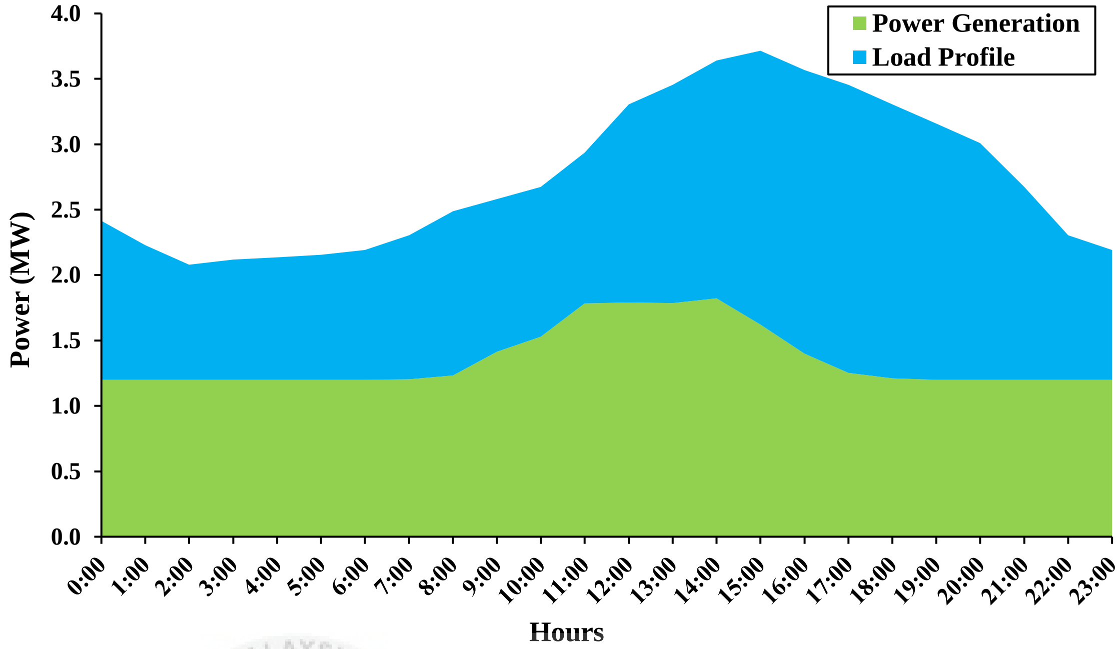


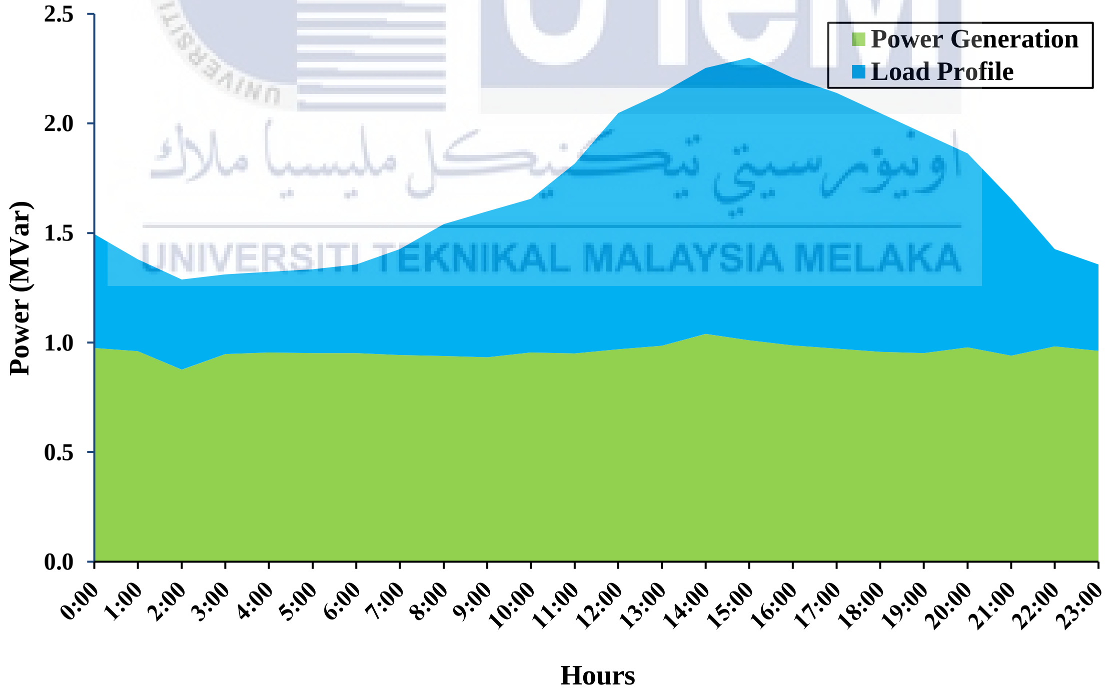
Figure 4.6: Variation of VSM of all feeders of 33-bus system

4.4 Case Study: Load-Generation Power Mismatch

When the protective device at bus one is disconnected from main substation, IEEE 33-bus radial distribution system with four DG units will form an islanded condition. The 33-bus system with total nominal load of 3.715 MW and 2.29 MVar, active and reactive load power respectively, should be supplied from all four units DG. Figure 4.7 shows the load demand of 33-bus system and available power generation from DGs on an hourly basis. From Figure 4.7 (a), the power mismatch between load demand and active power generation is large, which is between 43-57% from valley to peak load. Meanwhile for Figure 4.7 (b), the power mismatch between load demand and reactive power generation is between 48-67%, which is larger than power mismatch between load demand and active power generation. To ensure the operation of islanded power system is maintained and remained, proposed load shedding scheme should be applied in order to determine the location and amount of load to be shed in 33-bus system.



(a)



(b)

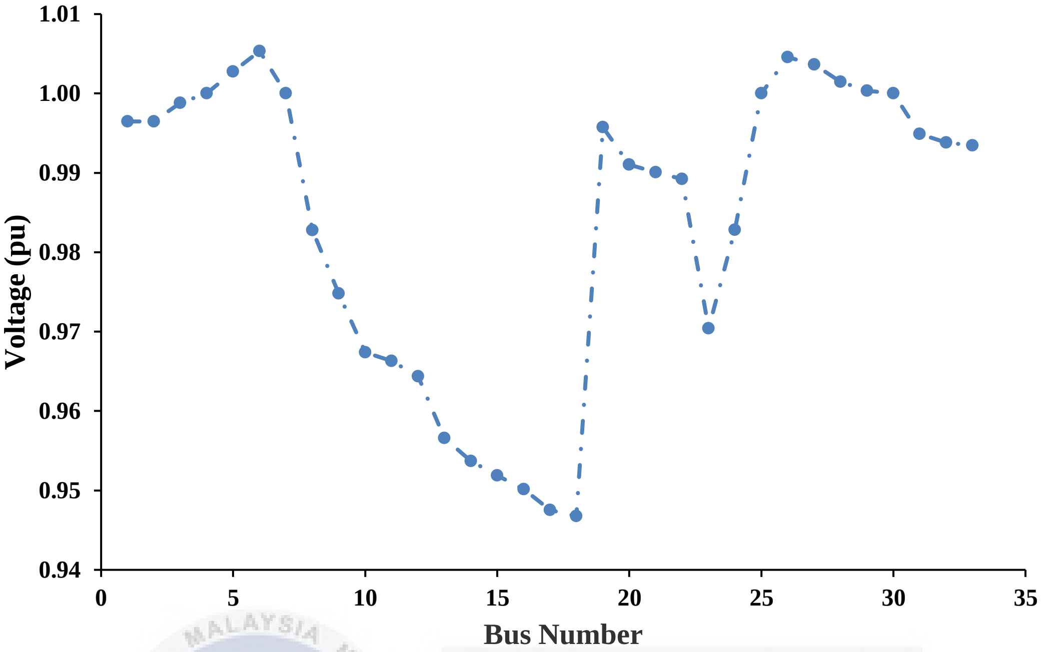
Figure 4.7: Daily load profile and power generation: (a) Active power and (b) Reactive power

a) Case Study: Power Mismatch performance at hour 10:00

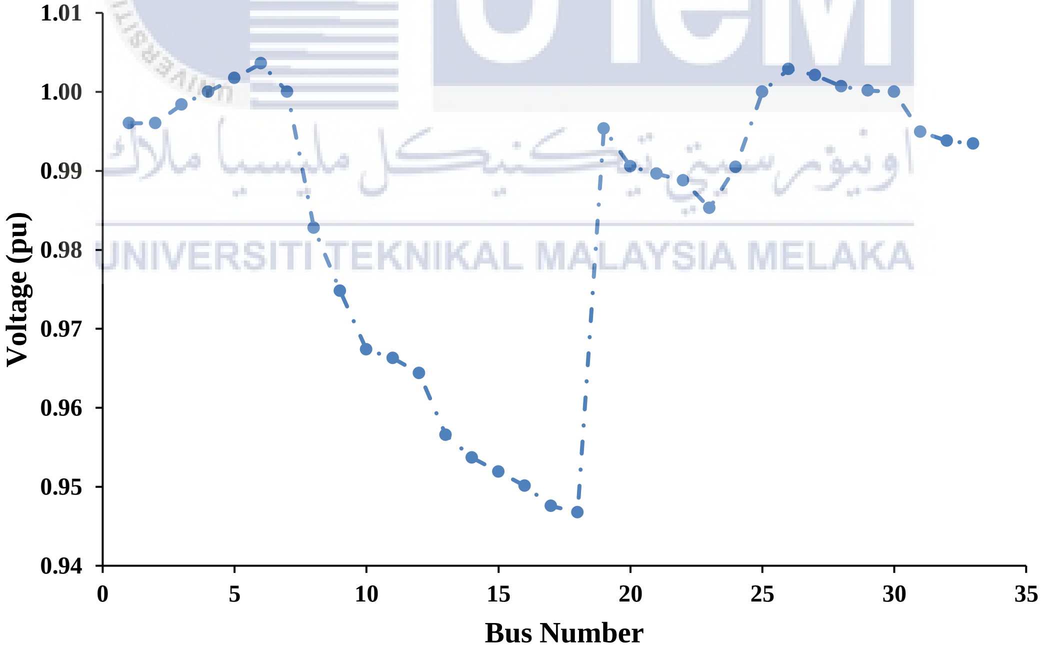
The performance at hour 10:00 is analysed in order to determine the percentage of power mismatch between load demand and power generation from DGs. From Figures 4.7(a) and (b), the load demand at 10:00 is 72%, which is approximately 2.6748 MW and 1.6488 MVar, However, the provided power generation from DGs at this hour is only 1.5279 MW and 0.7436 MVar, active and reactive power respectively. The power mismatch for active power is 43% and reactive power is 55%, respectively. Thus, this result indicates that 43% of active power load and 55% of reactive power load should be curtailed in order to maintain the operation of power system. Figure 4.8(a) shows the voltage profile of 33-bus system at hour 10:00. Based on regulation IEEE 18-2002, the acceptable range of bus voltage for 33-bus system is from 0.98 pu to 1.01 pu. The voltage profile from bus 9 to bus 18 and bus 23 are below 0.98 pu, which do not fulfil the requirement of regulation IEEE 18-2002. The VSM_{sys} at this hour is 0.8140, which is the factor that lead to voltage collapse at bus 9 to bus 18 and bus 23. Thus, curtailment of several optimum load should be done in order to improve the voltage profile of 33-bus system.

