BLACKOUTS MITIGATION OF POWER SYSTEM USING FUZZY TECHNIQUE

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BLACKOUTS MITIGATION OF POWER SYSTEM USING FUZZY TECHNIQUE

SITI NUR AIN BINTI ABDUL KADIR

A report submitted in partial fulfilment of the requirements of the award of the degree of Bachelor of Electrical Engineering (Power System)

Faculty of Electrical and Electronics Engineering
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STATEMENT OF AWARD FOR DEGREE

Bachelor Final Year Project Report

Report submitted in partial fulfilment of the requirements for the award of the degree of Bachelor of Electrical and Electronic Engineering (Power System).

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Electrical and Electronic Engineering (Power System).

Signature :

Name of supervisor : DR. AHMED MOHAMED AHMED HAIDAR

Date : JUNE 2012

STUDENT'S DECLARATION

I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature :

Author : SITI NUR AIN BINTI ABDUL KADIR

Date : JUNE 2012

Dedicated to my parents:

Abdul Kadir Bin Othman and Jamilah Binti Mohd Derim;

and siblings:

Siti Intan Syafinaz Binti Abdul Kadir and Siti Nur Syazwani Binti Abdul Kadir.

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ABSTRACT

Recently, power system protection devices have often been blamed for contributing to system disturbance. Indeed, current major blackouts found that false tripping of these devices play an important role in initiating and propagating cascading events. Various reasons have been declared for these failures. In this project, the main objective is to develop a technique based on fuzzy to reduce blackouts during emergency conditions. The first stage of this project is power flow analysis which is used to find the input data to apply to fuzzy technic. In the second stage, fuzzy logic method is used to detect the capability of power that should be shedding from the system in case of line outage happen in the power system. The proposed fuzzy technic is tested on IEEE 5 and 30-bus system utilizing the MATLAB. The presented results versify show that by using the proposed technique various power system blackouts may be prevented.

ABSTRAK

Kebelakangan ini, peranti perlindungan sistem kuasa telah sering dipersalahkan kerana menyumbang kepada gangguan sistem kuasa. Malah, kejadian teruk semasa tiadanya bekalan elektrik adalah berpunca daripada peranti yang tidak berfungsi dengan baik iaitu berfungsi apabila tiadanya berlaku apa-apa masalah pada sistem kuasa yang mana berperanan penting dalam memulakan kejadian buruk yang saling berkait. Pelbagai alasan telah diisytiharkan yang disebabkan oleh kegagalan tersebut. Di dalam projek ini, matlamat utama adalah membina teknik berdasarkan fuzzy untuk mengurangkan ketiadaan bekalan elektrik semasa kejadian-kejadian kecemasan. Pada peringkat pertama projek ini adalah analisis aliran kuasa yang mana akan digunakan sebagai data input untuk aplikasi teknik fuzzy. Pada peringkat kedua, kaedah fuzzy logic digunakan untuk mengesan kuasa keupayaan yang patut diagihkan daripada sistem sekiranya berlaku talian yang tiada bekalan elektrik dalam aliran kuasa. Kaedah yang dicadangkan diuji pada IEEE sistem 5 dan 30-bas dengan menggunakan perisian MATLAB. Keputusan telah membuktikan bahawa kaedah yang dicadangkan dapat mengatasi pelbagai masalah ketiadaan bekalan elektrik dalam sistem kuasa.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
CE-Net	Cause-Effect Network
EMS	Energy Management System
ES	Expert Systems
FDARC	Fault Diagnosis and Restoration Control
FIS	Fuzzy Inference System
FL	Fuzzy Logic
FLT	Fuzzy Logic Toolbox
GUI	Graphical User Interface
KBS	Knowledge-Based Systems
MF	Membership Function
NR	Newton Raphson
SCADA	Supervisory Control and Data Acquisition
TNB	Tenaga Nasional Berhad
UFLS	Under Frequency Load Shedding

CHAPTER 1

INTRODUCTION

Blackout or power outage is the effect of power quality problems. In power supply networks, the generation of power and the electrical load or demand side must be very close to equal every second to avoid components of network overloading that can damage them severely. The components used to automatically detect overloads and to disconnect circuits at risk of damage are the protective relays and fuses. However, under certain conditions, the shutting down of component can cause current fluctuations in the network neighbouring segments leading to a cascading failure of a larger section. For instance, this may range from a building to a block, to an entire city and unfortunately to an entire electrical grid [1].

1.1 Expert System

Knowledge-based or expert systems is called of Artificial Intelligence (AI) programs that achieve level of expert competence by solving problems in task areas, by bringing to bear knowledge body about specific tasks. In contrast to gather knowledge from textbooks or non-experts, these expert systems term is reserved for programs whose knowledge base contains used by human experts of knowledge. More often than not, the two terms, expert systems (ES) and knowledge-based systems (KBS) are used having the same meaning. By taken together, they represented the most widespread AI application type.

The attempt to achieve in human intellectual area to be captured in ES is called the task domain that can be refers to some goal-oriented or problem-solving activity while domain refers to the area within which the task is being performed. Diagnosis, planning, scheduling, configuration and design are among the typical tasks [2].

Knowledge engineering is called for building the ES and the knowledge engineers are called its practitioners. There are the two responsibilities for the knowledge engineer where they must make sure that the computer has all the knowledge needed to solve a problem and select one or more forms in which to represent the required knowledge as patterns of symbol in the memory of the computer. In addition, that person must ensure that the computer can use the knowledge efficiently by selecting from a handful of reasoning methods [2].

1.2 Fuzzy Logic

To start with, another words used for fuzzy is usually known as confused or indistinct or vague. However, fuzzy logic (FL) in this world nowadays is precise for developing sophisticated control system [3, 4]. The real reason behind it is very simple which FL can addresses the applications perfectly as it have common in quality of human decision making with an ability to generate accuracy solutions from certain or approximate information. In conventional way, all designs of control and system needed purely mathematical and logic-based approaches but by the presence of FL, it fills the gap in engineering design methods. In similar words, when other approaches require precise equations to model behaviours of real-world, FL design can fit the need of the real-world human language and logic inexactness [4].

Studies and experimental simulation on power outage in power flow for power supply networks have been carried out in large scale. Seyedi and Pasand [5] proposed new centralised adaptive load-shedding algorithms to mitigate power system blackouts. Carreras et al. [6] have investigated the relation between complex system dynamics impact the assessment and blackout risk mitigation. Tamronglak et al. [7] have studied on protective system hidden failures and determined to supervise their actions in highly stressed power operations time where the main contribution of this paper is to develop a method that helped solved the blackout problem. In addition, other studies for dynamic preventing and control methods for event of blackout have been conducted [8-11].

In this thesis, the study has been made using the standard IEEE 5 and 30-bus system. This study utilizes Fuzzy Logic Toolbox from MATLAB software. Based on result in simulation, the comparison is defined by the difference from simulation of PF and fuzzy technique. Then, the difference of output is the capacity or the power should be shed to the system in order to mitigate blackout. Besides, this can also prove the accuracy of fuzzy technique compared to the conventional way. Furthermore, the concepts and the performances of using FL are described in paper [12-18]. For instance, Chin [12] proposed fast diagnosis system to estimate power system fault section by using hybrid cause-effect networks and FL. He took the fuzzy set operation advantage and made the proposed system more systematic and easily detected the fault sections. Thus, FL is chosen for this project because of the advantages that stated in several paragraphs before.

1.3 Problem Statement

The problem statement of this project is as follows:

i. Increasing the number of power failure occurred primarily in Malaysia.
ii. Some line outages happen and causing major blackout.
iii. Intelligent technique such as fuzzy technique is not widely used.

1.4 Objectives

The objective of this project is to:

i. Evaluate the behaviour of power system before and after faults or contingency.
ii. Apply fuzzy technique for blackout mitigation.
iii. Verify this proposed technique with the conventional technique using data from the real power system.

