CHAPTER ONE

INTRODUCTION

1.1 Introduction

The process of investigating whether the system is secure or insecure in a set of proposed contingencies is called 'security analysis or contingency analysis'. The purpose of power system security analysis is to determine which contingencies cause component limit violations and also the severity of any such violations. Contingencies are ranked based on the value of a scalar performance index PI (or severity index), which measures system stress in terms of circuit overloads. This may be achieved by predicting the values of the performance index for each line outage and subsequently ranking the contingencies from the most important (largest value of the performance index) to the least important (smallest value of the performance index). The traditional procedure for static security assessment is to evaluate a large number of contingency cases, usually all single outages, with a numerical algorithm [1].

The security assessment plays an important role in the power distribution networks since it offers power system engineers a theoretical framework to measure the power supply quality served by the utilities, and provide a decision-aid tool at emergency situation. Contingency analysis is a key function of security assessment, which involves predicting and mitigating potential failures in the distribution network. [2]

Line outage contingencies are the most common problem in power system and have a considerable effect on altering the base case (pre-contingency case) voltage stability margin of a load bus. Generally, the system continues to operate in the contingency condition for a considerable duration of time, on occurrence of a line outage. The altered voltage stability margins of all the load buses for the various contingency conditions are to be known prior to monitor and initiate emergency control action to avoid voltage collapse. [3]

Monitoring and control of modern power systems have become very complex tasks due to the interconnection of power grids. These large-scale power grids confront system operators with a huge set of system inputs and control parameters. This work develops and compares intelligent systems-based algorithms which may be considered by power system operators or planners to help manage, process, and evaluate large amounts of data due to varying conditions within the system. The methods can be used to provide assistance in making operational control and planning decisions for the system in a timely manner [4]. A Fuzzy Set theory based algorithm is used to identify the weak buses in a power system. Bus voltage and bus power at that bus are represented by membership functions for voltage stability study. [3]

1.2 Statement of Problem

Contingencies such as unexpected line outages often contribute to voltage collapse or system blackouts. These contingencies generally reduce or even eliminate the voltage stability margin. Since the contingency causes the nose point to move to a lower loading. Stressed power systems, either due to increased loading or due to contingencies, often lead to situations where the systems are no longer remaining in security operating regions. Under such situations, the primary objective of the operator is to apply control actions to bring the systems back into the security operating regions. In the cases when systems are subjected to any kind of time delay or unavailability of control, systems may become unstable which is very dangerous situation for power systems. Ranking all possible contingencies based on their impact on the system voltage profile will help the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse.

This thesis represents a control system using fuzzy logic techniques control to accomplish the suitable control action for this problem.

1.3 Thesis Objectives

- To implement the national Sudanese grid with NELAN software program and organize the results of contingency analysis.
- To study the contingency analysis methods and the various indices which used to rank the contingency and select a suitable one.
- To apply the selected method for contingency analysis in the national Sudanese grid.
- To implement simulation design to control the contingency ranking using Fuzzy Interface System (FIS) at MATLAB SIMULINK.

1.4 Methodology

To achieve the contingency analysis in the network, there are many types of indices which depend on the various electrical amount on the network. The voltages profile and the megawatt loading of the electrical grid are commonly used values which are taken in form of indices to indicate the network status and to analyze the system. In this study the voltage profile index and the line flow index were used to analyze the system and to represent the contingency ranking. The combination between the severity index of voltage profile (SI_{VP}) and severity index of the line flow index (SI_{LF}) gives the composite index (CI) which represent the severity level of the system.

The fuzzy logic control action was applied in the Fuzzy Logic Interface system (FIS) in MATLAB SIMULIN toolbox. The fuzzification process was accomplished by taken the both values of the voltage profile index and the line flow index in per unit as input variable and the output variables are the severity index of the voltage profile and the severity index of line flow index the defuzzification process gives the total composite index for the system in per unit, the fuzzy implementation was achieved by selecting the (mamdani) sample at the (FIS) system. The NEPLAN software program was used to implement the national Sudanese grid and to evaluate the list of contingency ranking which was used to compare with the fuzzy logic control results.