b) Case Study: Power Mismatch performance at hour 14:00

The aim of this study is to differentiate the percentage of power mismatch for a different hourly load demand and power generation. Therefore, similar analysis at hour 14:00 is also performed. The load demand at hour 14:00 is 98% which approximately to 3.6407 MW and 2.2442 MVar respectively. At this hour, the power generation supplied from DGs is only 1.8227 MW and 1.032 MVar. The power mismatch between load demand and power generation at this hour is 50% and 54%, active and reactive power load respectively. Thus, it required 50% of active power load and 66% of reactive power load to be curtailed from 33-bus system. Figure 4.8(b) shows the voltage profile of 33-bus system at hour 14:00. The voltage profile from bus 9 to bus 18 are below 0.98 pu, which do not fulfil the requirement of regulation IEEE 18-2002. VSM_{sys} at this hour is 0.8158. These result prove that the percentage of load required to be curtailed is higher when the load demand is close to maximum load level (100%).



(a)



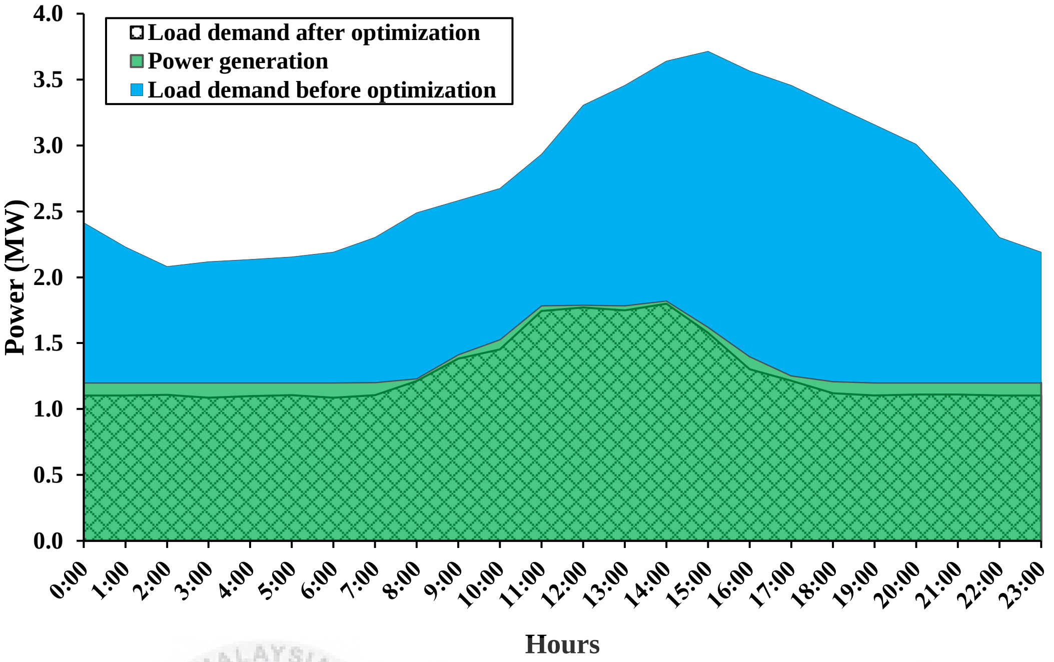
(b)

Figure 4.8: Voltage profile: (a) Hour 10:00 and (b) Hour 14:00

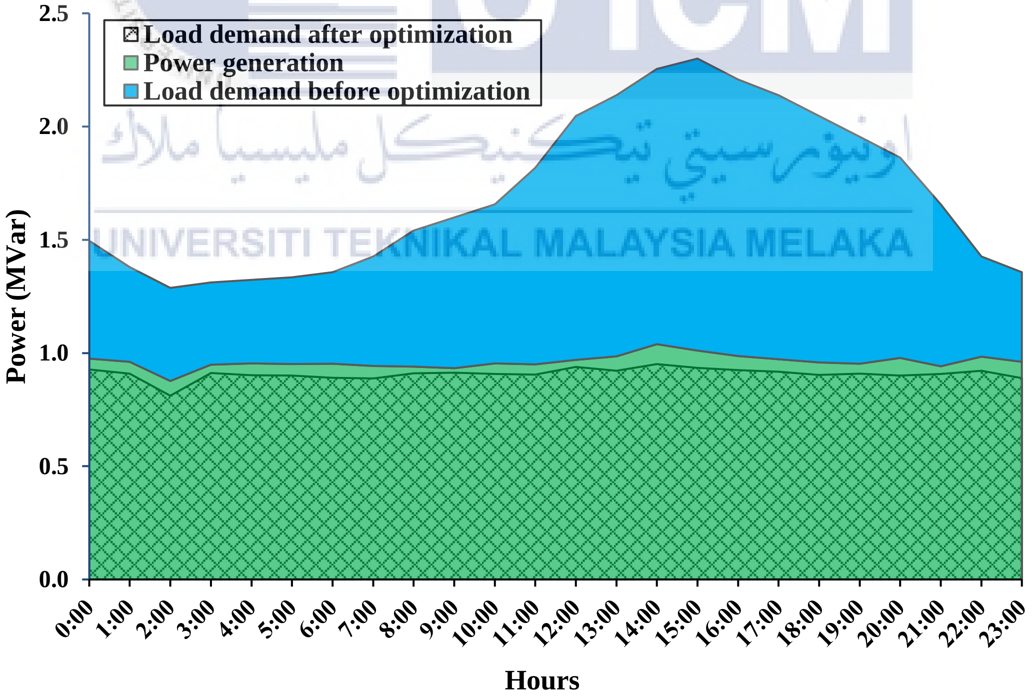
4.5 Optimal Load Shedding for Island A using BSA

When the protective device at bus one in the IEEE 33-bus with four DGs integrated system is opened, island A is formed as illustrated in Figure 4.4 (a). The total loads for power island A is 3.715 MW and 2.29 MVar, active and reactive power respectively. Thus, power island A should be fully supplied by all four DGs namely DG1, DG2, DG3, and DG4 with maximum amount of 1.83 MW and 1.154 MVar, active and reactive power respectively (Table 4.2). Therefore, the proposed optimal load shedding scheme based on BSA is applied in order to ensure power at island A able to maintain its operation, where amount of load demand to be shed will be determined. Besides that, 15 repetition runs of proposed optimization algorithm need to be conducted in order to evaluate the capabilities and convergence characteristic of proposed load shedding scheme.

Figure 4.9 shows the performance of proposed load shedding scheme based on BSA for power island A. From Figure 4.9 (a) and (b), the remaining loads (active and reactive) after optimization process does not exceed and almost close to the amount of power generated from DGs during hourly operation in islanding condition. This finding indicates that the proposed load shedding scheme has ability to decide amount of optimal load to be shed from bus system without cutting substantial load. Taking analyse at hour 15:00, this result may be explained by the fact that the loads being curtailed is approximately 58% and 57%, active and reactive load respectively, from 100% of load level in 33-bus system.



(a)



(b)

Figure 4.9: Proposed load shedding scheme performance for power island A, (a) Active load, (b) Reactive load

Meanwhile, Figure 4.10 illustrates the convergence characteristic for the proposed load shedding scheme based on BSA technique at hour 14:00. From the convergence characteristic, it shows that BSA converges and find its solution at 85 iterations. In evaluating the optimal load shedding scheme for this islanded scenario, the voltage stability margin and total remaining load in system network is considered by fitness function, where the evaluated fitness value for power island A is 1.8470.

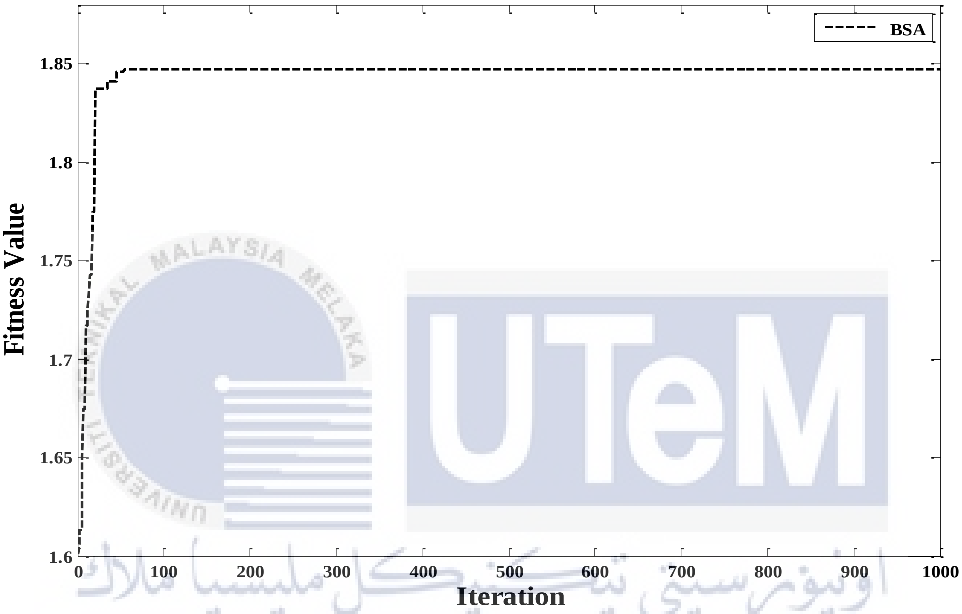


Figure 4.10: Convergence characteristic of proposed load shedding scheme for island A

Table 4.5 shows amount of hourly load curtailment (active and reactive) at individual bus in power island A. These are valuable findings in order to conclude the sensitivity of individual bus in power island A. The proposed load shedding scheme did not fully curtailed the loads (active and reactive) from individual buses with low priority limits such as buses 9,11, 23, 27, and 33 as stated in Table 4.4. From the findings, it can thus be suggested these buses are less sensitive compared to other buses in power island A. The amount of loads being curtailed from load shedding scheme is approximately 82%, 97%, 89%, 86%, and 87% of active loads, 69%, 86%, 84%, 85%, and 90% of reactive loads, for buses 9,11,23,27 and 33 in power island A.

