OPTIMAL LOAD SHEDDING FOR MICROGRIDS WITH LIMITED DGs (APPLICATION IN PERWAJA STEEL SDN BHD)

WAN NORHISYAM BIN ABD RASHID

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

Faculty of Electrical and Electronics Engineering
UniversitiTun Hussein Onn Malaysia

DECEMBER 2013

ABSTRACT

Electric generation and transmission systems may not always meet peak demands. However, when the total demand is more than the generation, overall demand must be lowered, either by turning off service to some devices or cutting back the supply voltage in order to prevent uncontrolled service disruptions such as power outages or equipment damage. Utilities may impose load shedding on service areas via rolling blackouts or by agreements with specific high use industrial consumers to turn off equipment at times of system-wide peak demand. However it is quite different when this is applied on microgrids. Since microgrid is normally isolated from the main transmission line, therefore they have their own generation which is the distributed generation (DGs). DGs resources can include fuels cells, wind, solar or other energy sources. Distributed generation allows collection of energy from many sources and may give lower environmental impacts and improved security of supply. The multiple dispersed generation sources and ability to isolate the microgrid from a larger network would provide highly reliable electric power. Therefore, differential evolution (DE) is applied in a microgrid system in order to optimize the load shedding by reducing the total curtailed load. Direct Reduction (DR) Plant in Perwaja Steel Sdn Bhd. has its own microgrid system which is used to produce direct reduction iron (iron sponge). Load shedding is one of the security measures which are applied in the plant in to maintain the stability of the system. After the load shedding process, more cost is needed to restore the curtailed load. However, cost will be reduced if the total curtailed loads which are needed to be restored are reduced. Therefore DE is applied to reduce the total curtailed load in the DR Plant microgrid system.

ABSTRAK

Sistem penjanaan dan penghantaran elektrik sering kali tidak berjaya memenuhi permintaan yang melebihi penawaran. Walau bagaimanapun, apabila jumlah permintaan adalah lebih daripada elektrik yang dijana, permintaan keseluruhan mesti dikurangkan, sama ada dengan memutuskan bekalan kepada beberapa pengguna atau mengurangkan voltan bekalan untuk mengelakkan gangguan perkhidmatan yang tidak terkawal seperti gangguan kuasa atau kerosakan peralatan. Pihak pembekal elektrik boleh melakukan tindakan ini dengan melakukan pemotongan bekalan elektrik secara bergilir kepada kawasan tertentu atau dengan membuat perjanjian dengan pihak industri yang untuk mematikan peralatan tertentu yang menggunakan peralatan elektrik yang banyak pada waktu beban puncak. Walau bagaimanapun ia adalah agak berbeza apabila ini digunakan pada *microgrids* . Biasanya pemasangan *microgrid* dilakukan berasingan daripada talian penghantaran utama. Oleh itu mereka mempunyai sistem penjanaan elektrik yang tersendiri yang merupakan sistem penjanaan yang berselerak. Contoh – contoh sistem penjanaan berselerak adalah seperti bateri, kincir angin, panel solar atau sumber tenaga yang lain. Sistem penjanaan berselerak membolehkan pengumpulan tenaga daripada pelbagai sumber dan boleh mengurangkan impak buruk kepada alam sekitar dan lebih menjamin keselamatan bekalan elektrik. Ini membolehkan proses penghantaran elektrik dapat dilakukan kepada semua pengguna dengan lebih berkesan. Oleh itu, *differential evolution* (DE) digunakan dalam sistem *microgrid* untuk mengoptimumkan jumlah beban yang dipotong apabila tindakan pemotongan bekalan dilakukan di loji *Direct Reduction* (DR) di Perwaja Steel Sdn Bhd. Tindakan pemotongan bekalan adalah salah satu daripada langkah-langkah keselamatan yang dilakukan di dalam kilang itu untuk mengekalkan kestabilan sistem. DE digunakan bagi mengurangkan jumlah beban yang dipotong dalam sistem *microgrid* di loji DR.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Project Background

Today, electricity is very essential in our daily life. Although long time ago, human can survive without electricity however nowadays it is almost impossible for us to have a comfortable life without electricity. Yet today almost 1.4 billion people worldwide have no access to electric power. As the generation of electric energy source is done mainly using fossil resources and it is distributed nationwide through the grids. Can we imagine what will happen to the human kind when fossil resources depleted. This is where new green technologies play the important role in providing sustainable electrical energy.

The main purpose of this technology is to provide efficient, safe, environmental friendly and economic value added to our life. It will focus on the effort to achieve a high yield of useful energy by maximizing the efficiency, while minimizing the negative side effects on humans, nature and the environment. We are quite familiar with wind power, solar energy, hydropower, biomass and biofuel. These are sources which are used to generate electricity and one of the components which are quite important in supporting the green environment is micro grid.

Micro grid is very ideal in satisfying the growing demand of electricity. It is expected that the demand will rise to 400 giga watts by 2025. To support this demand about 1000 new large power plants need to be built and in addition to that new power lines need to be added to the current existing power lines. It seems difficult however microgrids could help to prevent large blackouts or at least they can provide the power supply for essential equipment during a power failure.

Rather than rely only on large power plants, small distributed generators could take over a part of the power supply, for example, emergency generators, micro-turbines, fuel cells and photovoltaic systems. Such systems typically produce a maximum power of 500 kilowatts and could be used in a mail-sorting facility, an office building or a whole group of consumers supply.