1.5 Study Scope

The scope of this project is to:

i. Data collection
ii. Modelling and simulation of IEEE standard systems.
iii. Implementing the MATLAB coding for system analysis
iv. Applying FLT to calculate the load-shedding

CHAPTER 2

LITERATURE REVIEW

Power system for the most part is in steady state operation or in a state that could with sufficient accuracy. Moreover, there are always small load changes, switching actions, and other transients occurred so that in a complicated mathematical sense most of the variables are varying with the time [19]. There are much of studies that conducted in order to evaluate the performance of the effectiveness of FL in replacing the conventional way to solve power flow in power system. The difference between the other studies with this project is it used the real power flow data to determine the power of load-shedding as defined in chapter before. In this chapter, a few paper are been reviewed in order to understand the importance of this study.

2.1 Fault Section Diagnosis

By using information on operation of relays and circuit breakers, the fault section in power system can be identified. In order to make less the outage time and ensure stable supply of electric power for the customers, it is essential for dispatchers to quickly identify the fault section to start restorative operations. The fault section diagnosis can be stressful, consumed much time and the accuracy is restricted by the information availability as multiple protective devices mal-operations are involved [12].

The fast and fuzzy implication has been used and the fault section thus found very accurately. In addition, the results show that the proposed system which is by using FL and integrated with cause-effect network (CE-Net), is a very effective method and has the following advantages compared to conventional methods. The advantages are “fast and simplicity in inferring procedures, robustness in dealing with uncertainties and easiness of database maintenance” [12].

2.2 Load Behaviour under Blackout Conditions

The risk of blackouts seems to be systematic in interconnected power systems despite all efforts to prevent them has been recognised. Furthermore, accurate knowledge of load behaviour after blackouts, especially at the re-energisation instant, it is important to determine the best restoration building blocks (RBB) arrangements in order to produce secure and fast restoration actions. The problem is during the period of blackout, the load blocks characteristics can differ significantly that depended on load composition, type of equipment control, ambient temperature, day time and blackout of duration time [13].

The used of the expert system and along with the FL concepts application is succeeded deal with the inaccuracies and analytical difficulties imposed by conditions of restoration. The fuzzy expert system is responsible for the most important physical phenomena representation involved with the process of load re-energisation [13].

2.3 Voltage Stability Enhancement

Reliable power system requirement is to maintain voltage within the permissible ranges to ensure customer high quality service where in modern bulk power system, voltage instability would lead to blackout. This is major worry in power system planning and operation. It is characterized by variation in voltage magnitude which gradually decreases to sharp value accompanied with simultaneous decrease in power transfer from source to load end. The existing method is based on line based voltage stability index that detected critical lines for specific load scenario to monitor the system prior for experienced line outage [14].

Then, the voltage stability assessment via line based stability index is analysed using fuzzy based controller. The uncertainties at the input parameters is been dealt with the fuzzy sets. The fuzzy voltage stability index clearly showed the critical busbar location and status. Thus, the new technique has been achieved which is fuzzy based index and also performed according to expectations on power system under all possible conditions. The method will be highly beneficial to ensure power system voltage security by predicted the voltage collapse nearness with respect to the load condition and helped in determined the maximum load ability without causing voltage instability [14].

2.4 Prevent a System Blackout

Even when power systems are equipped with sophisticated systems like energy management system/supervisory control and data acquisition (EMS/SCADA) and automatic devices, they cannot prevent the system blackout from occur though rarely happen but might cause severe damage to the economy and social life. The operator experience can only be gained from practice but severe fault might occur only once in several years. In addition, one fault type experience might not applicable for other type of faults. In worst scenario, the operator might be confronted with hundreds of alarms of EMS without any analysis that made the operator became difficult to identify the main faults cause and might lead to the wrong decision [15].

The expert system that named as Fault Diagnosis and Restoration Control (FDARC) program that based on FL techniques has leave and impression results.

The test that has been conducted has shown that this system is reliable, simple to use and maintain for the operators as the tool to prevent the blackout of the system [15].

2.5 Adaptive Load Shedding Algorithm using a Real Network

Blackouts of power system have been a historical problem in interconnected grids. However in recent years, this phenomenon frequency and severity has considerably increased. This may be in part the new regulations effect and restrictions imposed by power system deregulation. Furthermore, it is not possible to completely prevent these catastrophic failures. By improving monitoring, control and protection techniques, this problem frequency and severity may be reduced [20].

During power system normal operation, the generation amount is equal to the load plus losses amount. If following a disturbance, either the amount of generation decreases or the amount of load suddenly increases, the generation and load plus losses balance would be break and the frequency begins to decline. Shedding a suitable load amount can match the imbalance between load and generation to avoid possible system collapse [20].

Under Frequency Load Shedding (UFLS) scheme is one of the most commonly used system protection which is the type of protection scheme is conventionally designed to preserve the generation and consumption equilibrium, following the outage of some generating units. In conventional design, the only measured system parameter that involved in decision making is frequency. This type of UFLS is simple and easy to implement, especially with electromechanical relays but it suffers from some disadvantages. The most important disadvantage is its adaptability lack. For instance, regardless of the disturbance severity, the settings are constant which may result in either over-shedding or under-shedding indifferent situations [20].

CHAPTER 3

METHODOLOGY

The main aim for this study is to analyse the system to find the optimal value of load shedding. In order to evaluate the configuration, IEEE 5 and 30-bus system as shown in Figure 3.1 (for IEEE 30-bus system) has been chosen as the test system throughout the simulation. Data for research are collected during the simulation. This study utilizes Fuzzy Logic Toolbox (FLT) that included in MATLAB power system simulation package that solve power flow problems. The latest version for MATLAB is version 7.14 which released in March 2012 has been employed in this project.

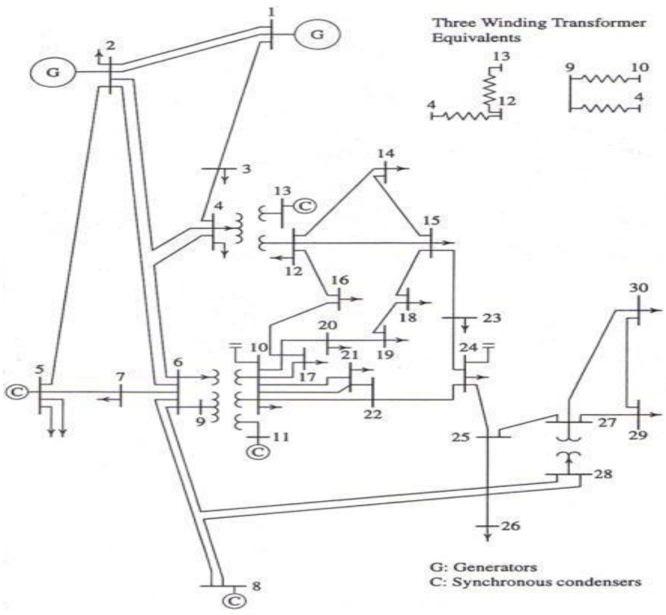

Figure 3.1 Diagram of IEEE 30-bus system

3.1 Flow Chart of the Project

The flow chart of the project is presented as shown in Figure 3.2 below:

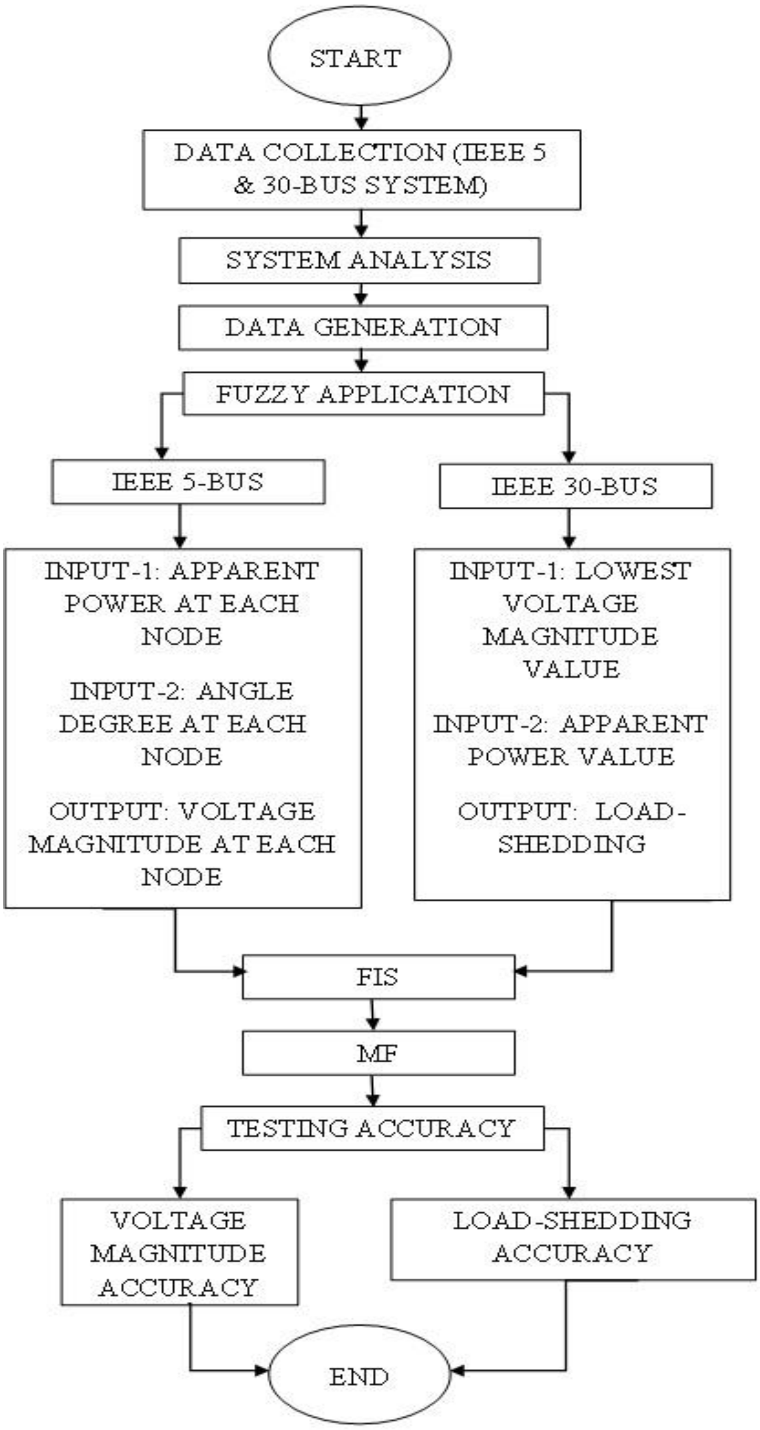

Figure 3.2 Flow Chart of the Project

3.2 Line Power Flow

As mentioned earlier, this project capitalizes MATLAB that it included the power system simulation package which can solve the power flow problems. Generally, MATLAB is for algorithm development, data analysis, visualization, and numerical computation of programming environment. Furthermore, rather than used traditional programming languages, such as C, C++, and FORTRAN, it also helped to solve technical computing problems much faster [21].

For this project, this first step is to run the data of IEEE 5 and 30-bus system. However, the coding has to be checked first like in Figure 3.2. There are three types of power flow iterations, which are by using Newton Raphson (NR), Gauss Seidel or Fast Decoupled Load Flow iteration and in this case, load flow solution by Newton Raphson has been chosen.

```
lfybus                          % form the bus admittance matrix
lfnewton             % Load flow solution by newton raphson method
busout                 % Prints the power flow solution on the screen
lineflow            % Computes and displays the line flow and losses
```

Figure 3.3 Data coding where load flow solution by NR has been chosen

In order to collect the first data, just run the data at the Editor Desktop. The result will be displayed at the Command Window Desktop. Then, just repeat the same steps for the following of 16 (for IEEE 5-bus system) and 20 (IEEE 30-bus system) data collections but removed the “linedata” (only for IEEE 30-bus system) at the “Line code” as shown in **Figure 3.4** and **Figure 3.5**.

```
%                               Line code
%          Bus bus   R       X      1/2 B     = 1 for lines
%          nl  nr  p.u.   p.u.   p.u.      > 1 or < 1 tr. tap at bus nl
linedata=[1   2   0.0192   0.0575   0.02640    1
          1   3   0.0452   0.1852   0.02040    1
          2   4   0.0570   0.1737   0.01840    1
          3   4   0.0132   0.0379   0.00420    1
          2   5   0.0472   0.1983   0.02090    1
          2   6   0.0581   0.1763   0.01870    1
```

Figure 3.4 Before "linedata" at bus 3 to bus 4 is removed

```
%                               Line code
%          Bus bus   R       X      1/2 B     = 1 for lines
%          nl  nr  p.u.   p.u.   p.u.      > 1 or < 1 tr. tap at bus nl
linedata=[1   2   0.0192   0.0575   0.02640    1
          1   3   0.0452   0.1852   0.02040    1
          2   4   0.0570   0.1737   0.01840    1
          2   5   0.0472   0.1983   0.02090    1
          2   6   0.0581   0.1763   0.01870    1
```

Figure 3.5 After "linedata" at bus 3 to 4 is removed

The summarized on line power flow for IEEE 5-bus system is shown in **Table 3.1** and for IEEE 30-bus system which "linedata" has been removed is shown in **Table 3.2**:

Table 3.1 Summarized of IEEE 5-bus system

No.	Apparent Power At Each Node, S (MVA)					Angle Degree At Each Node, δ (°)				
	1	2	3	4	5	1	2	3	4	5
1	88.716	27.634	10.000	58.310	72.111	0.000	-1.623	-2.464	-3.068	-4.287
2	44.055	30.049	22.361	44.721	58.310	0.000	-0.737	-1.338	-1.845	-2.913
3	21.121	40.002	36.056	31.623	44.721	0.000	-0.072	-0.397	-0.819	-1.756
4	52.883	52.406	50.000	20.000	31.623	0.000	0.729	0.615	0.272	-0.544
5	105.146	60.596	64.031	14.142	20.000	0.000	1.305	1.434	1.158	0.441
6	132.325	81.854	78.102	20.000	14.142	0.000	2.238	2.516	2.310	1.708
7	163.618	109.580	92.195	31.623	20.000	0.000	3.156	3.577	3.441	2.950
8	196.797	139.017	106.301	44.721	31.623	0.000	4.059	4.622	4.551	4.168
9	230.841	168.575	120.416	58.310	44.721	0.000	4.950	5.650	5.642	5.364
10	265.256	197.672	134.536	72.111	58.310	0.000	5.829	6.663	6.715	6.540
11	299.786	226.077	148.661	86.023	72.111	0.000	6.696	7.663	7.773	7.698
12	334.292	253.698	162.788	100.000	86.023	0.000	7.553	8.650	8.817	8.838
13	368.700	280.500	176.918	114.018	100.000	0.000	8.401	9.625	9.847	9.963
14	402.965	306.483	191.050	128.062	114.018	0.000	9.240	10.590	10.864	11.073
15	437.065	331.656	205.183	142.127	128.062	0.000	10.071	11.544	11.870	12.169
16	470.989	356.039	219.317	156.205	142.127	0.000	10.894	12.490	12.864	13.253