Table 4.5: Amount of hourly load curtailment at individual bus in island A, (a) Active load, (b) Reactive Load

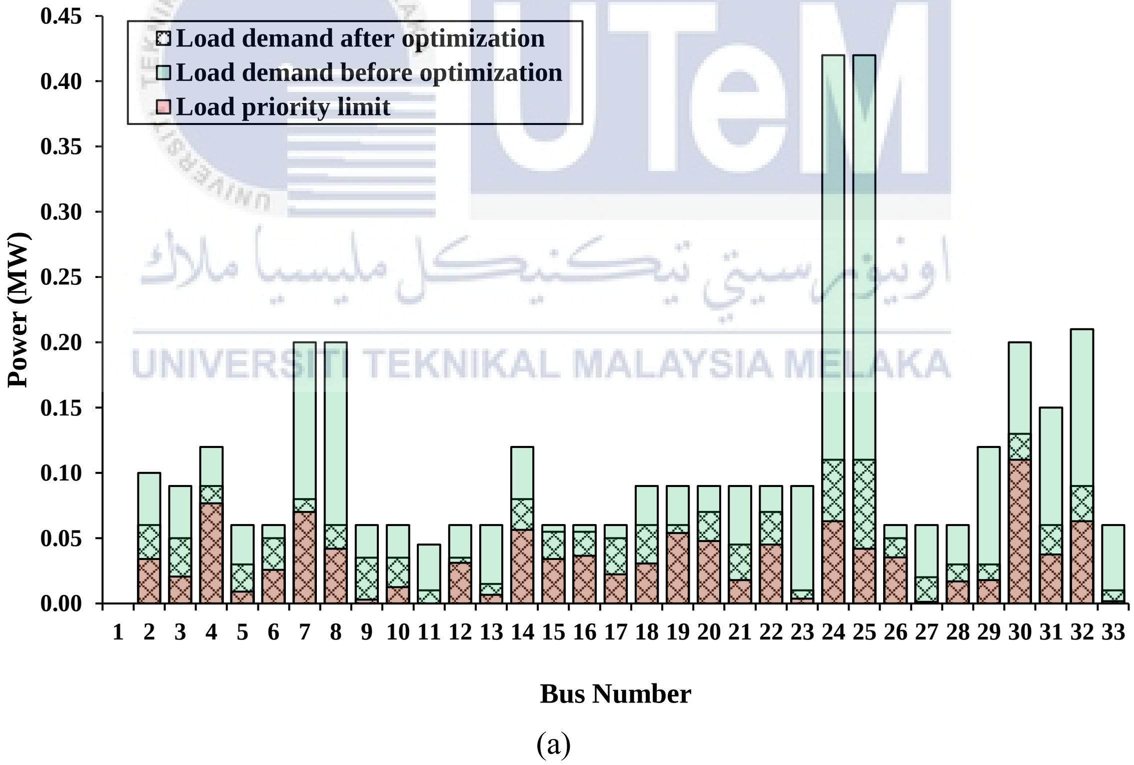
(a)

Bus	Hourly/ Amount of load curtailed (%)																							
No.	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
2	64	63	63	64	62	62	63	65	64	53	59	49	49	51	40	49	59	62	61	63	62	63	63	63
3	72	73	74	73	73	75	75	76	75	68	64	50	46	50	44	57	75	75	76	75	76	75	75	75
4	33	33	33	33	35	35	35	35	35	34	31	24	40	32	25	24	35	35	34	35	34	33	35	35
5	83	83	83	83	83	81	81	75	71	70	71	55	68	58	50	63	76	81	81	81	80	81	81	81
6	51	51	53	51	51	55	56	55	51	40	46	30	46	30	25	20	48	45	53	56	55	53	56	55
7	62	62	64	63	63	63	63	62	61	58	59	52	51	58	60	58	61	64	63	63	64	63	63	64
8	75	77	75	78	75	74	78	78	78	84	73	66	61	61	70	72	76	76	75	78	78	77	78	74
9	85	88	91	88	86	91	93	93	86	81	81	65	58	65	41	41	75	91	93	93	93	91	93	86
10	75	73	75	76	77	76	71	73	63	71	63	53	36	36	41	41	78	78	76	71	73	76	71	76
11	100	100	100	100	100	100	100	100	95	89	75	100	95	93	86	97	100	97	97	100	100	100	100	100
12	41	41	43	42	41	43	45	41	41	36	31	20	31	31	41	41	41	43	43	45	43	41	45	43
13	85	86	87	86	85	88	88	88	88	86	81	58	55	60	75	75	65	81	88	88	88	88	88	88
14	50	50	50	50	50	51	52	51	52	48	44	35	37	40	33	40	46	46	51	52	51	50	52	51
15	38	38	38	40	38	38	40	36	40	31	23	30	30	35	33	25	36	36	40	40	41	41	40	38
16	36	36	36	37	36	36	36	36	36	30	36	25	35	35	28	25	25	25	38	36	38	35	36	36
17	57	57	57	57	57	58	58	60	60	41	41	41	41	35	25	21	58	60	58	58	60	60	58	58
18	61	62	61	62	61	65	63	64	64	61	53	42	42	32	33	43	60	64	65	63	64	65	63	65
19	33	34	33	34	33	32	38	38	38	30	31	20	31	36	33	31	32	34	35	38	38	38	38	38
20	44	46	40	46	44	46	46	46	46	31	35	20	31	36	22	23	36	43	45	46	46	45	46	46
21	72	72	72	72	72	73	76	76	65	65	46	26	26	34	50	50	72	76	76	76	78	78	76	73
22	44	44	44	44	47	42	50	46	42	40	31	31	31	32	22	27	36	36	43	50	47	47	50	42
23	94	94	94	94	94	94	95	95	94	91	94	76	65	75	88	83	75	78	94	95	95	94	95	90
24	83	83	83	83	83	84	83	82	82	83	80	75	75	73	73	76	80	83	84	83	82	83	83	84
25	88	89	88	89	88	88	89	88	86	81	86	77	77	76	73	79	83	87	89	89	89	89	89	88
26	36	36	36	36	36	36	36	36	36	36	30	30	30	30	31	30	35	35	36	36	38	40	36	36
27	96	96	98	96	96	98	96	95	95	90	95	48	48	48	66	76	80	80	98	96	96	96	96	85
28	66	66	58	68	66	58	68	70	53	58	36	20	36	36	50	56	61	61	63	68	70	71	68	65
29	83	83	83	82	83	82	82	80	80	74	80	76	67	67	75	77	79	82	82	82	82	83	82	82
30	35	35	40	35	35	39	37	32	37	26	39	32	32	37	35	34	41	41	39	37	39	39	37	41
31	74	74	74	74	74	74	74	74	74	72	74	72	65	60	60	71	69	69	74	74	74	74	74	74
32	66	65	66	66	69	67	66	64	69	58	64	64	60	58	57	62	62	62	67	66	67	69	66	67
33	93	92	95	90	95	96	93	86	91	93	85	65	65	72	83	86	85	87	96	93	93	88	93	86

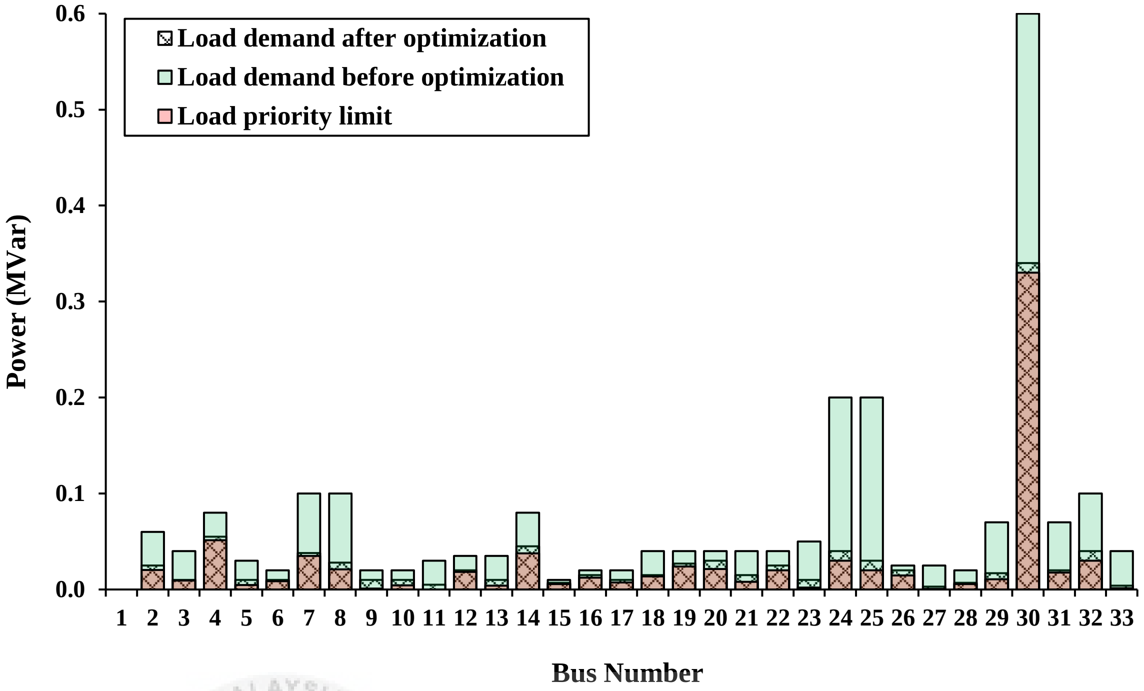
(b)