A distributed generator is a generator which generates electrical energy and normally it is owned by the consumer. Normally it is located within or near residential areas or industrial facilities which has small power plants. The performance of the generator is usually designed only to meet the energy needs of the connected consumer in the vicinity. Usually it has isolated networks namely the interconnection of smaller, less power producers and consumers in remote locations that are not connected to the main grids. It is also called as decentralized power generation.

As it is assumed as a network of power system, it will also experience some variations or interruptions during operations. These interruptions are due to sudden increase of electrical load demand, forced outage of a generator or transmission line or defect in equipment of a system. Sudden interruptions without any contingency plan will lead to total blackout in a large section of whole of the power system. That is where the method of load shedding is needed. Load shedding is done by shutting down loads base on priority.

Generally it represents a cut- off which is performed by opening the circuit breakers in substations. The unplanned event will trigger the power protection when certain preset values are exceeded. This process will affect parts of the network and the connected consumer. In special cases, for example in the context of resynchronization of single, larger network segments, load shedding can also be triggered manually by the control centers. Load shedding is the last possible option in order to avoid the complete collapse of the interconnected system and it will stabilize the remaining network segments.

As the distributed generators have many benefits such as to maintain system stability, to provide the spinning reserve for the generator, to reduce the distribution and transmission cost and to reduce the emission from the power plant, it will also introduce new problems, especially in performing optimal load shedding. It is very important to rectify the problem in order to maintain the power balance and system stability. Normally when there are problems in a distributed generation system, operators will shed most of the loads except the important loads which will get the supply from the nearby distributed generators. However this method can't utilize the maximum capacity of the distributed generators. We may face problem in defining the nearby generation when there are multiple distributed generations.

For this purpose a study is done in order to optimize the load shedding in the micro grids with limited number of distributed generators. The load shedding problem will be formulated as an optimization problem. Then the results will be discussed base on the formulated problem.

1.2 Problem Statements

Slowly in the near future both consumers and utility will implement distributed generation in their applications. Distributed generations will provide advantages for both parties. For utility, the stability of the system can be maintained with the help of DGs. It will also help the utility to reduce the transmission and distribution cost. Besides that it will also provide the spinning reserve for the generator at the power plant. The consumers will gain the flexibility of the power supply and the improvement of the power quality. The emission from the traditional power plants can also be reduced.

As more DGs will be installed, new problem will arise namely the optimal load shedding. A lot of studies have been done in order to obtain the optimal load shedding for DGs. Different techniques have been proposed to solve the load shedding problem in distribution network. Aoki et al [1]describes a load curtailment procedure as part of a service restoration algorithm considering a violation vector with current capacity and voltage drop violations as components. A quantity called effective length of remaining violations is defined in[1]. Loads in the end sections of the violating feeders that have the smallest value of this quantity are curtailed. Sharma et al [2]consider load shedding in system with switch able capacitors and on-load tap changers. For voltage drop violations, if the load point with violation does not have a switch able capacitor, it will be shed. For current capacity violation at a component, a low priority load at a point beyond that component is shed. However, the steps to be taken when several current capacity and voltage drop violations are simultaneously present are not specified in this paper. Wang et al [3]investigates the effect of load-shedding procedures on distribution system reliability cost indices. Customer concerns regarding interruption costs are incorporated in the load-shedding decision process when a bulk system deficiency occurs. Cost weight factors for different feeder types, based on capacity and cost match, are used to determine the load-shedding priority among feeders. In [4], an optimal load shedding strategy for power system with multiple DGs is presented and in this paper discretization and mathematical programming has been introduced. In [5], a genetic algorithm is employed to search for supply restoration and optimal load shedding in distribution networks.

However it is very difficult for us to find any literature which will provide us any information regarding the optimal load shedding which can minimize the system loss during unscheduled outages for DGs in micro grids. In [6]authors applied a GA optimization method for load shedding in distribution networks considering DG units.

Hence a new approach is proposed to optimize the load shedding problem in micro grids considering DGs units. Using DE techniques the problem is formulated to minimize the total curtailed load.

1.3 Project Objective

The main objectives are:

- To optimize the load shedding in micro grids in order to reduce the total curtailed load.
- To apply the method to the real power system in DR Plant Perwaja Steel SdnBhd in order to reduce the total curtailed load.

1.4 Project Scope

There are 2 scopes of this project. They are:

- This study is focusing on reducing curtailed load due to load shedding using DE technique.
- The obtained results of 2 DGs represent the limited number of DGs using DE technique.

1.5 Organization of the Thesis

The progress report is orderly into 5 chapters. The content of each chapter explained briefly below.

Chapter 1: presents the background, objective and the scope of the project. The chapter also summarizes the content of the thesis.

Chapter 2: discusses about the theory of the project along with the literature review.

Chapter 3: gives a detail discussion on the design of the project and the methodology used to construct the project.

Chapter 4: elaborate the finding and the results of the project and try to discuss the effect of the results to the case study.

Chapter 5: presents the project discussions, conclusions and recommendations. The conclusions and some future recommendations are also discussed in this chapter.

1.6 Summary

This chapter of this thesis discusses about the introduction for the whole project. Firstly, the principle and concept of the micro grids, distributed generation and load shedding are introduced. Next, the problem statement is discussed. Then, the next part is about the objectives and scopes of the project. Lastly, the thesis outline is discussed which will give an overview for the reader about the thesis.