1.5 Outlines of the Thesis

This thesis consists of five chapters. Chapter two discuss the contingency analysis of the network, its definition, methods, and the indices which used to analyze the system. Chapter three discuss the fuzzy logic control system, the fuzzification and defuzzification processes, and the functions which used in fuzzy logic control implementation, and the fuzzy tools implementation. In chapter four the all results of the contingency ranking was presented, the contingency analysis results which was taken from NELAN program, and fuzzy approach results which was applied on a part of the national grid and the results were discussed and compared with those results which taken from NEPLAN program. Chapter five represents the conclusion of the thesis and last recommendations of the project.

CHAPTER TWO

NETWORK CONTINGENCY ANALYSIS

2.1 Introduction

The study of contingency is an essential activity in planning, operation and control of power systems. Contingency analysis (CA) allows systems to be operated defensively. The operator cannot take action fast enough when many of the problems that occur on a power system that causes serious trouble within fraction of time period leading to cascading failures. Because of this aspect of system operation, modern operations computers and SCADA systems are equipped with contingency analysis programs that model possible system troubles before they arise. [5]

The main thrust of contingency studies carried out in power system control centers is to determine the steady state effects of outages [6]. Large power systems require the analysis of all the credible contingence within a very short time so as to exercise the control in the short time available for corrective action. [7]

Generally, the system continues to operate in the contingency condition for a considerable duration of time, on occurrence of a line outage. The altered voltage stability margins of all the load buses for the various contingency conditions are to be known prior to monitor and initiate emergency control action to avoid voltage collapse. The main cause for voltage collapse is the inability of the system to supply reactive power to cope up with the increasing load growth. The occurrence of voltage collapse is very much dependent upon the maximum load that can be supported at a particular load bus. Any attempt to increase the load beyond this point could force the entire system into instability, leading to voltage collapse. [4]

Many of the major power system instability incidents around the world has been triggered by some kind of contingencies [10]-[11]. Even though, the contingencies cannot be completely avoided, a catastrophic consequence can be prevented by proper design and control of power system. Hence, the contingency ranking becomes one of the important parts in stability assessment and prevention of instability incidents.

Some contingencies in power systems may lead to progressive decline in voltage and loss of stability due to loss of the equilibrium point. This type of instability problems occur due to the lack of reactive power and often referred as static voltage instability [11]. Another set of contingencies, especially the ones associated with large disturbance, may lead some machines connected to the system to loss of synchronism and hence lose the stability of the entire interconnected network. This type of problem is known as transient instability [12]. Some other contingencies, which are considered as small disturbance, may lead machines speed to oscillate with increasing amplitude and loss of stability due to unstable equilibrium point. This type of instability problem happens due to the lack of damping in the system [13]. Due to these contingencies system static and/or dynamic stability margins might be reduced or even completely eliminated. To maintain the adequate security level against such instability, it is desirable to estimate the effect of contingencies on the stability margin. The purpose of contingency ranking is to rapidly and accurately determine which contingencies may cause power system instability according to their severity so that the emergency preventive control actions can be implemented [14].

2.2 Literature Review

Mainly in contingency analysis field the studies go a head into advanced studies.Christie and Talukdar proposed the integration of a conventional algorithmic approach for contingency evaluation with expert systems for contingency selection and results interpretation. But due to an inadequate knowledge base, execution was too slow to fit into online environment. A rule-based system was presented for contingency screening designed partly on human operator expertise and partly from simulation model findings. The feasibility of the approach is demonstrated on moderate size system by monitoring 17 lines.