Bus	Hourly/ Amount of load curtailed (%)																						
No.	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
2	63	60	60	61	60	63	60	65	55	65	58	65	58	60	58	65	58	48	61	60	63	65	58	60
3	75	72	75	75	72	72	70	62	57	57	97	80	77	55	75	72	70	72	72	70	62	72	67	72
4	32	32	32	33	31	35	35	35	35	31	33	33	33	31	31	31	31	33	33	35	32	32	31	32
5	73	63	77	66	73	73	83	80	80	80	80	80	80	73	66	73	30	30	73	83	73	80	26	63
6	50	45	55	50	55	45	40	40	45	40	45	45	45	55	50	45	40	40	40	40	45	45	40	45
7	62	62	62	62	62	62	65	62	62	65	62	63	63	58	62	58	62	62	62	65	62	62	61	62
8	73	72	76	72	72	73	76	76	75	78	77	77	77	72	72	69	72	72	74	76	73	73	72	72
9	65	75	91	81	70	75	80	80	80	80	80	70	70	70	50	40	65	65	60	60	70	60	60	50
10	61	50	68	50	60	45	45	45	40	45	40	40	45	40	50	45	66	66	40	45	60	70	66	50
11	83	83	100	100	83	96	96	96	96	63	90	93	93	83	83	90	96	96	96	96	83	83	93	83
12	45	42	42	42	40	45	45	45	45	40	40	40	40	40	42	31	37	37	48	45	45	45	37	42
13	71	71	86	71	65	80	80	80	80	82	88	88	85	65	71	51	74	80	80	80	48	77	77	71
14	43	45	51	51	43	43	43	43	43	51	43	43	46	43	43	43	43	38	45	43	43	43	43	45
15	38	30	35	35	40	30	40	40	40	40	30	30	30	40	30	30	30	30	30	40	30	10	20	30
16	35	30	26	32	25	25	35	30	25	25	35	45	35	35	25	30	25	25	30	25	35	35	25	35
17	53	50	55	55	45	40	45	45	45	45	45	45	35	40	50	45	55	45	40	45	55	55	55	50
18	62	62	62	62	62	62	62	65	62	57	55	57	57	62	62	62	62	62	60	62	62	62	57	62
19	32	32	34	32	32	32	32	32	40	35	20	20	35	32	32	32	32	27	32	32	32	32	32	32
20	37	22	28	30	37	37	37	37	42	32	27	37	37	35	25	20	27	27	35	37	37	37	27	30
21	74	65	76	62	62	62	72	72	72	47	52	77	77	62	62	62	62	62	62	72	62	52	55	65
22	40	37	40	37	37	37	47	42	42	47	40	20	45	40	37	27	37	37	42	47	40	40	37	37
23	93	82	92	80	84	78	84	84	84	84	84	84	64	84	80	76	86	86	78	84	94	92	88	82
24	80	80	83	80	81	82	82	82	82	82	82	77	77	82	80	79	79	79	81	82	79	77	79	80
25	86	86	85	85	87	84	89	89	89	89	89	89	89	86	85	84	86	89	84	89	85	87	87	86
26	20	20	36	25	32	36	40	40	36	36	36	32	36	40	20	24	36	32	32	24	40	36	36	36
27	88	88	88	88	88	88	88	88	88	84	92	92	92	72	88	80	68	68	88	88	88	88	68	88
28	70	65	65	65	65	65	65	65	65	65	55	55	60	65	65	65	65	65	65	65	70	70	60	65
29	82	77	75	75	77	75	75	75	77	75	75	77	72	78.	75	77	75	75	75	75	82	82	77	77
30	43	43	43	43	42	43	43	44	44	43	42	40	40	40	43	43	43	43	43	43	43	46	43	43
31	71	71	74	71	72	70	70	70	68	67	60	54	54	72	71	70	68	72	70	70	65	65	67	71
32	64	60	65	68	63	62	62	68	68	65	58	61	59	64	60	58	61	62	59	62	65	65	58	60
33	92	90	96	93	90	93	95	95	95	95	92	92	80	80	90	85	77	77	93	95	92	90	77	90

An important issue that emerged at the initial stages of the analytic process was the total amount of load demand in power island A (3.6407 MW + j2.2442 MVar) is higher than the available power generation supplied from DGs (1.8227 MW + j 1.0393 MVar) at hour 14:00. Figure 4.11 shows the performance of the optimal load shedding scheme for power island A which can fulfil the load priority limit requirement. After applying optimal load shedding scheme for power island A, 1.8957 MW of the active load demand is curtailed, which leaving only 1.745 MW as the total remaining active load in power island A, as illustrated in Figure 4.11 (a). Meanwhile, 1.2932 MVar of reactive load demand is curtailed and leaving only 0.951 MVar as the total remaining reactive load in power island as illustrated in Figure 4.11 (b). Therefore, the power generation from DGs with 1.8227 MW and 1.0393 MVar, active and reactive power respectively, can fulfil the load demand requirement for power island A at hour 14:00.



(a)



(b)

Figure 4.11: Individual load demand after optimization based on BSA, (a) Active load, (b) Reactive load

Figure 4.12 shows the improved voltage profile of IEEE 33-bus system after proposed optimization using BSA technique for power island A. This finding indicates that all of the bus voltages of 33-bus are improved and within the acceptable range between 0.98 pu to 1.01 pu, which fulfil the requirement of regulation IEEE 18-2002. Besides that, the reduction of voltage profile for all buses is based on objective function and operational constrains as stated in **Section 3.3**. Thus, the finding proves that BSA technique can be used to identify the optimal amount of load to be curtailed in IEEE 33-bus system.

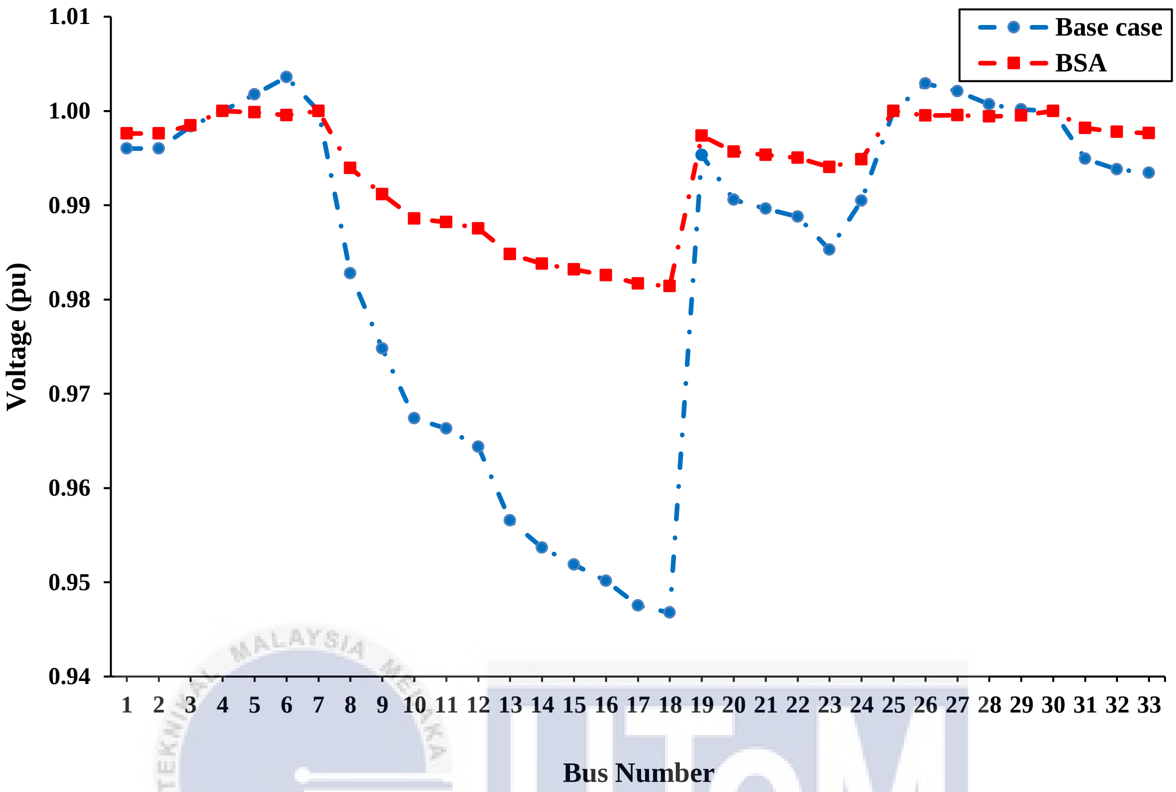
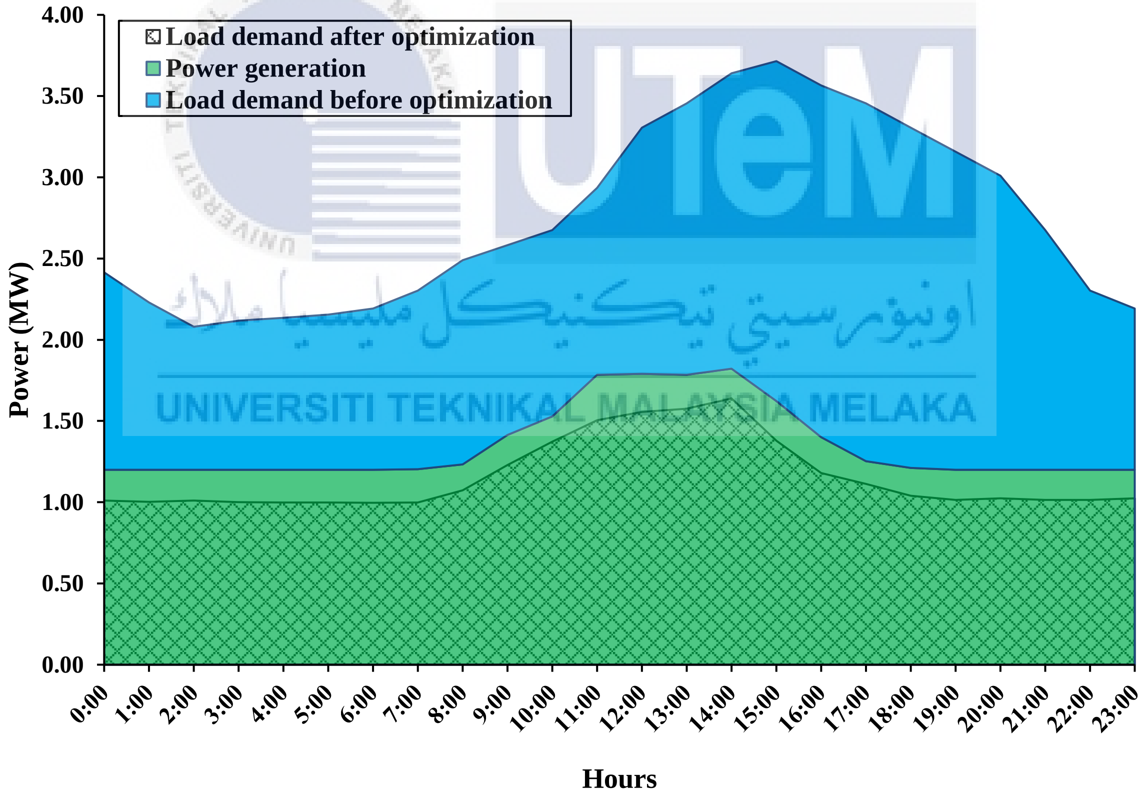