Chapter 2

LITERATURE REVIEW

2.1 Power System Operation

Electrical energy is the most versatile usable energy, which can also being converted into other forms of energy. It is a prerequisite for any modern industry and cannot be replaced by other energy sources without taking large losses. A power outage is a nightmare for any electrical energy consumers and it will affect the economy and must therefore being limited.

As the electrical energy is very important, creating it is more important. It is being created by a rotating electrical machine namely the generator. It is located at the generation site. Another 2 important components in power system is the transmission or the distribution and the load or consumption. It will become an interconnected power system when these 3 components are connected together through transmission or distribution lines.

In thermal power plants only three-phase synchronous generators are being used. It is also being used in wind turbines and hydroelectric plant. However three-phase asynchronous generators are also being used at the generation site.

The main challenge is to distribute the supply to the whole country via main grids, as the electric current can be distributed with low losses and a lot of area can be supplied by the number of connected power plants. Hence it will ensure the security of the supply. In spite of changes in load or available resources, the goal of the power system needs to be achieved in order to keep the electrical flows and bus voltage magnitudes and angles within acceptable limits.

2.2 Stability

In power system, we cannot avoid to relate it with dynamic and stability of the system. It refers to the capability of the system to return back to its original state after it is interrupted by any disturbance. As we know the power is generated by the synchronous generator which operates in synchronism with the whole system whereby they have same frequency, voltage and phase sequence. The system is stable when it returns to steady state after any disturbances without losing synchronism. It can be categorized into steady state, transient state and dynamic stability.

Steady state stability is the stability of the system under conditions of gradual or relatively slow changes in load. The load is assumed to be applied at a rate which is slow when compared either with the natural frequency of oscillation of the major parts of the system or with the rate of change of field flux in the machine in response to the change in loading.

The study of the power system after a major disturbance is called transient stability. Normally the angle of the load changes after the sudden acceleration of the rotor shaft due to large disturbance. This is where transient stability is very important to study the load angle returns to the steady state after the disturbance has been cleared.

The opposite of the transient stability is the dynamic stability. After a small disturbance, the ability of the power system will be investigated. Normally the small interruptions are caused by random fluctuations in loads and generation level. Although it seems a small problem however catastrophic failure can happened after the rotor angle increase steadily.

2.3 Reliability and Security

In power system, the function of the system is fulfilled when it can satisfy the system load requirement within accepted standards and in the amount desired. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability. Adequacy of the system relates to the existence of sufficient facilities within the system to satisfy the consumer load demand. It means that the facilities supposed to generate sufficient energy and the energy is transferred to the consumer load points via transmission and distribution facilities appropriately.

Security of the system is in the good condition when it is able to respond to disturbances arising within the system. Most of the probabilistic techniques presently available for power-system reliability evaluation are in the domain of adequacy assessment.

2.4 Micro grids

Micro grid is expected to become an important component in the near future. But what is a micro grid, anyway? It is actually items that are available for generating structures whose energy output are supplied to the consumers and they are located close to the customer. Electricity and heat are often considered together in such structures, but this is not always the case.

The microgrid appears as a single consumer by the national supply system. It can be quickly switched on and off from the large network. If a utility company offers cheap electricity, the owner of microgrid may purchase electricity from them. However when the power offered is expensive or fails completely, the consumer can use the microgrid separately.

Micro grids have several advantages: Ideally, they can provide a limited range of power even if the main grids fail to supply the power. In addition, they can be disconnected temporarily when problems occur within its limits, so that large-scale failures can be avoided. In practice, however, the road is still a long way to go. It lacks not only local energy storage, but also standard networking.

Another important advantage of the microgrid is to support the decentralized combined heat and power energy. Ideally only 20 to 40 percent of the energy used can be converted into electricity. The rest is lost as waste heat. Unlike current, heat cannot be transported over long distances. For local power generation, however, the waste heat can be used locally for water heating. Therefore, the generation should take place there, where heat is needed. The residual heat can also dehumidify and cool the buildings. This reduces the heat load which would otherwise consume more electricity. Microgrids could also feed excess power into the national grid, thereby facilitating the supply.

The transition to microgrid does not come overnight. Together with higher efficiency, better transmission lines and renewable energy they contribute to the transition from a decades-long central generation to a new era of flexible, decentralized and environmentally friendly power generation.

2.5 Distributed Generations

Distributed generation is defined as a small-scale electricity generation and normally it is part of micro grids which is mainly used in a limited area. The system has become more popular as it can be operated independently from large power networks. The advantages are their flexibility, a wide range of energy sources usage and the improvement of the CO2 balance in the air. Distributed generations consist of load cells, micro turbines including renewable energy resources such as wind and solar energy.

All energy utilities company worldwide is currently in a transitional phase. On one hand, they are forced to reduce greenhouse gases due to the rapid climate change; on the other hand they need to fulfil the dramatically increasing energy demand from a shortage of fossil fuels. Possible way out of this situation: Decentralized energy supply concepts. Based on renewable energy sources and efficient use of fossil fuels by power-heat coupling, this can make a valuable contribution to solve these problems.

Normally distributed generation is related to the use of renewable energy whereby the goal of using this system is to improve the efficiency and security of energy supply. This requires a demand-oriented design of systems. Compared to the central power supply, detailed knowledge of the existing local demand of electricity and heat requirement is needed to optimize the supply to the customers. Despite increasing number of consumers who are very concern with the energy efficiency and the impact to the environment, new power applications will lead to increasing power demand - combined with higher quality.