Shobha Shankar, Dr. T. Ananthapadmanabha, represent a study of contingency ranking for normal and line outage by using fuzzy logic system depend on the concept of composite index. [3]

Lo and Ping presented the use of a counter propagation network to identify the secure and insecure regions of operation with a feature selector in supervised mode. Since an operating point may be secure to one contingency but at the same time may be insecure for other contingencies, feature selection becomes more complex and vulnerable to misclassification under supervised mode. [4]

Also a modified counter propagation network (CPN) with Neuro-fuzzy (NF) feature selector is used for real power contingency ranking of the transmission system. The CPN is trained to estimate the severity of a series of contingencies for given pre-contingencies line flows. But for larger size system it becomes rather difficult to cope with the increased size of input pattern and network as well. This adversely affected the performance of the network and computational overhead. [4]

A. Y. Abdelaziz*, A. T. M. Taha, M. A. Mostafa, represent a study of ranking the contingencies on the IEEE 14 bus system by using fuzzy logic system and the modeling was extended into 30 bus system. [28]

2.3 Static Security Analysis

During power systems normal operating conditions the following constraints must be satisfied:

$$\left.\begin{aligned} P_k^{\text{known}} - P_k(\mathbf{v}, \theta) &= 0, \; k=1,\ldots,\text{nb} \\ Q_k^{\text{known}} - Q_k(\mathbf{v}, \theta) &= 0, \; k=1,\ldots,\text{nb} \end{aligned}\right] \ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

$$\left.\begin{aligned} V_k^{\min} \le V_k \le V_k^{\max}&, \; k=1,\ldots, \text{nb} \\ P_{km} \le P_{km}^{\max}&, \text{ for every branch } k\text{–}m \end{aligned}\right] \ldots\ldots\ldots\ldots\ldots (2.2)$$

Where:

P_k^{known} and Q_k^{known}: are the injected real and reactive power at bus k, respectively.

v: are nodal voltage angle and magnitude vectors.

V_k**:** is the voltage magnitude at bus k; P_{km} represents real power flow at branch k–m; and nb is the number of system buses. Equation (2.1) corresponds to power balance requirements (power flow equations), while Equation (2.2) corresponds to system operational constraints, represented by limits imposed to nodal voltage magnitudes and real power flows at system branches and transformers.

The system operating state is classified as secure, if constraints (1) and (2) are satisfied for a given operating condition (basic scenario) and also for operating scenarios derived from the occurrence of contingencies, such as transmission lines outages, transformers outages, etc. (post-contingency scenarios). If constraints in (2.1) and/or (2.2) are violated for at least one of the post contingency scenarios, the system operating state is classified as insecure [15]. Constraints (2.1) and (2.2), when referred to the post-contingency scenarios, are also known as security constraints. The evaluation of system performance for all possible post-contingency scenarios is not practical. Therefore it becomes necessary to define a limited set of contingencies to be tested, which should include only those that are more likely to occur. This set is usually built based on the utility's operational knowledge and experience, and also on off-line simulations and analyses.

The need for efficiency in real-time power system contingency analysis can make the analysis of all contingencies not feasible even for the pre-selected set. Then, it is still necessary to choose, among the pre-selected contingencies set, the potentially harmful ones, i.e. those whose occurrence can really drive the system to an emergency condition (violation of constraints (1) and/or (2) in the post-contingency scenario). It is important to observe that, as system operating conditions change, the harmful contingencies also change. Then, the critical contingencies set should be dynamically constructed during real-time operation. The contingency selection based only on the utility operational experience may be inadequate. Methods for automatic contingency selection have been proposed [16]. These methods employ approximate models, which may increase the risk of false alarms or miss to select contingencies that are really critical. [17]

2.4 System State Classifications

Figure 2.1 shows the power system security levels.