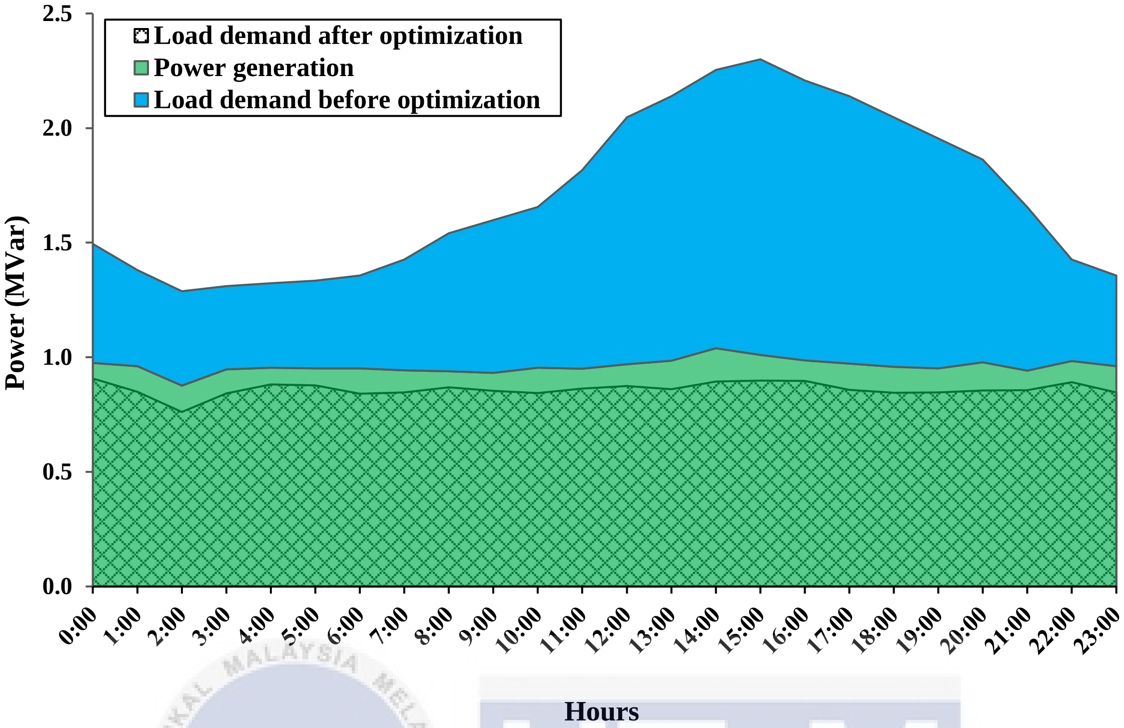
Figure 4.12: Voltage profile after optimization

4.5 Optimal Load Shedding for Island A using GA

The proposed load shedding scheme based on GA is tested and simulated by applying the same procedures as BSA technique in order to validate the performance of both techniques. The parameters setting for GA technique are presented in Table 4.3. The finding of the generation and load mismatch for optimal load shedding scheme based GA is illustrated in Figure 4.13. The remaining loads (active and reactive) after optimization process does not exceed and almost close to the amount of power generated from DGs during hourly operation in islanding condition, as shown in Figure 4.13 (a) and (b). However, this finding indicates that the amount of loads have been shed based on GA technique during hourly operation is larger than proposed load shedding scheme (Figure 4.9).



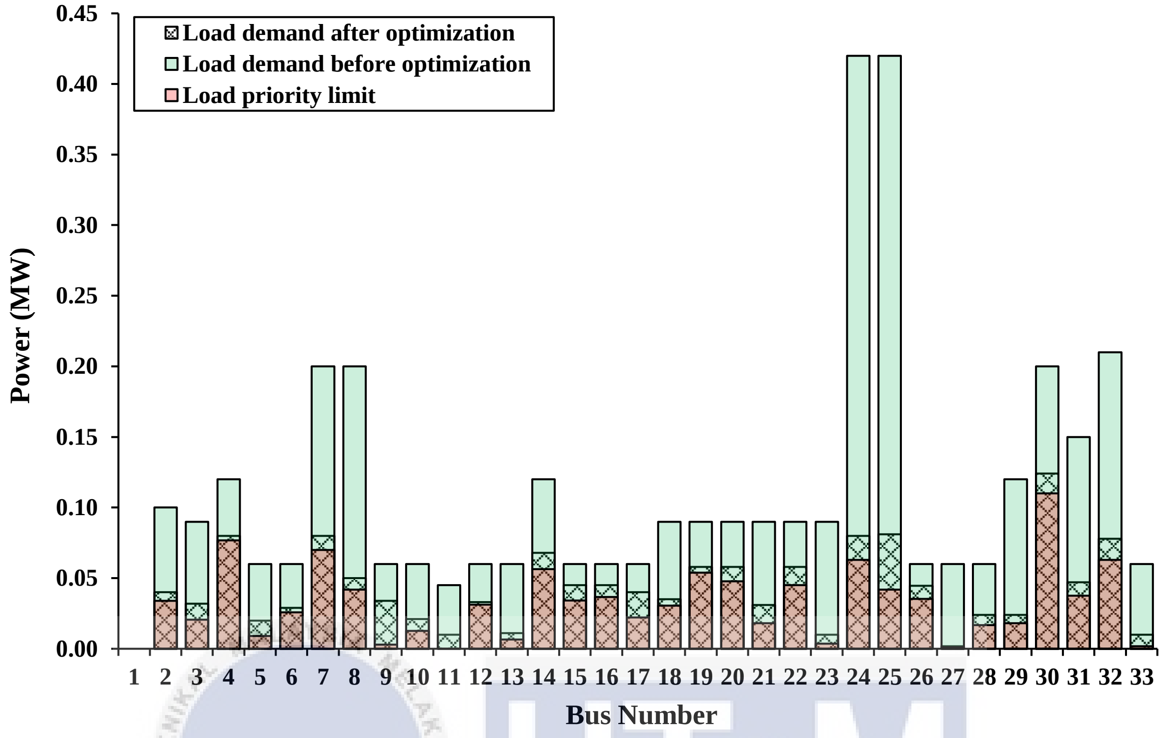
(a)



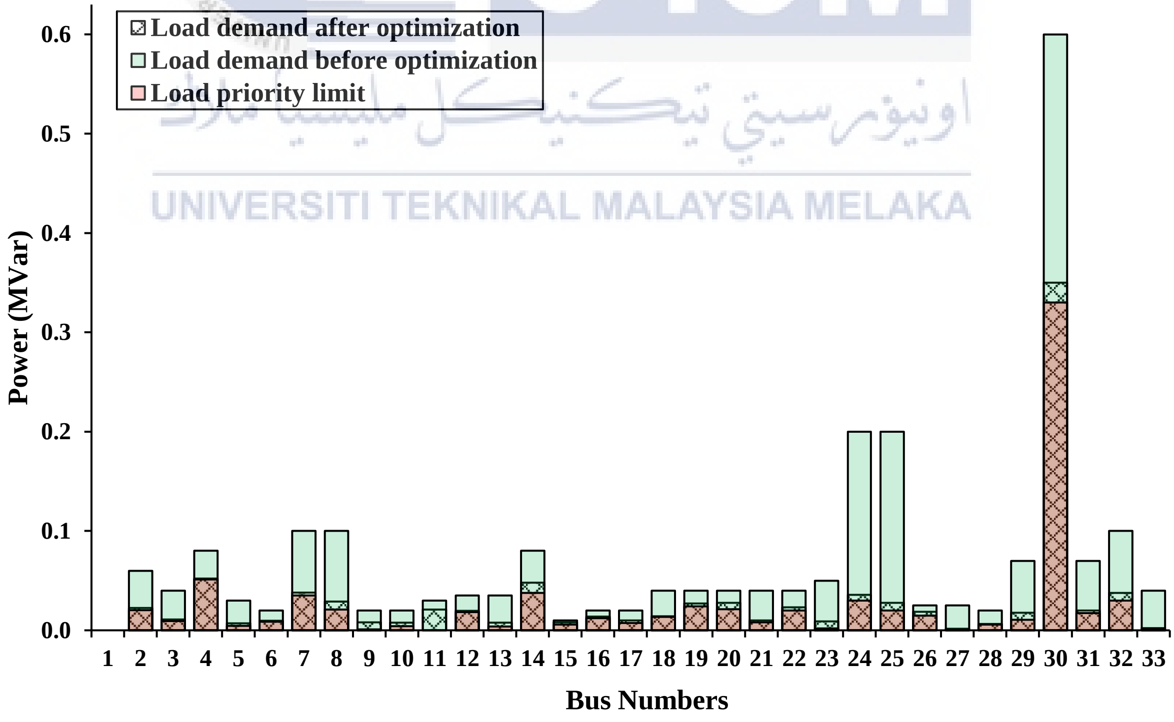
(b)

Figure 4.13: Load shedding scheme performance for power island A based GA, (a) Active load,(b) Reactive load

Meanwhile, the performance of optimal load shedding scheme based on GA at hour 14:00 is further analysed and findings are illustrated in Figure 4.14. After optimal load shedding scheme based on GA is applied, 2.2385 MW of active load demand is being curtailed from bus system, which leaving only 1.4022 MW of total active load in power island A, as shown in Figure 4.14 (a). Besides that, 1.3029 MVar of reactive load demand is being shed and leaving 0.9413 MVar as total remaining reactive load in power island A as illustrated in Figure 4.14 (b). These finding indicates that power generation from DGs with 1.8227 MW and 1.0393 MVar, active and reactive power respectively, can fulfil the load demand requirement for power island A.