2.6 Load Shedding

Power systems are designed and operated so that for any normal system condition, including a defined set of contingency conditions, there is adequate generating and transmission capacities to meet load requirements. However, there are economic limits on the excess capacity designed into a system and the contingency outages under which a system may be designed to operate satisfactorily. For those rare conditions where the system’s capability is exceeded, there are usually processes in place to automatically monitor a power system’s loading levels and reduce loading when required. The load shed processes automatically sense overload conditions, then shed enough load to relieve the overloaded equipment before there is loss of generation, line tripping, equipment damage, or a chaotic random shutdown of the system.

Automated load shedding systems are necessary for industrial power systems since sudden disturbances can plunge a system into a hazardous state much faster than an operator can react. These automated schemes must be designed and implemented to possess in-depth knowledge of system operating parameters and must rely on time sensitive monitoring and control communication networks in order to achieve the desired outcome of fast and optimal load shedding at the onset of a disturbance.

Load shedding serves as the ultimate guard that protects the power system from a disturbance-induced collapse. Normally, this critical load preservation is done with the use of under-frequency relaying and PLC-based schemes. Common drawbacks of these schemes include the lack of detailed system operating information such as pre- and post-disturbance data, system topology and configuration, generation and load distribution, type of disturbances, duration of the disturbances, and other pertinent information. That is why intelligent load shedding is better since all parameters will be incorporated into its calculation and decision making process. Techniques such as Neural Network, Generic algorithm and fuzzy logic have been used in the power system in order to solve the problem effectively.

2.7 Differential Evolution

There are a lot of optimization method such as genetic algorithm, particle swarm optimization and bee colony just to name a few of them. Differential evolution (DE) is one of the optimization methods which are quite popular in computer science study. It is actually a metaheuristics method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. It just makes a few assumptions or sometimes no assumptions at all about the problem which are being optimize and it can look for very large spaces candidate solutions. However there is no guarantee at all that optimal solution can be found. It was introduced by Storn and Price as they tried to solve the Chebychev Polynomial fitting problem.

The general purpose of this optimization method has a number of parameters that determine its behaviour and efficacy in optimizing a given problem. DE offers a way of optimizing a problem without using its gradient. This is very useful if the gradient is difficult or even impossible to derive. It maintains a population of agents which are iteratively combined and updated using simple formulae to form new agents. The practitioner has to set a number of behavioural parameters that influence the performance of this process.

A basic variant of the DE algorithm works by having a population of candidate solutions (called agents). These agents are moved around in the search-space by using simple mathematical formulae to combine the positions of existing agents from the population. If the new position of an agent is an improvement it is accepted and forms part of the population, otherwise the new position is simply discarded. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered.

Formally, let$f: R^n \rightarrow R$ be the cost function which must be minimized or fitness function which must be maximized. The function takes a candidate solution as argument in the form of a vector of real numbers and produces a real number as output which indicates the fitness of the given candidate solution. The gradient of $f$is not known. The goal is to find a solution for$m$ which for$f(m) \leq f(p)$all p in the search-space, which would mean m is the global minimum. Maximization can be performed by considering the function$h \coloneqq -f$ instead.

Let $x \in R^n$designate a candidate solution (agent) in the population. The basic DE algorithm can then be described as follows:

- Initialize all agents x with random positions in the search-space.
- Until a termination criterion is met (e.g. number of iterations performed, or adequate fitness reached), repeat the following:
  - For each agent$x$ in the population do:
    - Pick three agentsa, b , $c$from the population at random, they must be distinct from each other as well as from agent *x*.
    - Pick a random index$\in \{1, \ldots \ldots, n\}$, (n being the dimensionality of the problem to be optimized).
    - Compute the agent's potentially new position$y = [y_1, \ldots \ldots \ldots, y_n]$ as follows:
      - For each *i*, pick a uniformly distributed number $r_i \equiv U\,(0{,}1)$
      - If$r_i < CR$ or$i = R$ then set$y_i = a_i + F(b_i + c_i)$ otherwise set$y_i = x_i$
      - (In essence, the new position is outcome of binary crossover of agent x with intermediate agent$z = a + F(b - c)$.)
    - If$f(y) < f(x)$ then replace the agent in the population with the improved candidate solution, that is, replace $x$with y in the population.
- Pick the agent from the population that has the highest fitness or lowest cost and return it as the best found candidate solution.

Note that$F \in [0{,}2]$ is called the differential weight and$CR \in [0{,}1]$ is called the crossover probability, both these parameters are selectable by the practitioner along with the population size$NP \geq 4$.

2.8 Summary

This chapter has discussed about the literature review for this project. The short review on power system definition and operation is discussed. The explanation of microgrids and distributed generation are also discussed. To relate it with the title of this project, the definition of load shedding is also discussed. Lastly the introduction and basic overview of differential evolution is discussed.

Chapter 3

METHODOLOGY

3.1 Load Shedding Concept

Load shedding is an emergency control action to ensure system stability, by curtailing system load. The emergency LS would only be used if the frequency/voltage falls below a specified frequency/voltage threshold. Typically, the LS protects against excessive frequency or voltage decline by attempting to balance real and reactive power supply and demand in the system. Most common LS schemes are the UFLS schemes, which involve shedding predetermined amounts of load if the frequency drops below specified frequency thresholds. The UVLS schemes, in a similar manner, are used to protect against excessive voltage decline.

The LS curtails amount of load in the power system until the available generation could supply the remind loads. If the power system is unable to supply its active and reactive load demands, the under-frequency and under-voltage conditions will be intense.