Table 3.2 Summarized on line outage of IEEE 30-bus system

No.	Line Outage	
	From Bus (n1)	To Bus (nr)
1	-	-
2	29	30
3	28	27
4	26	28
5	2	4
6	12	15
7	6	9
8	18	19
9	19	20
10	15	23
11	6	7
12	12	16
13	27	29
14	22	24
15	6	8
16	5	7
17	27	30
18	1	2
19	6	10
	9	11
20	18	19
	19	20

3.2.1 Modelling of Line Power Flow

The Newton Raphson power flow solution is more efficient and practical than Gauss Seidel method. However, large set of repetitive solution of linear equations in the load flow problem is one of the most time consuming parts of power system simulations. Large calculations number need on account of factorisation, re-factorization and computations of Jacobian matrix. Nowadays, the conventional way has been less popular since the presence of expert system like FL. By using FL systems, the algorithm used in NR method can be converted into the linguistic control. The following are the complicated and long formula that involved in NR method [22]:

Current entering bus *i* in polar form am given by,

$$Ii = \sum_{j=i}^{n} |Yij||Vj| \angle(\theta ij + \delta j) \quad ...(1)$$

Complex power at bus *i* is,

$$Pi - jQi = Vi^{*}Ii \quad \dots(2)$$

Separating real and imaginary part,

$$Pi = \sum_{j=1}^{n} |Vi||Vj||Yij| \cos(\theta ij - \delta i + \delta j) \quad \dots(3)$$

$$Qi = -\sum_{j=1}^{n} |Vi||Vj||Yij| \sin(\theta ij - \delta i + \delta j) \quad \dots(4)$$

In short form,

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \begin{pmatrix} J_1 & J_2 \\ J_3 & J_4 \end{pmatrix} \begin{pmatrix} \Delta\delta \\ \Delta|V| \end{pmatrix} \quad \dots(5)$$

The Jacobian matrix, $J_{1,}$

$$\frac{\partial Pi}{\partial \delta i} = \sum_{j=1}^{n} |Vi||Vj||Yij| \sin(\theta ij - \delta i + \delta j) \quad \ldots (6)$$

$$\frac{\partial Pi}{\partial \delta j} = -|Vi||Vj||Yij| \sin(\theta ij - \delta i + \delta j)\ j \neq i \quad \ldots (7)$$

The Jacobian matrix, $J_{2,}$

$$\frac{\partial Pi}{\partial |Vi|} = 2|Vi||Yij| cos\ \theta ii + \sum_{j=1}^{n} |Vj||Vij||Yij| \cos(\theta ij - \delta i + \delta j) \quad \ldots (8)$$

$$\frac{\partial Pi}{\partial |Vj|} = |Vi||Yij| \cos(\theta ij - \delta i + \delta j)\ j \neq i \quad \ldots (9)$$

The Jacobian matrix, $J_{3,}$

$$\frac{\partial Qi}{\partial \delta i} = \sum_{j=1}^{n} |Vi||Vj||Yij| co\ s(\theta ij - \delta i + \delta j) \quad \ldots (10)$$

$$\frac{\partial Qi}{\partial \delta j} = -|Vi||Vj||Yij| \sin(\theta ij - \delta i + \delta j)\ j \neq i \quad \ldots (11)$$

The Jacobian matrix, $J_{4,}$

$$\frac{\partial Qi}{\partial |Vi|} = -2|Vi||Yij| sin\ \theta ii - \sum_{j=1}^{n} |Vj||Yij| \sin(\theta ij - \delta i + \delta j) \quad \ldots (12)$$

$$\frac{\partial Qi}{\partial |Vj|} = -|Vi||Yij| \sin(\theta ij - \delta i + \delta j)\ j \neq i \quad \ldots (13)$$

The terms $\Delta Pi^{(k)}$ and $\Delta Qi^{(k)}$ are the difference between the scheduled and calculated values (power residuals),

$$\Delta Pi^{(k)} = Pi - Pi^{(k)} \quad \ldots (14)$$

$$\Delta Qi^{(k)} = Qi - Qi^{(k)} \quad \ldots (15)$$

The new estimates for bus voltages,

$$\delta i^{(k+1)} = \delta i^{(k)} - \Delta\delta i^{(k)} \quad \ldots (16)$$

$$|Vi^{(k+1)}| = |Vi^{(k)}| - \Delta|Vi^{(k)}| \quad \ldots (17)$$

There are three types of buses that exist in power flow and are described as follows [23]:

i. Slack bus (swing bus)
   a. Voltage magnitude and angle are specified, reference bus
   b. Solution: Active and reactive power injections
ii. Regulated bus (generator bus, P-V bus)
   a. Models of generation-station buses
   b. Real power and voltage magnitude are specified
   c. Solution: Reactive power injection and voltage angle
iii. Load bus (P-Q bus)
   a. Models of load-centre buses
   b. Active and reactive power is specified (negative values for loads)
   c. Solution: Voltage magnitude and angle

In addition, there are several of reasons in order for blackouts to occur. However, in power system the problems might be infrequently and at random locations. For instance, the Table 3.3 is summarized on the type, description and effects of faults as shown as follow [24]:

Table 3.3 Summarized on the type, description and effects of faults

Faults		
Type	Description	Effects
Active	• Occur when current flows from one phase conductor to another or alternatively from one phase conductor to earth (in simple words, phase-to-phase or phase-to-ground). • Fault can be further classified into two areas which are "solid" that happen when immediate complete insulation breakdown and "incipient" that starts from very small and the developing into "solid" fault.	• Probability for earth faults to spread to other phases will increase. • If occur in plant, mechanical and thermal stressing are higher because of the current fault is carried together to the load. • Motor and generator instability due to voltage dips that lead to extensive shut down of the plant itself and possibly to other plants.
Passive	• Not real faults but rather conditions that are worsening the system beyond its design capacity then developed the Active fault.	• Overloading that lead to insulation overheating and caused the quality to deteriorate, life span of the equipment is reduced and ultimate failure. • Overvoltage that stressed the insulation beyond its limits. • Under frequency which caused the plant to behave incorrectly.

3.3 FL Simulation

3.3.1 Modelling of FLT

The membership degree is known as the function of membership or truth since it establishes a one-to-one correspondence between an element in the domain and the truth value indicating its membership degree that takes the form [25],

$$\mu A(x) \leftarrow f(x \in A) \quad \ldots (18)$$

Let X as objects set which is called as universe, whose elements are denoted x. Membership in a subset A of X is the function of membership, μ_A from X to the real interval [0, 1].

The complement of A, ~A, which is the domain part not in the set can be characterized by Not-A. By inverting the truth function along each point of the fuzzy set then the Not-A is produced and is defined by the membership function [25],

$$\forall x \in X, \mu \bar{A} x = (x) = 1 - \mu \bar{A}(x) \quad \ldots (19)$$

For the base case, the calculation involved is as follows,

$$Ploss\ Accuracy\ (\%) = \frac{Ploss\ from\ PF\ - Ploss\ from\ FL}{Ploss\ from\ PF} \times 100\ \% \quad \ldots (20)$$

For the contingency case, the calculation involved is,

$$Output\ Accuracy\ (\%) = \frac{[Po(A.S)\ - Po(B.S)] - Po(FL)}{[Po(A.S)\ - Po(B.S)]} \times 100\ \% \quad \ldots (21)$$

Where,

Po(A.S): Power output after simulation

Po(B.S): Power output before simulation

Po(FL): Power output of FL

3.3.2 Building Systems Using the FLT

The graphical user interface (GUI) tools are used to build, edit, and view fuzzy inference systems. There are Fuzzy Inference System (FIS) Editor, Membership Function Editor, Rule Editor, Rule Viewer and Surface Viewer.