(a)



(b)

Figure 4.14: Individual load demand after optimization based on GA, (a) Active load, (b) Reactive load

However, the total loads suggested by optimal load shedding based on GA is 0.3428 MW and 0.0097 MVar, active and reactive load respectively, are less than amount of load calculated by BSA optimization technique. This finding states that BSA is better than GA technique in determining the optimal remaining active and reactive loads, that considering the main objective of this study which is to minimize amount of load to be curtailed without shedding a substantial load from power system network. Meanwhile, the improvement of voltage profile at buses is observed after optimal load shedding scheme based on GA is applied (Figure 4.15). Perhaps the most important finding is the voltage profiles acquired from GA technique are higher than those obtained by BSA. This improvement in voltage are in line with those larger amounts of load that have be curtailed by GA than BSA in power system network during optimization.

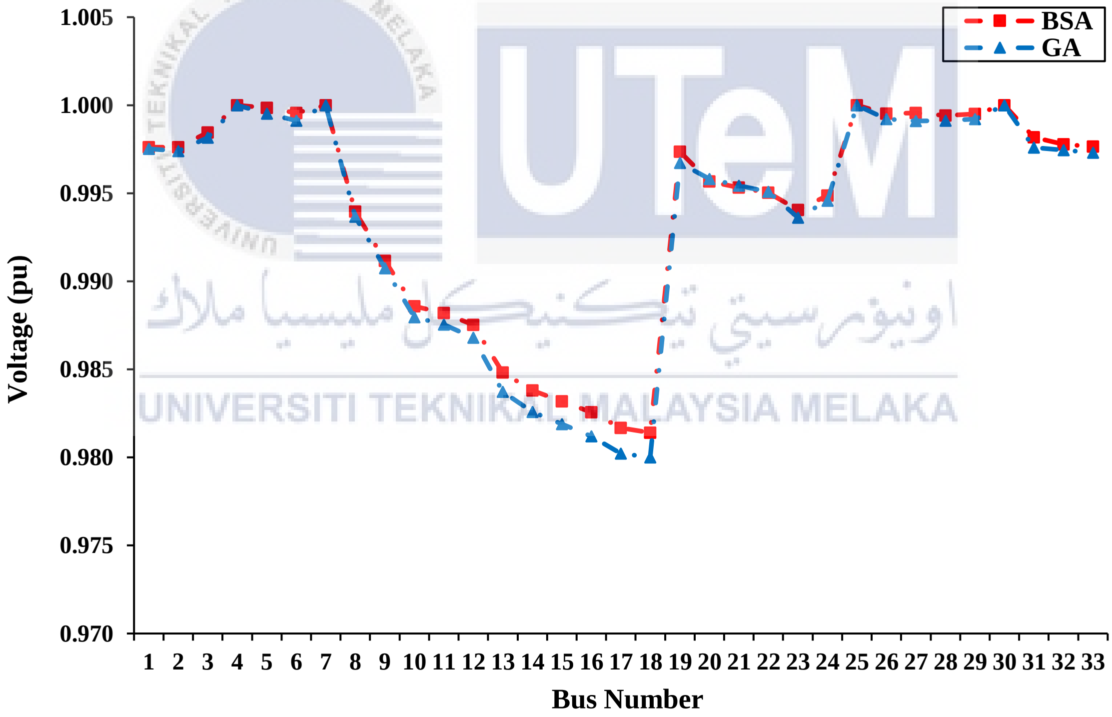


Figure 4.15: Voltage profile obtained by BSA and GA

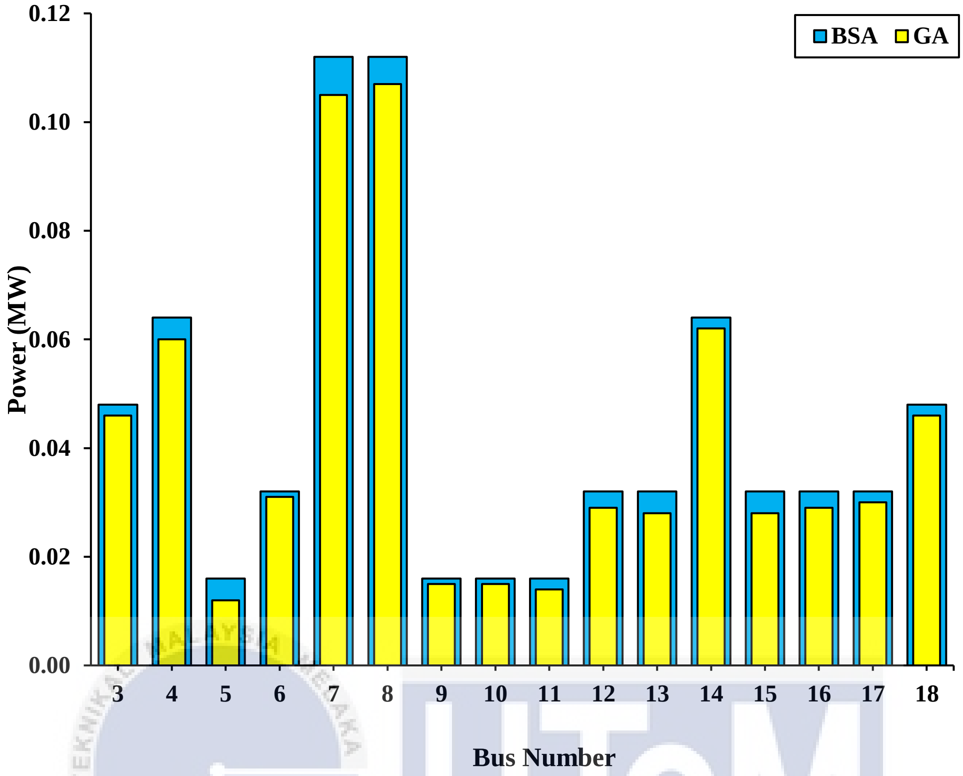
4.6 Optimal Load Shedding for Other Islanded Systems

To validate the effectiveness of load shedding scheme, the similar optimization procedures of load shedding scheme based on GA and BSA techniques that was applied to island power island A are adopted to others islanding scenarios namely, power island B, C and D. The performance of load shedding scheme at hour 14:00 is further analysed. Table 4.6 summarized the statistical findings at hour 14:00 for load demand, load curtailment and total remaining load after the optimization using BSA and GA techniques. Similar with the finding obtained in power island A, the table can infer that load shedding scheme based on BSA optimization technique performs better and more effective compared to GA technique due to less amount of load being curtailed in all the islanded cases.

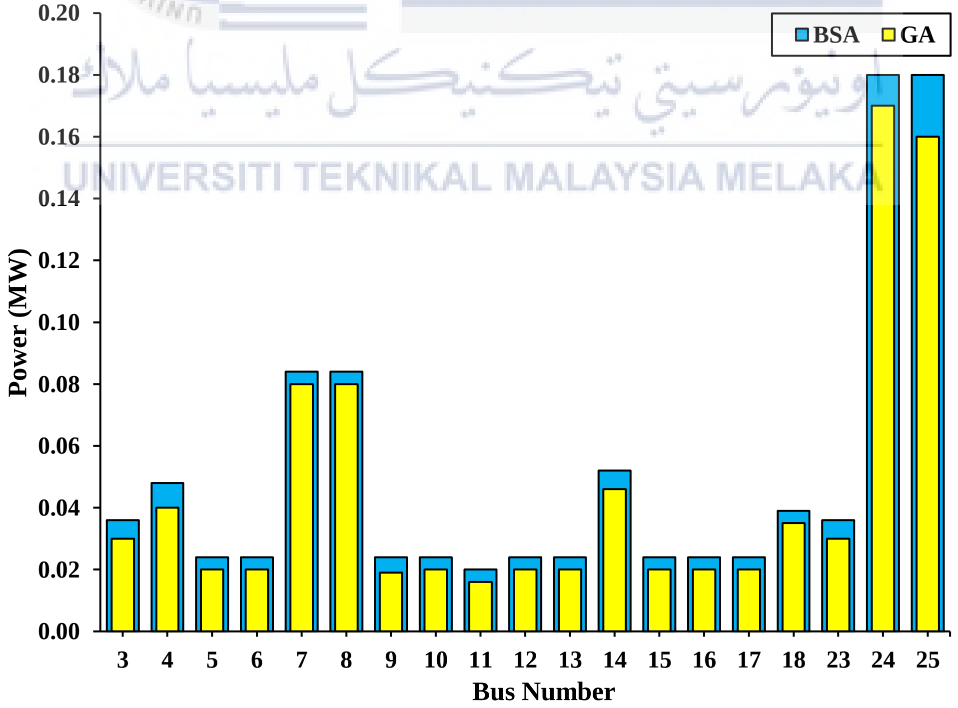
Table 4.6: Summary of load shedding performance at hour 14:00

Island	Load Demand (MVA)	Load curtailment (MVA)		Total remaining load after optimization (MVA)	
		BSA	GA	BSA	GA
B	1.405 + j0.680	0.701 + j0.350	0.918 + j0.420	0.704 + j0.330	0.487 + j0.260
C	2.335 + j1.105	1.360 + j0.426	1.469 + j0.500	0.975 + j0.679	0.866 + j0.605
D	2.325 + j1.630	1.232 + j1.224	1.359 + j1.261	1.093 + j0.406	0.966 + j0.369