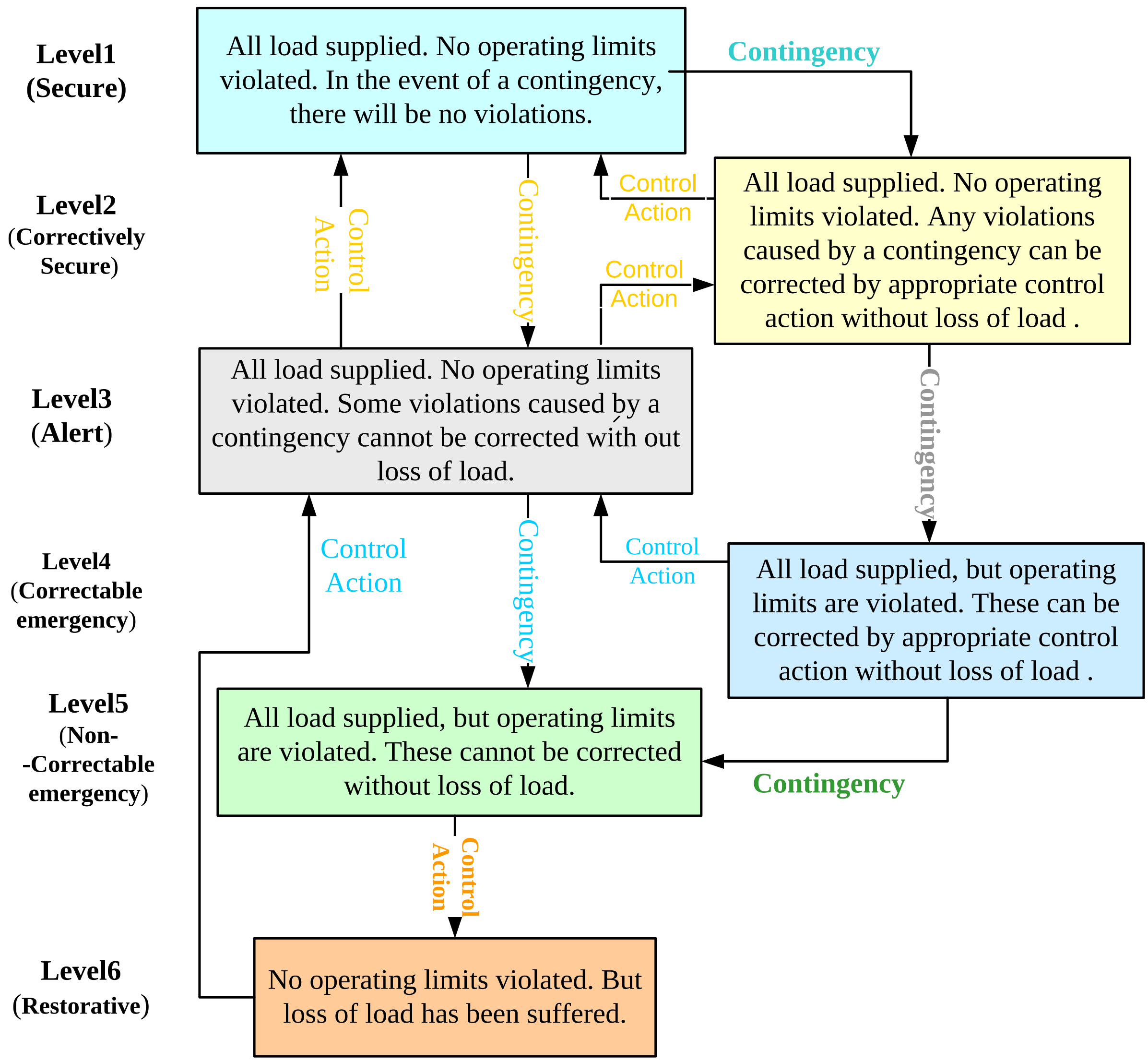


Figure 2.1: power system security levels.

A format classification in power system security level, was first suggested by Dyliacco and further clarified by Fink and Carlsenl23l in order to define relevant Energy Management System (EMS) functions. Stott et. al have also presented a more practical static security level diagram by incorporating correctively secure (Level 2) and correctable emergency (Level 4) security levels. [18]

In the Figure 2.1, arrowed line represent involuntary transitions between Levels 1 to 5 due to contingencies. The removal of violations from Level 4 normally requires EMS directed "corrective rescheduling" or "remedial action" bringing the system to Level 3, from where it can return to either Level I or 2 by further EMS, directed "preventive rescheduling" depending upon the desired operational security objectives. Levels 1 and 2 represent normal power system operation. Level 1 has the ideal security but is too conservative and costly. The power system survives any of the credible contingencies without relying on any post-contingency corrective action.Level2 is more economical, but depends on post contingency corrective rescheduling to alleviate violations without loss of load, within a specified period of time. Post contingency operating limits might be different from their pre-contingency values. [18]

System security can be broken down into two major functions that are carried out in an operations control center:

(i) Security assessment.