3.3.3 Fuzzy Inference Systems (FIS)

It is the process of formulating the mapping to output from input by using FL that provides basis which decisions can be made or discerned of patterns [26]. For this study, Mamdani's fuzzy inference method has been used because it is the most common methodology.

3.3.4 Membership Function (MF)

It is a curve that defines how each point in the input space is mapped to a membership value or degree between 0 and 1. The fancy name for simple concept of input space can be referred as the discourse universe. The function itself can be an arbitrary curve whose shape can be defined as function that suitable from the point of view of simplicity, convenience, speed, and efficiency. The FLT included 11 built-in MF types as follows [26]:

i. Triangular: trimf

ii. Trapezoidal: trapmf
iii. Gaussian: gaussmf and gauss2mf
iv. Generalized bell: gbellmf
v. Two sigmoidal: sigmf
vi. Difference between two sigmoidal: dsigmf
vii. Product of two sigmoidal: psigmf
viii. Polynomial: zmf, pimf and smf

3.3.5 Rule Editor

This is user can edit the rules list that defined the system behaviour [26].

3.3.6 Rule Viewer

This is where user can view the fuzzy inference diagram that can be used to do some diagnostic. In another words, “which rules are active, or how individual MF shapes influenced the results” [26].

3.3.7 Surface Viewer

This is where the user can view the one of the outputs dependency on any one or two of input which is it can be generated and plotted the output surface map for the system [26].

3.3.8 Logical Operation

The important thing about fuzzy logical reasoning is the fact that it is standard Boolean logic superset. For instance, if the fuzzy values are keep at their extremes of 1 which is completely true and 0 as the completely false then standard logical operation will hold [26]. For this study, the classical operators for function AND = min and OR = max.

3.3.9 FL

The FIS Editor is opened by typing the 'fuzzy' command at the MATLAB prompt. There are two types of inference which is the default Mamdani-type inference and the Sugeno-type inference. The default Mamdani-type inference is used for the simulation. In the drop-down lists, the fuzzy inference functions can be modified as the following:

i. For **And method**: min is selected
ii. For **Or method**: max is selected
iii. For **Implication method**: min is selected
iv. For **Aggregation method**: max is selected
v. For **Defuzzification method**: Centroid method is selected.

The FIS Editor handles the issues of high level for the system namely the input and output variables number used and their names. In this paper, two input and one output variables are selected. FLT software does not limit the number of inputs. However, the number of inputs may be limited by the available memory of your machine. If the inputs number is too large, or the membership functions (MF) number is too big, then it may also be difficult to analyse the FIS using the other GUI tools [26].

For IEEE 5-bus system, as shown in Figure 3.5, the Input variable-1 is the apparent power at each node, S (MVA) and Input variable-2 is the angle degree at each node, δ (°). Output variable is the voltage magnitude at each node, |V| (p.u). S and δ range varies of ±5% from its original value while for the |V|, it range of ±0.1% from its original value. In this study, five MF are selected for each variable which is labelled as PS, PM, PL, PXL and P for both S and |V| while for δ, it is labelled as L, LM, M, HM and H. The triangular shape is been selected for each variable. Figure 3.6, 3.7 and 3.8 is the MF plot for each of the variable.

Based on the input and output variables descriptions defined with the FIS Editor, the Rule Editor has allowed the user to construct the rule statements automatically, just clicked on and one item is selected in each variable item. In addition, rules might be changed, deleted or added just by clicking the right button It then can also be viewed from the Rule Viewer and the Surface Viewer as shown in Figure 3.9 and 3.10. For this study, rules are defined to determine the accurate value of power of load-shedding where 25 rules are developed. For instance:

i. If **S** is **PS** and **δ** is **LM** then **|V|** is **PL**.
ii. If **S** is **PM** and **δ** is **LM** then **|V|** is **PL**.
iii. If **S** is **PL** and **δ** is **L** then **|V|** is **PL**.