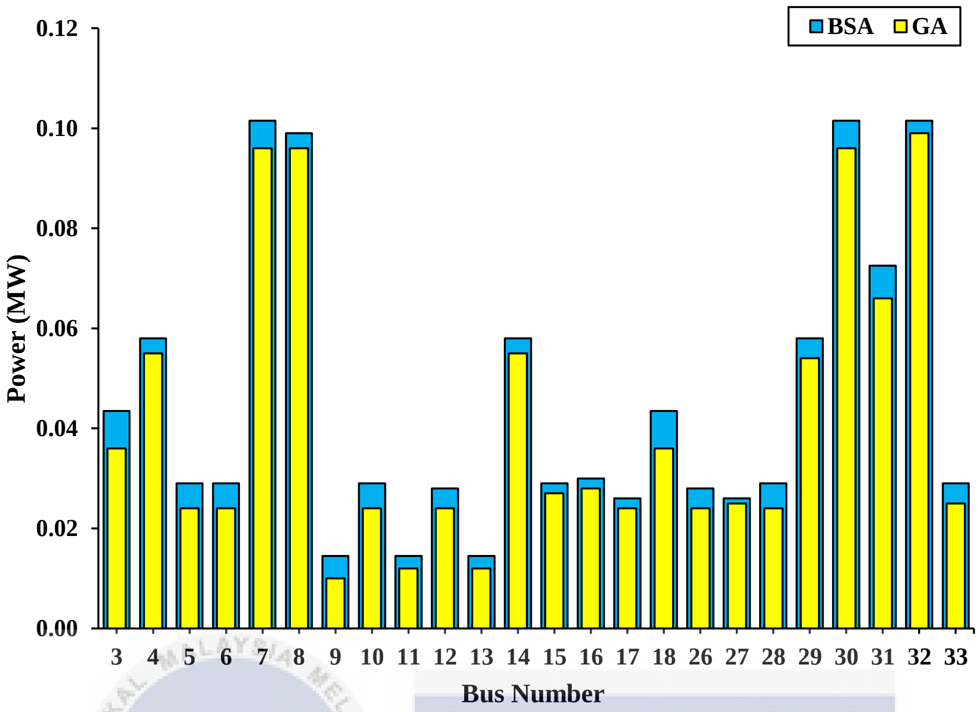
Meanwhile, the statistical findings for power island B, C and D is then summarized in Figure 4.16 and 4.17, which illustrated amount of load (active and reactive) have been curtailed. According to these findings, it can thus be suggested that GA-based load shedding scheme curtails more loads and leaving lesser remaining loads compared to BSA-based scheme in all scenarios of islanded system. These findings prove that the proposed load shedding scheme based on BSA able to decide in determining optimal load to be shed from buses without cutting substantial loads.


BSA
GA
Power (MW)
0.12
0.10
0.08
0.06
0.04
0.02
0.00
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Bus Number

(a)

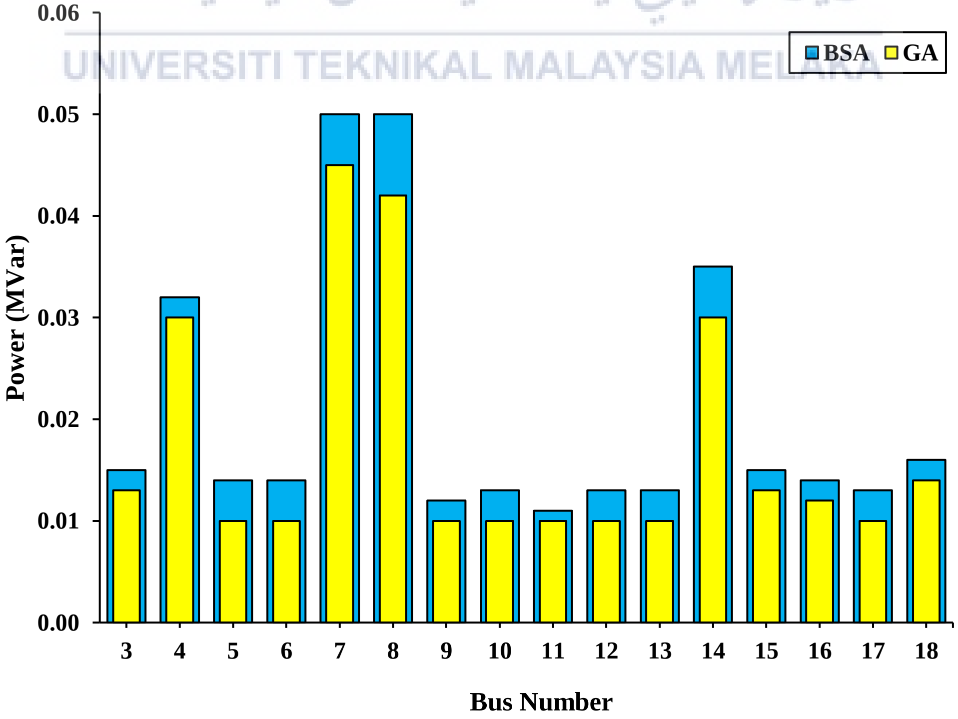

BSA
GA
Power (MW)
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
23
24
25
Bus Number

(b)

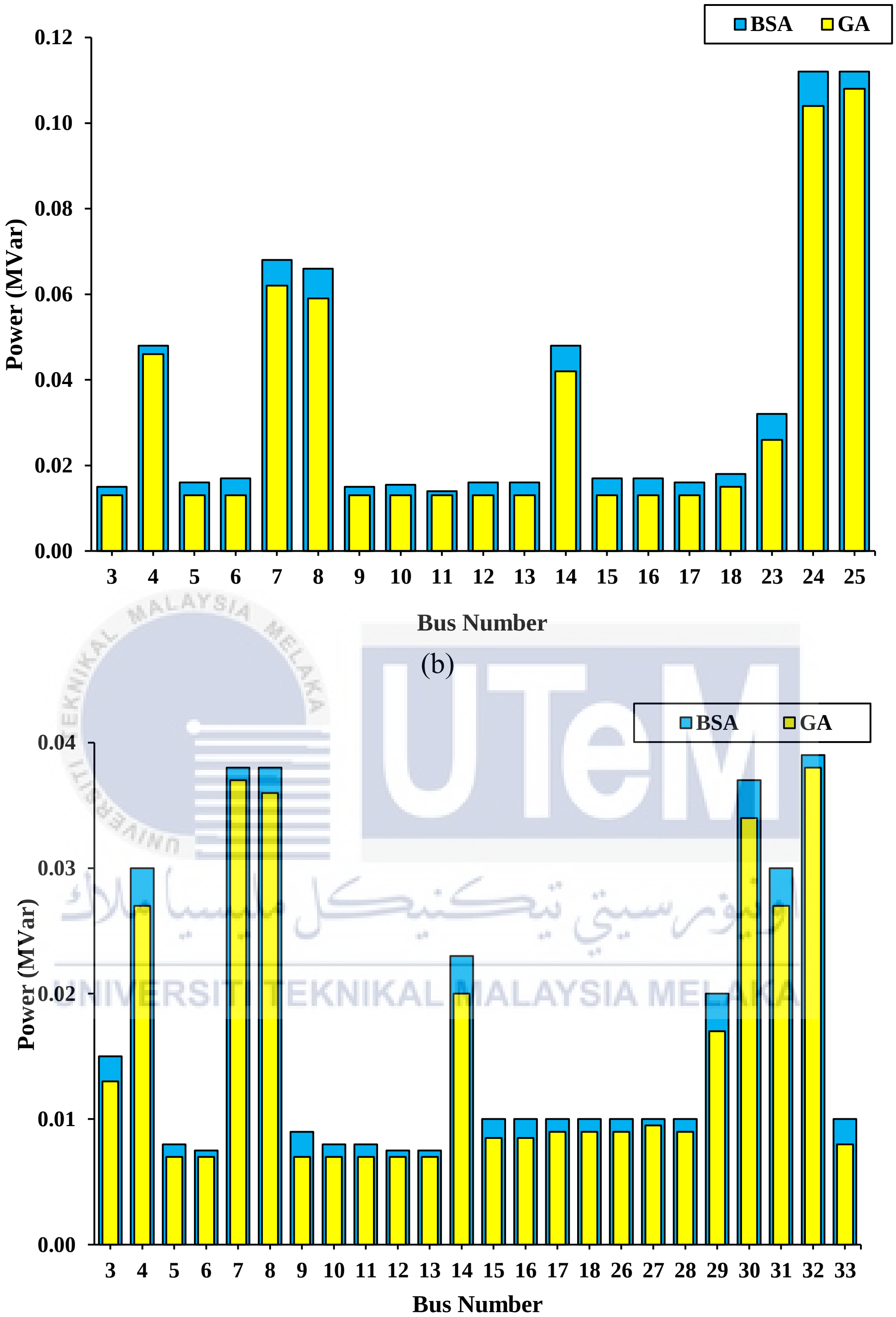


(c)

Figure 4.16: Comparison of individual active load demand after optimization for BSA and GA at hour 14:00 for (a) Power island B, (b) Power island C, (c) Power island D



(a)

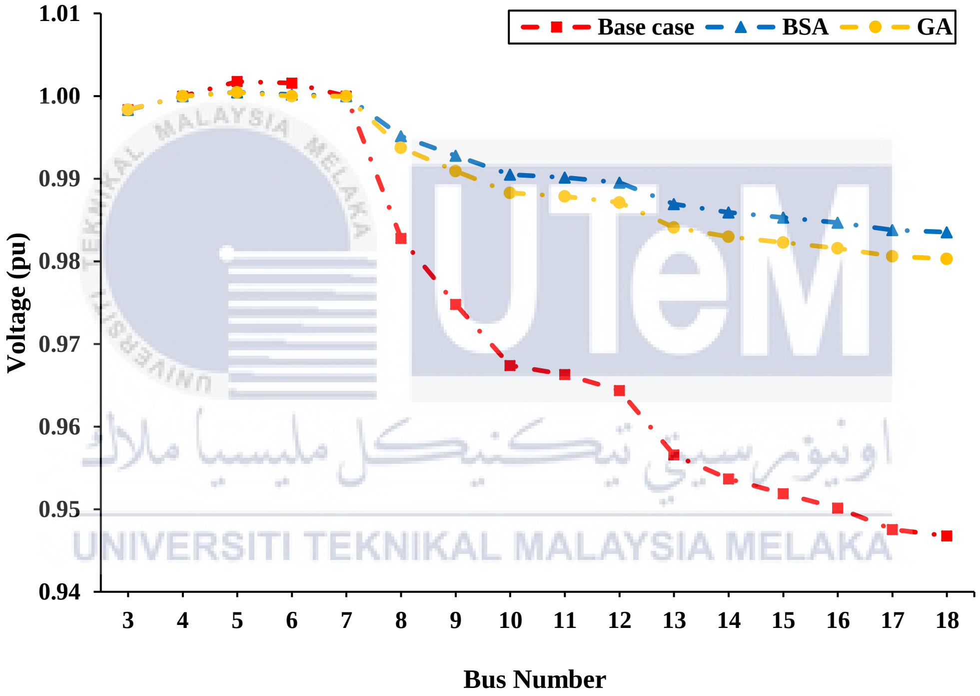


(b)