To prevent the post-load shedding problems and over loading, the location bus for the LS will be determined based on the load importance, cost, and distance to the contingency location. Coordination between amount of spinning reserve allocation and LS can reduce total costs that generation companies should pay in the emergency conditions.

The number of LS steps, amount of load that should be shed in each step, the delay between the stages, and the location of shed load are the important objects that should be determined in an LS algorithm.

An LS scheme is usually composed of several stages. Each stage is characterized by frequency/voltage threshold, an effective amount of load, and delay before tripping. The objective ofLS scheme is to curtail a minimum amount of load, and provide a quick, smooth, and safe transition of the system from an emergency situation to a normal equilibrium state.

3.2 Power Flow Analysis

Power flow analysis is fundamental to the study of power systems. In fact, power flow forms the core of power system analysis. Power flow study plays a key role in the planning of additions or expansions to transmission and generation facilities. A power flow solution is often the starting point for many other types of power system analyses. In addition, power flow analysis is at the heart of contingency analysis and the implementation of real-time monitoring systems.

Network equations can be formulated systematically in a variety of forms. However the node-voltage method which is the most suitable form for many power system analyses is commonly used. The formulation of the network equation in the nodal admittance form results in complex linear simultaneous algebraic equations in terms of node currents. Thus, the resulting equations in terms of power known as the power flow equations become nonlinear and must be solved by iterative techniques. Power flow studies commonly referred to as load flow are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition power flow analysis is required for many other analyses such as transient stability and contingency studies.

In power flow analysis, normally we will engage with bus admittance matrix. There are four quantities of interest associated with each bus:

1. Real Power, P
2. Reactive Power, Q
3. Voltage Magnitude, V
4. Voltage Angle, δ

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

The slack bus for the system is a single bus for which the voltage magnitude and angle are specified. The real and reactive power is unknowns. The bus selected as the slack bus must have a source of both real and reactive power, since the injected power at this bus must "swing" to take up the "slack" in the solution. The best choice for the slack bus (since, in most power systems, many buses have real and reactive power sources) requires experience with the particular system under study. The behaviour of the solution is often influenced by the bus chosen.

Load Bus (P-Q Bus): A load bus is defined as any bus of the system for which the real and reactive power is specified. Load buses may contain generators with specified real and reactive power outputs. However, it is often convenient to designate any bus with specified injected complex power as a load bus.

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

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

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

It is important to have a good approximation to the load-flow solution, which is then used as a starting estimate (or initial guess) in the iterative procedure. A fairly simple process can be used to evaluate a good approximation to the unknown voltages and phase angles. The process is implemented in two stages: the first calculates the approximate angles, and the second calculates the approximate voltage magnitudes.

3.3 Continuation Power Flow Analysis

As we know, Power Flow Analysis is the backbone of the power system studies. However there is some limitation that needs to be overcome. A particular difficulty being encountered in such research is that the Jacobian of a Newton-Raphson power flow becomes singular at the steady state voltage stability limit. In fact, this stability limit, also called the critical point, is often defined as the point where the power flow Jacobian is singular. As a consequence, attempts at power flow solutions near the critical point are prone to divergence and error. For this reason, double precision computation and anti-divergence algorithms such as the one found in have been used in attempts to overcome the numerical instability.

This paper demonstrates how singularity in the Jacobian can be avoided by slightly reformulating the power flow equations and applying a locally parameterized continuation technique. During the resulting "continuation power flow", the reformulated set of equations remains well-conditioned so that divergence and error due to a singular Jacobian are not encountered. As a result, single precision computations can be used to obtain power flow solutions at and near the critical point.

The continuation power flow (CPF) is an important tool that traces the P–V curves of an electric power system. It also allows the determination of the maximum loading point of a transmission system. The CPF is based on the application of Newton–Raphson (NR) method. The continuation method sequentially predicts a solution (the predictor step) and corrects this predicted solution to return to the P–V curve (the corrector step). It uses an augmented Jacobian of the system to predict a solution in the predictor step. Thereafter, the CPF algorithm uses the traditional NR method to return to the P–V curve in the corrector step. This method of tracing P–V curves has been demonstrated to be very successful for transmission systems.

In the case of radial distribution system (RDS), the system Jacobian formed on the basis of the AC power balance equations is usually ill-conditioned. This is due to a higher R/X ratio in distribution systems lines and a resulting lack of diagonal dominance of the system Jacobian. Further, due to this reason, AC power flow methods are particularly unstable when an RDS is closer to its maximum loading point. This has restricted the use of NR method in determining the voltage solution of a RDS and its extension to form a continuation method for RDS. Hence, while attempting CPF for RDS, one needs to address two issues: (a) develop a stable NR method for RDS and (b) extend this stable NR method through continuation technique for RDS.