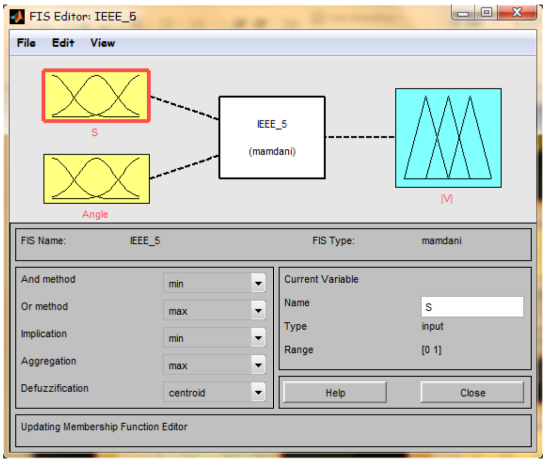

Figure 3.6 Diagram of FIS Editor of IEEE 5-bus system

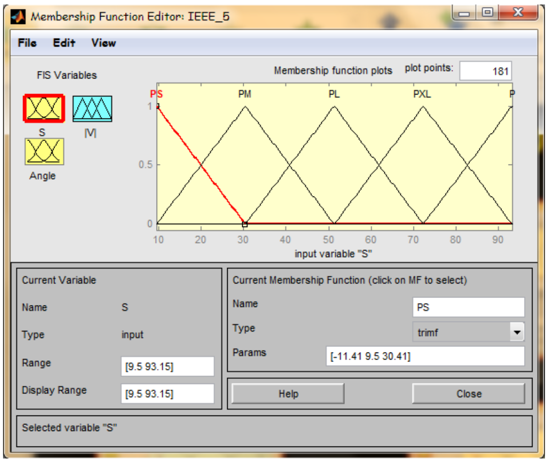

Figure 3.7 Diagram of MF plot for S of IEEE 5-bus system

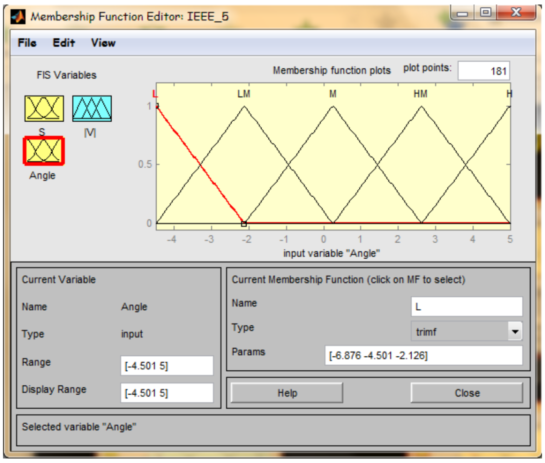

Figure 3.8 Diagram of MF plot for δ of IEEE 5-bus system

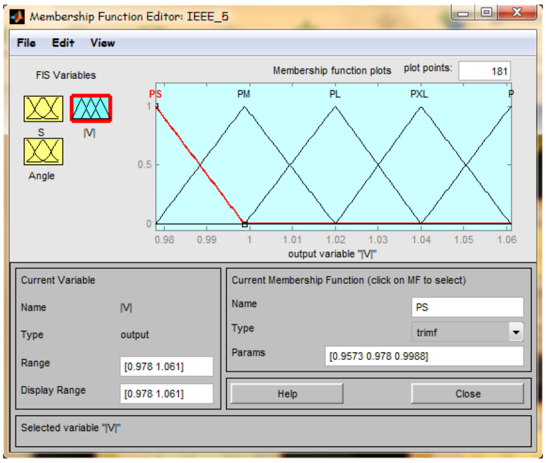

Figure 3.9 Diagram of MF plot |V| of IEEE 5-bus system

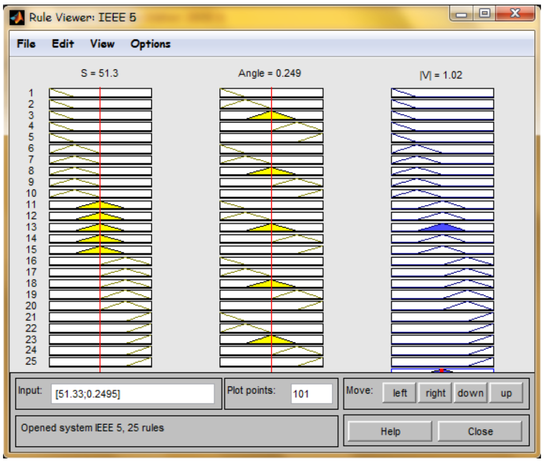

Figure 3.10 Diagram of Rule Viewer of IEEE 5-bus system

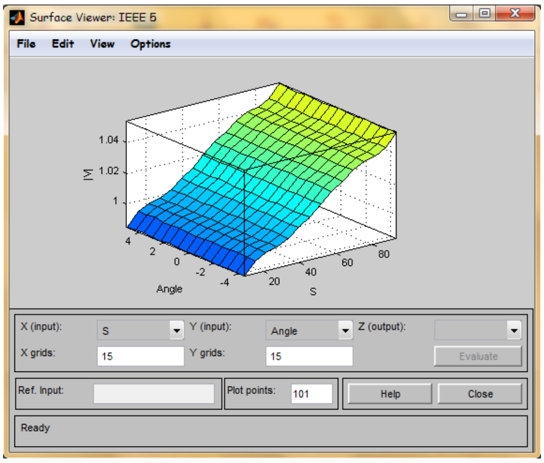

Figure 3.11 Diagram of Surface Viewer of IEEE 5-bus system

For IEEE 30-bus system, as shown in **Figure 3.11**, the Input variable-1 is the lowest value magnitude of voltage at bus in per unit, |V| (p.u) and Input variable-2 is the total value at generation, S (p.u). Output variable is total power of load-shedding, P (p.u). |V| range varies from 0 to 0.977 p.u while the S range varies from 0 to 326.2319 MVA and for the P, it range from 0 to 0.141 MW. In this study, five MF are also selected for each variable which is labelled as L, LM, M, HM and H. The triangular shape is been selected for each variable. For reference, the range is exclusively belongs for the data number one only. **Figure 3.12**, **Figure 3.13** and **Figure 3.14** are the MF plot for each of the variable.

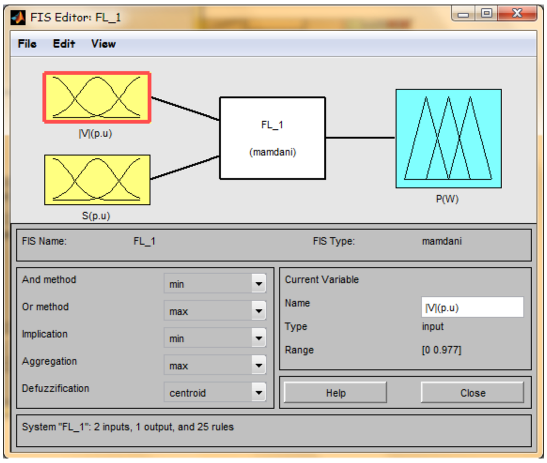

Figure 3.12 Diagram of FIS Editor for line outage at bus 29 to 30

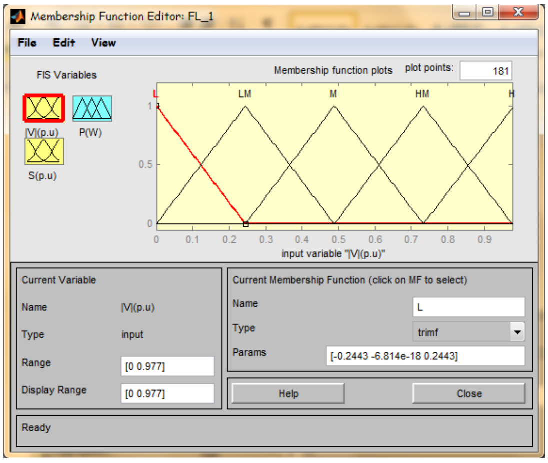

Figure 3.13 Diagram of MF plot for |V| of line outage at bus 29 to 30

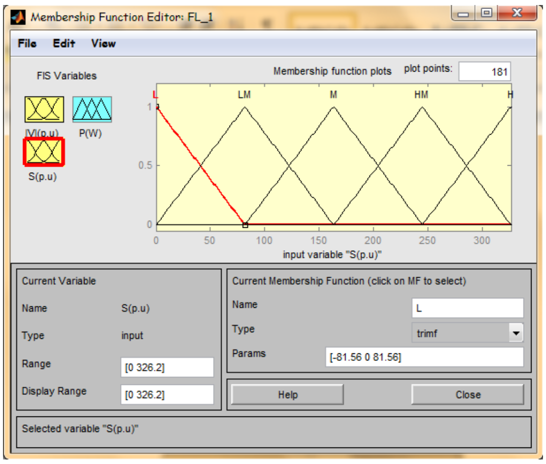

Figure 3.14 Diagram of MF plot for S of line outage at bus 29 to 30

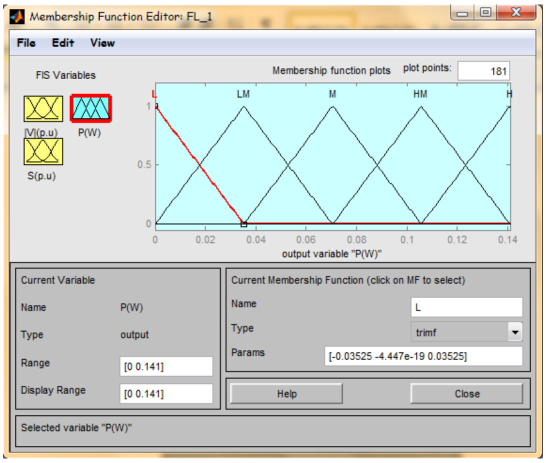

Figure 3.15 Diagram of MF plot P of line outage at bus 29 to 30

Based on the input and output variables descriptions defined with the FIS Editor, the Rule Editor has allowed the user to construct the rule statements automatically, just clicked on and one item is selected in each variable item. In addition, rules might be changed, deleted or added just by clicking the right button. It then can also be viewed from the Rule Viewer and the Surface Viewer as shown in **Figure 3.16** and **Figure 3.17**. For this study, rules are defined to determine the accurate value of power of load-shedding where 25 rules are developed. For instance:

i. If **|V|** is **L** and **S** is **L** then **P** is **L**.
ii. If **|V|** is **LM** and **S** is **M** then **P** is **LM**.
iii. If **|V|** is **H** and **S** is **HM** then **P** is **H**.