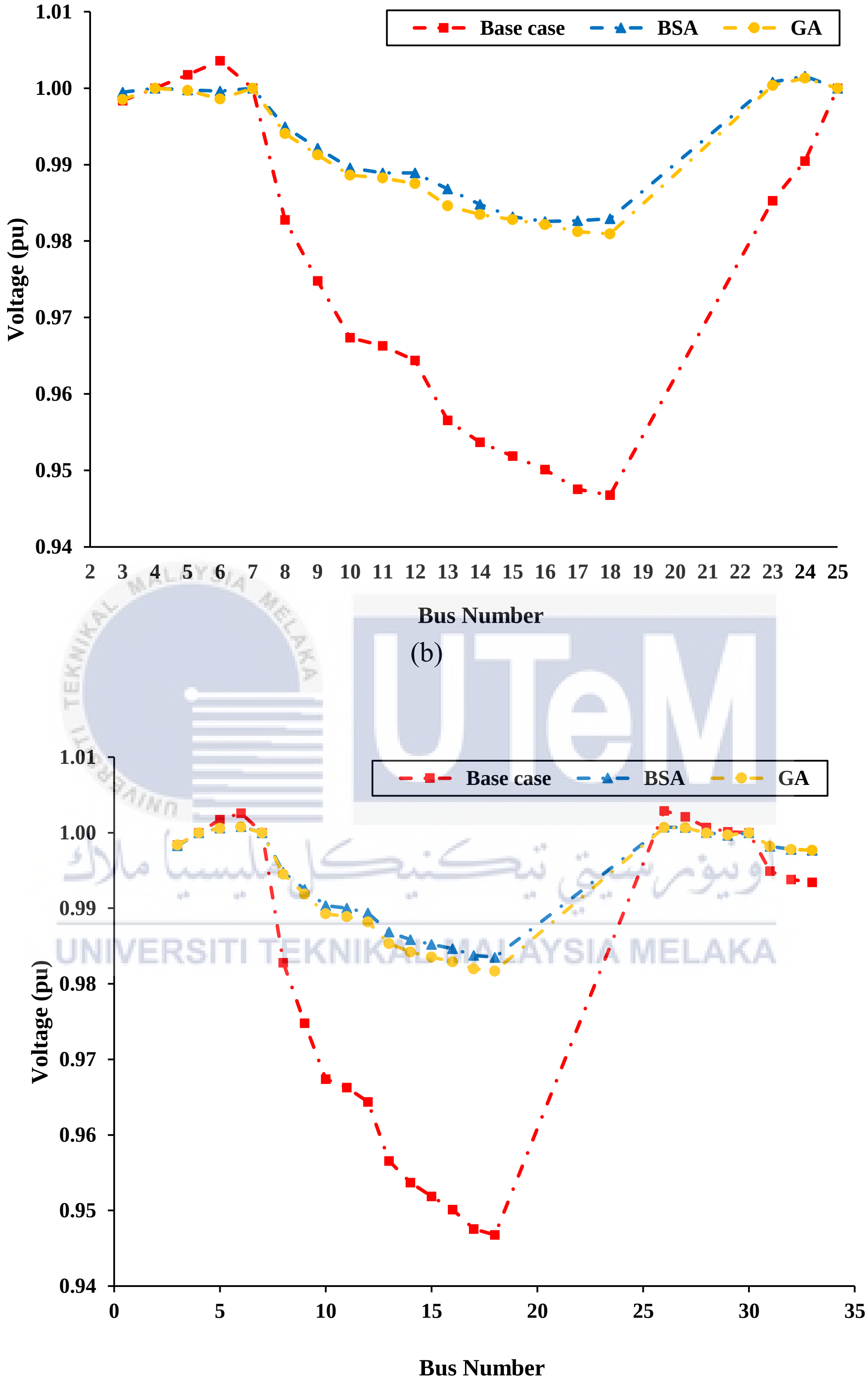
(c)

Figure 4.17: Comparison of individual reactive load demand after optimization for BSA and GA at hour 14:00 for (a) Power island B, (b) Power island C, (c) Power island D

Besides that, Figure 4.18 illustrates the improvement in voltage profile at buses which can be observed after optimization process. There is slightly different in voltage profile performed by load shedding scheme based on BSA and GA. Some of the voltage magnitude obtained from BSA techniques is lower than those obtained from GA. It is possible to be explained that this condition is less likely to occur in larger amount of load being curtailed by GA than BSA in system. However, the improved voltage profiles obtained using BSA and GA techniques are within the acceptable range between 0.98 pu to 1.01 pu, which fulfil the requirement of regulation IEEE 18-2002.



(a)



(c)

Figure 4.18: Comparison of voltage profile before and after load shedding at hour 14:00 for (a) Power island B, (b) Power island C, (c) Power island D

CHAPTER 5

CONCLUSION

5.1 Conclusion

This thesis presented the development of load shedding scheme for distributed generation integrated with radial distribution system. There are three research objectives had been presented, where the first objective was to develop an optimal load shedding scheme after system experiences unintentional islanding condition. Meanwhile, the second objective was to maintain the voltage stability due to load-generation mismatch in islanding condition. Lastly, the third objective is to minimize the amount of active and reactive load to shed without disconnects substantial load in islanding condition.

To accomplish the first objective, a multi-objective function has been formulated to maximize the amount of remaining load (real and reactive load) and the VSM in islanded system. This multi-objective optimization problems are evaluated using power flow algorithm called MATPOWER in MATLAB simulation. To evaluate the optimal load shedding scheme, several islanding cases based on IEEE 33-bus radial distribution system with four DG units are simulated using BSA optimization tool. From the simulation results, it was proven that the proposed load shedding scheme is capable to shed optimum load and maintain the system voltage stability. In addition, the algorithm satisfy all the system constrains such as load priority limit, voltage and generation limits.

To achieve second objective, VSM is used as one of the main objective function in this study. This VSM is utilized in order to estimate the distance of system to voltage collapse. Besides, this element had the capability to evaluate the critical load in an islanded system using the system voltage profile. Therefore, the amount of voltage profile can be maintained at acceptable limits and comply with IEEE Standard 18-2002. From the statistical results, it manages to show an improvement of system voltage profile with minimum load curtailment.

The third objective are addressed by evaluated the objective function in order to optimize the load shedding scheme. By setting higher amount of active and reactive remaining load, less amount of load will be shed. Thus, from the simulation result, it proves that the proposed load shedding scheme based on fitness function constrains is capable to evaluate and deciding the optimal amount of load to be shed without cutting substantial load in the system.

Furthermore, the performance evaluations are investigated for evaluating the effectiveness of proposed technique by comparing the proposed technique with widely used GA optimization method. From the statistical results, several conclusions can be made: i) the proposed BSA technique can optimally determine the amount of load to be shed in the system based on the amount of connected load and amount of generation resources in islanded system, ii) BSA can decide the optimal amount of load to be shed without cutting substantial loads in the system, and the voltage stability can be maintained when the optimal load shedding scheme is applied. Thus, the result proves the effectiveness of the BSA technique in obtaining optimal load shedding scheme in islanded system compared to conventional GA technique.

Therefore, all the test results indicate that the entire research objectives are met and results are effective. The development of the proposed technique in this research fulfilled the recent need for optimal load shedding scheme in radial distribution system with DGs.

5.2 Recommendation

This study presented a better techniques of an optimal load shedding scheme for radial distribution network. Thus, future studies of load shedding scheme are suggested for further development of the research work as follow:

i. The development of load shedding scheme should be implemented and tested in other radial distribution system such as IEEE 37-bus, 69-bus, and 85-bus, in order to validate the effectiveness of proposed load shedding scheme.
ii. The obtained findings from using MATPOWER Newton-Rapson based power flow algorithm in MATLAB® software should be presented in Graphic User Interface (GUI), so that the data presented from the system can be easily understand.

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APPENDIX A

Table A: System data for 33-bus radial distribution network

Branch Number	Sending Bus	Receiving Bus	Resistance Ω	Reactance Ω	Nominal Load at Receiving Bus	
					P (kW)	Q (kVAr)
1	1	2	0.0922	0.0477	100	60
2	2	3	0.4930	0.2511	90	40
3	3	4	0.3660	0.1864	120	80
4	4	5	0.3811	0.1941	60	30
5	5	6	0.8190	0.7070	60	20
6	6	7	0.1872	0.6188	200	100
7	7	8	0.7114	0.2351	200	100
8	8	9	1.0300	0.7400	60	20
9	9	10	1.0440	0.7400	60	20
10	10	11	0.1966	0.0650	45	30
11	11	12	0.3744	0.1238	60	35
12	12	13	1.4680	1.1550	60	35
13	13	14	0.5416	0.7129	120	80
14	14	15	0.5910	0.5260	60	10
15	15	16	0.7463	0.5450	60	20
16	16	17	1.2890	1.7210	60	20
17	17	18	0.7320	0.5740	90	40
18	2	19	0.1640	0.1565	90	40
19	19	20	1.5042	1.3554	90	40
20	20	21	0.4095	0.4784	90	40
21	21	22	0.7089	0.9373	90	40
22	3	23	0.4512	0.3083	90	50
23	23	24	0.8980	0.7091	420	200
24	24	25	0.8960	0.7011	420	200
25	6	26	0.2030	0.1034	60	25
26	26	27	0.2842	0.1447	60	25
27	27	28	1.0590	0.9337	60	20
28	28	29	0.8042	0.7006	120	70
29	29	30	0.5075	0.2585	200	600
30	30	31	0.9744	0.9630	150	70
31	31	32	0.3105	0.3619	210	100
32	32	33	0.3410	0.5302	60	40