3.4 Mathematical Model of the Problem

The load shedding problem can be formulated as an optimization problem with the following objective function and constraints:

$$Min\left(\sum_{k=1}^{N_b} R_k * I_k^2\right) + CL \qquad (1)$$

Such that

$$P_{gi} - P_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \cos\left(\delta_i - \delta_j - \theta_{ij}\right) = 0 \qquad (2)$$

$$Q_{gi} - Q_{di} - V_i \sum_{j=1}^{N} V_j Y_{ij} \sin\left(\delta_i - \delta_j - \theta_{ij}\right) = 0 \qquad (3)$$

$$V_i^{min} \le V_i \le V_i^{max} \quad i = 1 \ldots . N_b \qquad (4)$$

$$P_{ij}^{min} \le P_{ij} \le P_{ij}^{max} \quad i = 1 \ldots . N_1 \qquad (5)$$

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad i = 1 \ldots . N_{DG} \qquad (6)$$

$$Q_{gi} = Q_g \; if \; Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \qquad (7)$$

$$Q_{gi} = Q_{gi}^{min} \; if \; Q_{gi} \le Q_{gi}^{min}$$

$$Q_{gi} = Q_{gi}^{max} \; if \; Q_{gi}^{max} \le Q_{gi}$$

Where:

N_b : $Total\ number\ of\ branches$

R_k : $Resistor\ of\ kth\ branch$

I_k : $Absolute\ value\ of\ current\ of\ the\ kth\ branch$

CL : $Curtailed\ Load$

P_L : $Demand\ active\ power\ of\ Load\ L$

P_{gi} : $Generating\ active\ power\ at\ bus\ i$

P_{gi}^{min} : $Minimum\ limit\ for\ generating\ active\ power\ at\ bus\ i$

P_{gi}^{max} : $Maximum\ limit\ for\ generating\ active\ power\ at\ bus\ i$

P_{di} : $Demand\ active\ power\ at\ bus\ i$

V_i : $Magnitude\ of\ voltage\ at\ bus\ i$

Y_{ij} : $Magnitude\ of\ (i,j) element\ of\ Y_{bus}\ admittance\ matrix$

θ_{ij} : $Angle\ of\ (i,j) element\ of\ Y_{bus}\ admittance\ matrix$

δ_i : $Angle\ of\ voltage\ at\ bus\ i$

Q_{gi} : $Generating\ reactive\ power\ at\ bus\ i$

Q_{di} : $Demand\ reactive\ power\ at\ bus\ i$

V_i^{min} : $Minimum\ limit\ for\ magnitude\ of\ voltage\ at\ bus\ i$

V_i^{max} : $Maximum\ limit\ for\ magnitude\ of\ voltage\ at\ bus\ i$

P_{ij}^{min} : $Minimum\ limit\ for\ active\ power\ of\ branch\ between\ buses\ i\ and\ j$

P_{ij}^{max} : $Maximum\ limit\ for\ active\ power\ of\ branch\ between\ buses\ i\ and\ j$

In the set of equations (1) through (7), $R_k \times I_k^2$ is the Ohmic loss of the kth branch while k refers to kth branch of the network. Equations (2) and (3) are well-known load flow equations. Security and operational constraints have been formulated as (4) and (5). Where, (4) refers to voltage limits and (5) point at thermal limit of distribution lines of the network. Equation set (7) refers to reactive limits of dispersed generators.

The steady state model of DG is used in this project. This model is suitable for some kind of DGs such as gas turbine, combustion engines and hydro generation. DGs are modelled as constant power factor units. Considering this point, the bus connected to the DG can be modelled as PQ bus. The output and the ramp rate are two constraints for this kind of DG. It must be pointed out that minimum output of some generation is an important constraint because of the cogeneration. They must generate certain power to ensure the heat supply. These constraints can be written as set of equations 7 with N_{dg} as the number of installed DG in the system. Now the problem can be stated as minimization of the objective function (OBF) satisfying all system constraints stated above. A DE software package was written for simulation of load shedding in electrical distribution networks with DGs. This program initializes a random sample of individuals with different parameters to be optimized using the differential evolution.

3.5 Differential Evolution

Differential evolution (DE) is a very simple population based stochastic function minimizer and has been found very powerful to solve various natures of engineering problems. DE optimizes the problem by sampling the objective function at multiple randomly chosen initial points. Pre-set parameter bounds define the region from which ‘M’ vectors in this initial population are chosen. DE generates new solution points in ‘D’ dimensional space that are perturbations of existing points. It perturbs vectors with the scaled difference of two randomly selected population vectors. To produce a mutated vector, DE adds the scaled, random vector difference to a third selected population vector (called as base vector). Further DE also employs a uniform crossover to produce trial vector from target vector and mutated vector. The following are 3 fundamental steps which explain the process of DE.

Step-(a) Initialization: Initial population of size ‘M’ is generated.

Step-(b) Mutation: DE mutates and recombines the population to produce a population of ‘M’ trial vectors. Differential mutation adds a scaled, randomly sampled, vector difference to a third vector.

Step-(c) Crossover: DE employs a uniform crossover strategy.

Step-(d) Selection: Objective function is evaluated for target vector and trial vector, trial vector is selected if it provides better value of the function than target vector.

3.6 Progress of the Project

Phase 1: Literature reviews on micro grids analysis, the concept of distributed generation and load shedding.

- To study the basic principle and basic structure of micro grid.
- To discover the micro grid system components.
- To study the islanding operation of micro grid of the main grid.
- To study the concept of differential evolution.

Phase 2: Establish the formulation of load shedding problems

- To formulate the equations and formula for load shedding problem.
- To study the programming method of differential evolution using MATLAB.
- To study the details about power flow analysis.

Phase 3: Simulations and results

- To carry out simulation to find the optimum load shedding.
- To do apply the DE method to minimize the total curtailed load for DR Plant Perwaja Steel Sdn. Bhd.
- To include comments on the test results in the simulation.
- To write discussion along with observation on the simulation results.

3.7 Expected Result

The expected results of this project are:

1. Minimize the total curtailed load for IEEE 69 test bus system.
2. Minimize the total curtailed load for load shedding in the distribution system of Perwaja Steel Sdn Bhd.