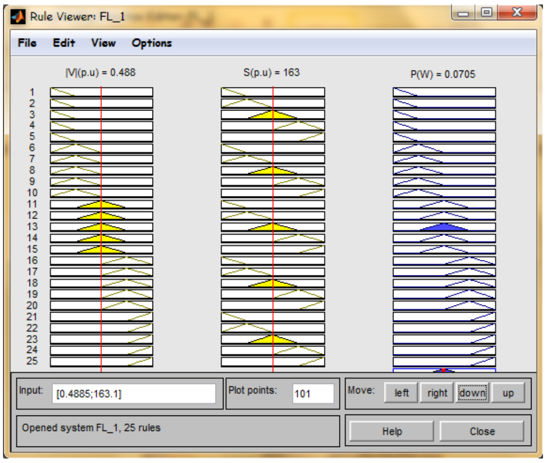

Figure 3.16 Diagram of Rule Viewer of line outage at bus 29 to 30

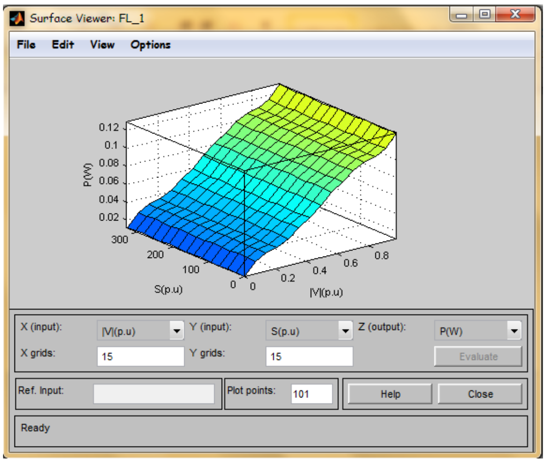

Figure 3.17 Diagram of Surface Viewer of line outage at bus 29 and 30

In order to save the current file, File is clicked and Export to Workspace or Export to File is selected.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Power Flow Analysis

Load or power flow studies are performed in order to determine the electric power system steady-state operation. It can be used to calculate the voltage drop on each feeder, the voltage at each bus, and the power flow in all branch and feeder circuits. In addition, the used of power flow studies is also to determine if system voltages remain within specified limits under various contingency conditions, and whether equipment such as transformers and conductors are overloaded. Load flow studies are often used to identify the need for additional generation, capacitive, or inductive VAR support, or the placement of capacitors and/or reactors to maintain system voltages within specified limits. Furthermore, the losses in each branch and total system power losses are also calculated. For instance, the planning, economic scheduling, and control of existing system as well as planning its future expansion are among the important issues for each country. In another word, it can be called as the heart of the power system [24].

4.2 Power Flow using FL for IEEE 5-Bus System

For this case, as the beginner to get used with FLT, the base case is created. There are 16 data that has been tested out but only the first two data are selected.

The criterion that has been considered is the |V| values must be ± 6%. **Table 4.1** as shown below is the decision matrix to determine the |V| (p.u) at each node based on the S (MVA) and δ (°) values which has been achieved from **Table 3.1** in **Chapter 3**.

Table 4.1 Fuzzy decision matrix in determine the |V| (p.u)

AND		**δ**				
		L	**LM**	**M**	**HM**	**H**
S	**PS**	PM	PL	PXL	PM	PM
	PM	PL	PL	PL	PL	PL
	PL	PL	PL	PL	PL	PXL
	PXL	PM	PXL	PXL	PXL	PXL
	P	PXL	PXL	PXL	PXL	PXL

The following is the definition and range varies of input-variable and output-variable for the first two data in **Table 3.1** of **Chapter 3**:

i. For **S:**
   a. Positive Small (**PS**): (9.5000 <**PS**< 26.23036)
   b. Positive Medium (**PM**): (26.23037 <**PM**< 42.96072)
   c. Positive Large (**PL**): (42.96073 <**PL**< 59.69108)
   d. Positive Extra Large (**PXL**): (59.69109 <**PXL**< 76.42144)
   e. Positive (**P**): (76.42145 <**P**< 93.1518)

ii. For **δ**:
   a. Low (**L**): (-4.50135 <**L**< -2.60108)
   b. Low Medium (**LM**): (-2.60107 <**LM**< -0.70081)
   c. Medium (**M**): (-0.70080 <**M**< 1.19946)
   d. High Medium (**HM**): (1.19947 <**HM**< 3.099731)
   e. High (**H**): (3.09974 <**H**< 5.0000)

iii. For **|V|**:

a. Positive Small (**PS**): (0.93005 <**PS**< 0.96664)
b. Positive Medium (**PM**): (0.96665 <**PM**< 1.00323)
c. Positive Large (**PL**): (1.00324 <**PL**< 1.03982)
d. Positive Extra Large (**PXL**): (1.03983 <**PXL**< 1.07641)
e. Positive (**P**): (1.07642 <**P**< 1.113)

Table 4.2 as shown below is the summarized on |V| and Table 4.3 is the summarized of |V| accuracy of IEEE 5-bus system. Based on the simulation result, the conclusions that drawn is the proposed of fuzzy technique approach is capable of determining the value of |V|. The |V| accuracy range varies from 0.943 to 6.231 %. The result is not very satisfactory and might due to the big scale of range varies of the S and δ or there are too many MF in each variable.

Table 4.2 Summarized of |V| of IEEE 5-bus system

<table>
<tr><th colspan="5">|V| (p.u)
Using PF</th><th colspan="5">|V| (p.u)
Using FL</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>1.060</td><td>1.035</td><td>1.017</td><td>1.006</td><td>0.979</td><td>1.050</td><td>0.999</td><td>0.986</td><td>1.030</td><td>1.040</td></tr>
<tr><td>1.060</td><td>1.045</td><td>1.042</td><td>1.032</td><td>1.006</td><td>1.01</td><td>0.999</td><td>0.997</td><td>1.010</td><td>1.030</td></tr>
</table>

Table 4.3 Summarized of |V| accuracy of IEEE 5-bus system

<table>
<tr><th colspan="5">|V| Accuracy (%)</th></tr>
<tr><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>0.943</td><td>3.478</td><td>3.048</td><td>2.386</td><td>6.231</td></tr>
<tr><td>4.717</td><td>4.402</td><td>4.319</td><td>2.132</td><td>2.386</td></tr>
</table>

4.3 Power Flow using FL for IEEE 30-Bus System

There are three types of power flow iterations, which are by using Newton Raphson, Gauss Seidel or Fast Decoupled Load Flow iteration and in this case, load flow solution by Newton Raphson has been chosen thus the analysis for the data of IEEE 30-bus system is simply done.

Table 4.4 as shown as follow is the decision matrix to determine the P for load-shedding (MW) at line based on the |V| (p.u) and S (MVA) values which has been achieved from **Table 4.5**, **Table 4.6** and **Table 4.7**.

Table 4.4 Fuzzy decision matrix in determined the load-shedding power

AND		**S**				
		L	**LM**	**M**	**HM**	**H**
|V|	**L**	L	L	L	L	L
	LM	LM	LM	LM	LM	LM
	M	M	M	M	M	M
	HM	HM	HM	HM	HM	HM
	H	H	H	H	H	H

The following is the definition and range varies of input-variable and output-variable for data No. 1:

i. For **|V|:**

   a. Low (**L**): (0.9432 <**L**< 0.9568)
   b. Low Medium (**LM**): (0.95 <**LM**< 0.9635)
   c. Medium (**M**): (0.9567 <**M**< 0.9702)
   d. High Medium (**HM**): (0.9635 <**HM**< 0.977)
   e. High (**H**): (0.9702 <**H**< 0.9838)

ii. For **S**:

a. Low (**L**): (301.7 <**L**< 318)
b. Low Medium (**LM**): (309.9 <**LM**< 326.3)
c. Medium (**M**): (318 <**M**< 334.4)
d. High Medium (**HM**): (326.3 <**HM**< 342.6)
e. High (**H**): (334.4 <**H**< 350.7)

iii. For **P**:

a. Low (**L**): (0.1408 <**L**< 0.1409)
b. Low Medium (**LM**): (0.1409 <**LM**< 0.141)
c. Medium (**M**): (0.1409 <**M**< 0.1411)
d. High Medium (**HM**): (0.141 <**HM**< 0.1411)
e. High (**H**): (0.1411 <**H**< 0.1412)

The removed of "linedata" in the coding section analysis are done by randomly selected. For the sake of this study, the data has been collected and presented as shown in **Table 4.5** below. "Data is not available" in data number 19 and 20. This is because the power flow has two lines outage happened at the same that result no data available. Thus, the system is in blackout state.