(ii) Security control.

The former gives the security level of the system operating state. The latter determines the appropriate security constrained scheduling required to optimally attain the target security level. The security functions in an EMS can be executed in "real time" and "study" modes. Real time application functions have a particular need for computing speed and reliability. 'the static security level of a power system is characterized by the presence or otherwise of emergency operating conditions (limit violations) in its actual (pre-contingency)or potential (post-contingency)operating states. System security assessment is the process by which any such violations are detected.

System assessment involves two functions:

(i) System monitoring.

(ii) Contingency analysis.

System monitoring provides the operator of the power system with pertinent up-to-date information on the current conditions of the power system. In its simplest form, this just detects violations in the actual system operating state. [18]

Only a small proportion of work on optimal power flow (OPF) has taken into account the security constraints. The most successful applications have been to the security constrained MW dispatch OPF sub-problem. The contingency constrained voltage/var rescheduling problem, as of the writing of this text, still remains to be solved to a satisfactory degree. It is important to know which line or unit outages will render line flows or voltages to cross the limits. To find the effects of outages, contingency analysis techniques are employed. Contingency analysis models single failure events (i.e. one-line outages or one unit outages) or multiple equipment failure events (failure of multiple unit or lines or their combination) one after another until all "credible outages" are considered .For each outage, all lines and voltages in the network are checked against their respective limits.

Figure 2.2 depicts a flow chart illustrating a simple method for carrying out a contingency analysis. [18]