3.8 Summary

In this chapter, the basic procedures of load shedding concept, power flow analysis, continuous power flow analysis, test system, mathematical equation for the problem and differential evolutions method are discussed.

In the load shedding concept, the overview of the load shedding procedures was elaborate briefly as well as the alternatives of each of the criteria.

In Power Flow Analysis, the concept for establishing a power flow data set suitable for use in analyses was described.

However there is some limitation of using power flow analysis and the continuation power flow analysis is the method which is used to overcome the limitation. Here the concept of continuation of power flow analysis is described.

Later detailed stages and phases briefly discussed in this chapter. There are three main phases undertaken to complete this studies. The focused generations and loads are briefly discussed. Project planning for two semesters to complete these studies also explained. The three main phases are feasibilities studies, data gathering and simulation and results.

Chapter 4

RESULT AND DISCUSSION

4.1 Test System

Test systems are widely used in power system research and education. The reasons for using test system rather than using a model of practical system is because practical power systems data are partially confidential. Besides that dynamic and static data of the systems are not well documented. Next, calculations of numerous scenarios are difficult due to large set of data. Another reason is because there is lack of software capabilities for handling large set of data and less generic results from practical power system.

For better understanding of test application, broadly they can be categorized as follows:

- Transmission system
- Distribution system
- Unbalanced distribution system

For our case, we are using 69 bus test system which is under category distribution system. The test system for the case study is a 12.66 kV radial distribution system with 69 buses, 7 laterals and 5 tie-lines (looping branches). The current carrying capacity of branch No.1-9 is 400 A, No. 46-49 and No. 52-64 are 300 A and the other remaining branches including the tie lines are 200 A. It is a long radial system with 47 load points totalling 3.8 MW and 2.69 MVar load.