Table 4.5 Summarized data of line outage of IEEE 30-bus system

<table>
<tr><th rowspan="2">Data No.</th><th colspan="2">Line Outage</th><th colspan="2">Voltage magnitude, |V| (p.u)</th><th rowspan="2">Apparent Power At Generation, S (MVA)</th><th rowspan="2">Power Loss, P (W)</th></tr>
<tr><th>From Bus (n1)</th><th>To Bus (nr)</th><th>Lowest Value</th><th>At Bus</th></tr>
<tr><td>1</td><td>-</td><td>-</td><td>0.995</td><td>30</td><td>325.9767</td><td>17.599</td></tr>
<tr><td>2</td><td>29</td><td>30</td><td>0.977</td><td>30</td><td>326.2319</td><td>17.740</td></tr>
<tr><td>3</td><td>28</td><td>27</td><td>0.861</td><td>30</td><td>331.3003</td><td>19.934</td></tr>
<tr><td>4</td><td>6</td><td>28</td><td>0.970</td><td>30</td><td>332.8732</td><td>18.092</td></tr>
<tr><td>5</td><td>2</td><td>4</td><td>0.985</td><td>30</td><td>331.8647</td><td>19.055</td></tr>
<tr><td>6</td><td>12</td><td>15</td><td>0.989</td><td>30</td><td>327.3550</td><td>18.399</td></tr>
<tr><td>7</td><td>6</td><td>9</td><td>0.990</td><td>30</td><td>328.5699</td><td>18.059</td></tr>
<tr><td>8</td><td>18</td><td>19</td><td>0.994</td><td>30</td><td>326.0215</td><td>17.622</td></tr>
<tr><td>9</td><td>19</td><td>20</td><td>0.994</td><td>30</td><td>326.5149</td><td>17.877</td></tr>
<tr><td>10</td><td>15</td><td>23</td><td>0.989</td><td>30</td><td>326.2139</td><td>17.738</td></tr>
<tr><td>11</td><td>6</td><td>7</td><td>0.946</td><td>7</td><td>332.2270</td><td>19.414</td></tr>
<tr><td>12</td><td>12</td><td>16</td><td>0.993</td><td>30</td><td>326.2733</td><td>17.759</td></tr>
<tr><td>13</td><td>27</td><td>29</td><td>0.949</td><td>29</td><td>326.7139</td><td>18.006</td></tr>
<tr><td>14</td><td>22</td><td>24</td><td>0.987</td><td>30</td><td>326.2350</td><td>17.720</td></tr>
<tr><td>15</td><td>6</td><td>8</td><td>0.994</td><td>30</td><td>328.4173</td><td>18.554</td></tr>
<tr><td>16</td><td>5</td><td>7</td><td>0.986</td><td>30</td><td>327.9556</td><td>17.721</td></tr>
<tr><td>17</td><td>27</td><td>30</td><td>0.940</td><td>30</td><td>326.9567</td><td>18.139</td></tr>
<tr><td>18</td><td>1</td><td>2</td><td>0.932</td><td>3</td><td>473.2977</td><td>64.681</td></tr>
<tr><td rowspan="2">19</td><td>6</td><td>10</td><td colspan="4" rowspan="4">Data is not available</td></tr>
<tr><td>9</td><td>11</td></tr>
<tr><td rowspan="2">20</td><td>18</td><td>19</td></tr>
<tr><td>19</td><td>20</td></tr>
</table>

Fuzzy approach is used in order to compare the power loss from line power flow and power loss from the simulation using FLT. The inputs and output to be inserted to FL are shown in Table 4.6 while the result of percentage of output accuracy is shown in Table 4.7 as follows:

Table 4.6 Input and output to be inserted in FL

Data No.	Line Outage		Input		Output of Power (MW)		
	From Bus (n1)	To Bus (nr)	Lowest Voltage Value At Bus (p.u)	Apparent Power, S (MVA)	After Simulation	Before Simulation	Load-Shedding
1	-	-	0.995	325.977	-	17.599	0.000
2	29	30	0.977	326.232	17.740	17.599	0.141
3	28	27	0.861	331.300	19.934	17.599	2.335
4	6	28	0.970	332.873	18.092	17.599	0.493
5	2	4	0.985	331.865	19.055	17.599	1.456
6	12	15	0.989	327.355	18.399	17.599	0.800
7	6	9	0.990	328.570	18.059	17.599	0.460
8	18	19	0.994	326.022	17.622	17.599	0.023
9	19	20	0.994	326.515	17.877	17.599	0.278
10	15	23	0.989	326.214	17.738	17.599	0.139
11	6	7	0.946	332.227	19.414	17.599	1.815
12	12	16	0.993	326.273	17.759	17.599	0.160
13	27	29	0.949	326.714	18.006	17.599	0.407
14	22	24	0.987	326.235	17.720	17.599	0.121
15	6	8	0.994	328.417	18.554	17.599	0.995
16	5	7	0.986	327.956	17.721	17.599	0.122
17	27	30	0.940	326.957	18.139	17.599	0.540
18	1	2	0.932	473.298	64.681	17.599	47.082
19	6	10	Data is not available				
	9	11					
20	18	19					
	19	20					

Table 4.7 Percentage of output accuracy

Data No.	Calculated Output	FL Output	Output Accuracy (%)
1	0.000	-	-
2	0.141	0.141	0.000
3	2.335	2.330	0.214
4	0.493	0.493	0.000
5	1.456	1.460	0.275
6	0.800	0.801	0.125
7	0.460	0.460	0.000
8	0.023	0.023	0.000
9	0.278	0.278	0.000
10	0.139	0.139	0.000
11	1.815	1.810	0.275
12	0.160	0.160	0.000
13	0.407	0.407	0.000
14	0.121	0.121	0.000
15	0.995	0.996	0.101
16	0.122	0.122	0.000
17	0.540	0.540	0.000
18	47.082	47.000	0.174
19	Data is not available		
20			

Based on the simulation result, the conclusions that drawn is the proposed of fuzzy technique approach is capable of determining the value power of load-shedding. The percentage of output accuracy is range varies from 0.000 to 0.275. For instance, data number 11 is taken. If used PF, then the power of load-shedding that need to consider is 1.815 MW while if used FLT, then the load-shedding power is equal to 1.810 MW. When the power loss is increased 1.810 MW due to line outage from 17.599 MW (power loss with no line outage), then data can be send to the operator to act faster to prevent the event of blackout like load-shedding then to wait for the power loss equal to 1.815 MW. This explanation is the same for the other data.

CHAPTER 5

CONCLUSION

In this thesis FL as the expert technologies is proposed to mitigate the blackout of power system as well as to compare the data from line power flow with the data from FLT. Mitigation of the blackout of power system is selected based on the fast decision making and the accuracy of the data. Based on this study, the IEEE 30-bus system is simulated using the MATLAB software which is the data of 30-bus system and by using the GUI in FLT. The Ultimately, FL has shown the effective way to solve the blackout mitigation of power system as proven and discussed on chapter before. By using the FL, the data of power system is more precise compared to the conventional line power flow due to the complexity and difficulty of mathematical equations. FLT is beneficial in term of speed in solving power flow despite on the size of the power system. Therefore FL is practically, simply and effectively can be considered as the more reliable solution compared to the traditional way.

5.1 Contribution of the Thesis

This thesis has made the major contributions that are summarized as follows:

i. The behaviour of power system before and after faults or contingency has been evaluated. The values of the power loss are increased due to the line outages.

ii. The blackout mitigation of developed or evaluated technique has been determined. This finding will help to improve the power system profile in Malaysia that will ensure the less cost due to the severity for the economy from major blackout.

iii. The proposed technique with the conventional way using real power system has been verified. The comparison between them is the most important thing for the future development for the stability and robustness of power system flows in Malaysia.

5.2 Recommendation for Future Works

The recommended for future works in this field is listed as follows:

i. Comprehensive study should be undertaken by a qualified and experienced people in the field of power system.

ii. Applications that have successfully being developed will be shared with other countries without thinking much on the profit.

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