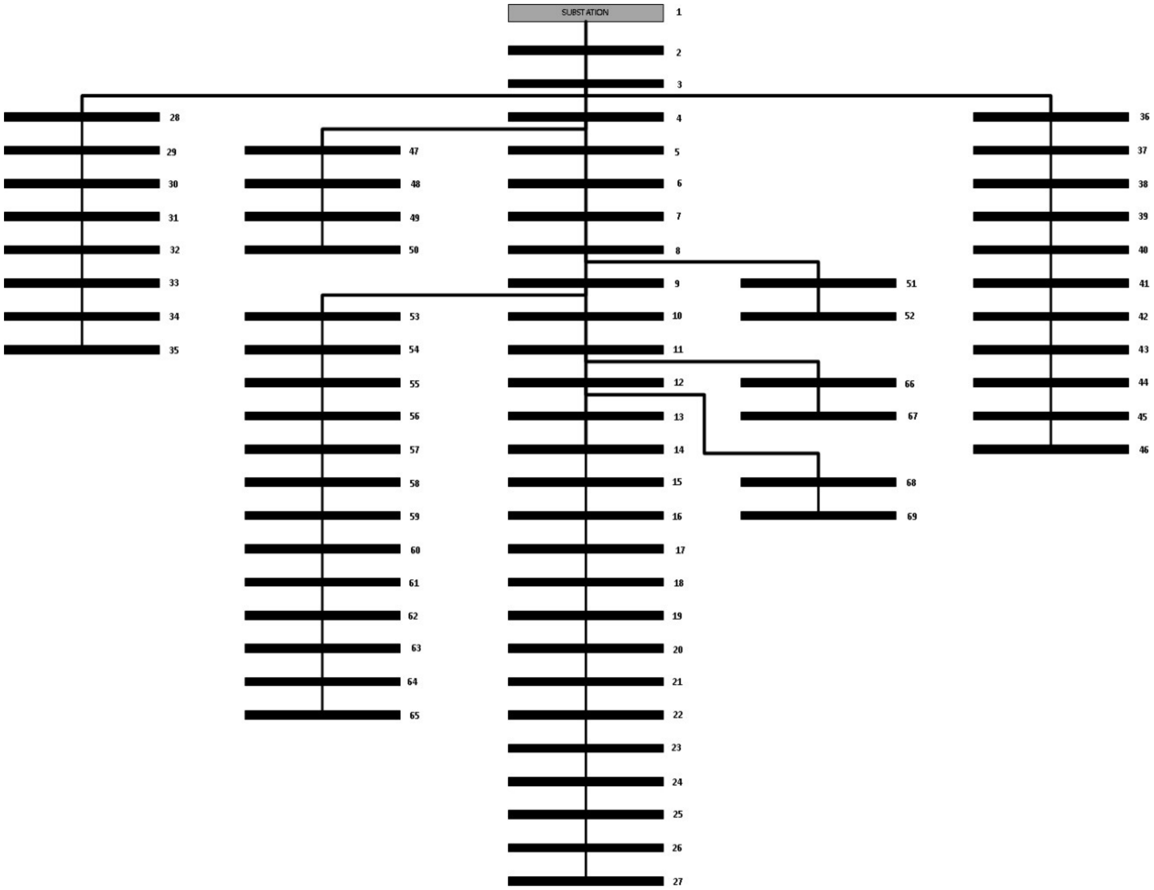

Figure 4-1 : IEEE 69 Test Bus Systems

Table 4-1: Line and Load Data of 69 Bus Systems from Bus 1 to Bus 29

Branch Number	Sending End Node	Receiving End Node	R (Ohm)	X (Ohm)	PL (kW)	QL (kVar)
1	1	2	0.0005	0.0012	0	0
2	2	3	0.0005	0.0012	0	0
3	3	4	0.0015	0.0036	0	0
4	4	5	0.0251	0.0294	0	0
5	5	6	0.366	0.1864	0.0026	0.0022
6	6	7	0.381	0.1941	0.0404	0.03
7	7	8	0.0922	0.047	0.075	0.054
8	8	9	0.0493	0.0251	0.03	0.022
9	9	10	0.819	0.2707	0.028	0.019
10	10	11	0.1872	0.619	0.145	0.104
11	11	12	0.7114	0.2351	0.145	0.104
12	12	13	1.03	0.34	0.008	0.0055
13	13	14	1.044	0.345	0.008	0.0055
14	14	15	1.058	0.3496	0	0
15	15	16	0.1966	0.065	0.0455	0.03
16	16	17	0.3744	0.1238	0.06	0.035
17	17	18	0.0047	0.0016	0.06	0.035
18	18	19	0.3276	0.1083	0	0
19	19	20	0.2106	0.069	0.001	0.0006
20	20	21	0.3416	0.1129	0.114	0.081
21	21	22	0.014	0.0046	0.0053	0.0035
22	22	23	0.1591	0.0526	0	0
23	23	24	0.3463	0.1145	0.028	0.02
24	24	25	0.7488	0.2475	0	0
25	25	26	0.3089	0.1021	0.014	0.01
26	26	27	0.1732	0.0572	0.014	0.01
27	3	28	0.0044	0.0108	0.026	0.0186
28	28	29	0.064	0.1565	0.026	0.0186
29	29	30	0.3978	0.1315	0	0

REFERENCES

[1] K. Aoki, N. Nara, M. Itoh, T. Satoh and H Kuwabara, "A new algorithm for service restoration in distribution systems," *IEEE PWRD,* vol. 4, no. 3, pp. 1832-1839, 1989.

[2] K.A. Palaniswanny and J. Sharma, "Optimum load shedding taking into account of voltage and frequency characteristics of loads," *IEEE Transactions on Power Appratus and Systems,* vol. 104, no. 6, pp. 1342-1348, 1985.

[3] P. Wang and R. Billinton, "Optimum load shedding technique to reduce the total customer interruption cost in a distribution system," *IEEE Proc. Generation Transmission Distribution ,* vol. 147, no. 1, pp. 51-56, Jan 2000.

[4] Ding Xu and Adly Girgis, "Optimal Load Shedding Strategy in Power Systems with Distributed Generation," *IEEE Winter Meeting, Power Engineering Society,* vol. 2, pp. 788-792, 2001.

[5] W.P. Luan, M.R. Irving and J.S. Daniel, "Genetic algorithm for supply restoration and optimal load shedding in power system distribution networks," *IEE Proc-Gener.Transm.Distrib,* vol. 149, March 2002.

[6] R. Malekpour, A. R. Seifi and M. R. Hesamzadeh, "Considering Dispersed Generation in Optimal Load Shedding for Distribution Networks," in *14th Iranian Conference on Electrical Engineering ICEE2006*, 2006.

[7] T. Ackermann, G. Andersson and L. Soder, "Distributed Generation: A Definition," *Electric Power Systems Research,* vol. 57, pp. 195-204, 2001.

[8] A. Malekpour and S. A. R, "An Optimal Load Shedding Approach for Distribution

Networks with DGs Considering Capacity Modelling of Bulked Power Supply".

[9] A. L.D, S. Pushpendra and LS Titare, "Differential Evolution Applied for Anticipatory Load Shedding with Voltage Stability Considerations," 2012.

[10] TKA Rahman, SRA Rahim and I. Musirin, "Optimal Allocation and Sizing of Embedded Generators," in *National Power and Energy Conference (PECon) 2004 Proceeding*, Kuala Lumpur, 2004.

[11] Hadi Saadat, Power System Analysis, McGraw Hill, 2004.

[12] Kwang Y. Lee and Mohamed A. El-Sharkawi, Modern Heuristic Optimization Techniques, Theory And Applications To Power System, IEEE Press Editorial Board, 2008.

[13] Y Halevi and D. Kottick, "Optimization of Load Shedding System," *IEEE Transactions in Energy Conversion,* vol. 8, pp. 207-213, 1993.

[14] L.P. Hajdu, J. Peschon, W.F.Tinney and D.S. Piercy, "Optimum load shedding policy for power systems," *IEEE Transactions on Power Apparatus and Systems,* vol. 87, no. 3, pp. 784-795, 1968.

[15] Ding Xu and Adly A Girgis, "Optimal Load Sheding Using Dynamic Model," in *IASTED Conference Power and Energy Systems(PES)*, Marbella, Spain, 2000.

[16] John Doughlas, "Power Delivery in the 21st Century," *EPRI Journal,* Summer 1999.

[17] N.D.R Sarma, S. Ghosh, K.S. Prakasa Rao and M. Srivinas, "Real Time Service Restoration in Distribution Networks - a practical approach," *IEEE PWRD,* pp. 2064 - 2070, 1994.

[18] P. Daly and J. Morrison, "Understanding the Potential Benefits of Distributed Generation on Power Delivery Systems," in *IEEE Power Engineering Society Summer Meeting*.

[19] Kevin Warwick, Arthur Ekwue and Raj Aggarwal, "Artificial Intellignet techniques in Power Systems," *The Institution of Electrical Engineers London,* 1997.