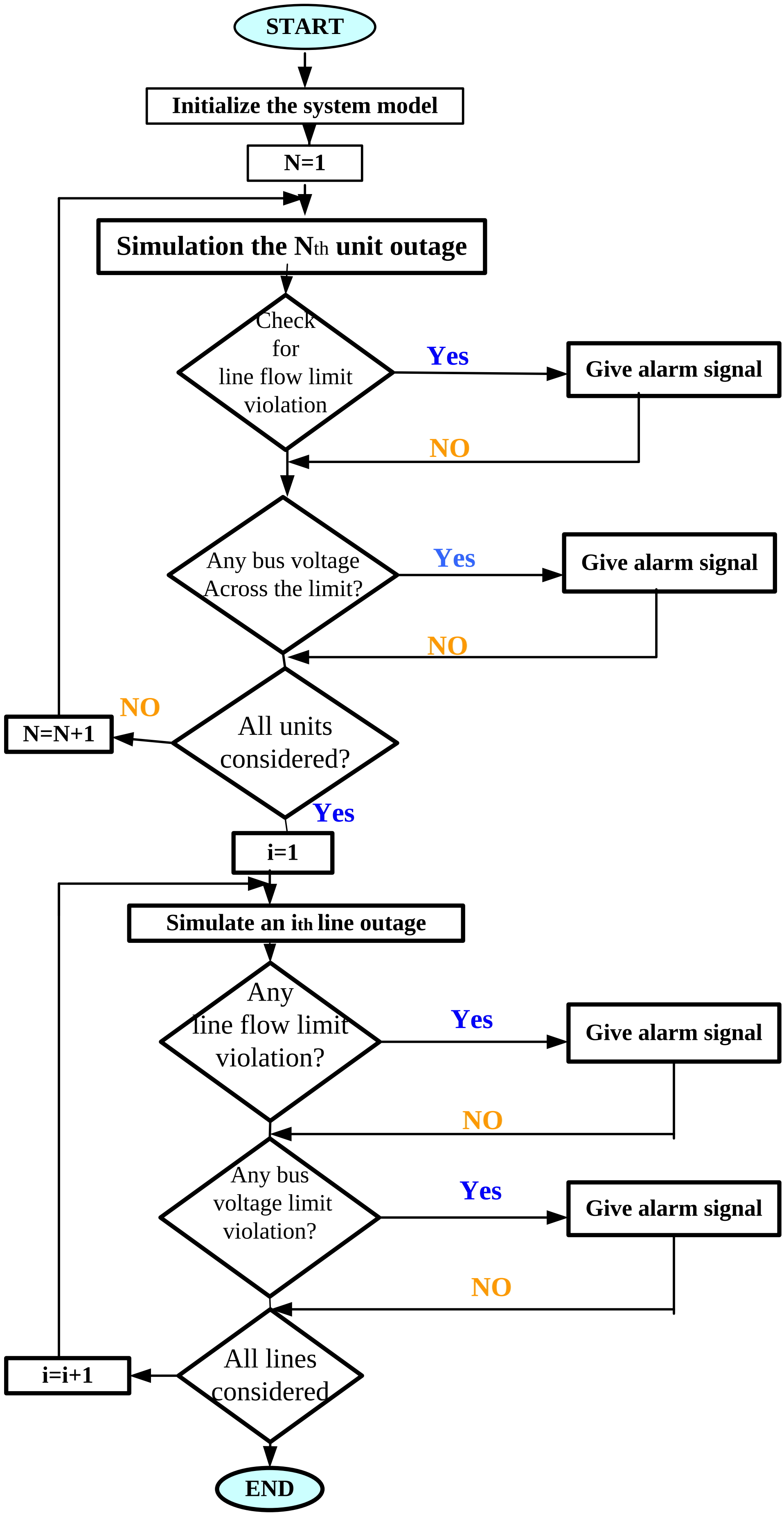


Figure 2.2: A simple technique for contingency analysis.

2.5 Network Performance Indices

In general, the network stability indices are classified into Bus Voltage Stability Indices (BVSIs), line Voltage Stability Indices (LVSIs), and overall voltage stability indices (OVSIs). The accuracy of the (OVSIs) is better than the (BVSIs) and (LVSIs) but they are complex and need more computational efforts. Another classification of Voltage stability Indices (VSIs) can be performed based on the main concepts of the (VSIs). The VSIs have main concepts as follows:

1. Maximum transferable power through a line.
2. Existence of solutions for voltage equation.
3. P-V curve.
4. Lyapunov stability theory.
5. Jacobian matrix.
6. Maximum power flow transfer theorem. [9]

In performance index method with high exponent, the resultant performance index value will depend heavily on loading of the particular line which is loaded closest to its limit [5]. So, Line Flow index (LF index) is used to estimate the maximum loadability of a particular load bus in the system. The load buses are ranked according to their maximum loadability, where the load bus having the smallest maximum loadability is ranked highest. Hence this bus is identified as the weakest bus [4]. Also ranking all possible contingencies based on their impact on the system voltage profile (VP index) will help the operators in choosing the most suitable remedial actions before the system moves toward voltage collapse. [8]

The expansion in using the performance indices on the network, develops so as to evaluate more reliable results. The combination between the most common two performance indices (LF &VP indices) becomes more adoptable. This chapter represents two performance indices to analyze the system. The application of these two indices into the national Sudanese grid and the last contingency ranking is obtained from NEPLAN software and represents later on in chapter four.

2.5.1 Voltage Profile Index (I_{VP})

Voltage stability assessment is a major issue in monitoring the power system stability. Different voltage stability indices (VSIs) have been proposed in the literature for voltage stability assessment. These indices cab be used for distributed generation (DG) placement and sizing, detecting the weak lines and buses and triggering the countermeasures against voltage instability. Some indices are functions of the power system impedance but some others are independent of it and only need the voltage and current of buses [9]. The voltage profile of each bus is represented in this thesis as indicator to voltage stability and used in contingency ranking

2.5.2 Line Flow Index (I_{LF})

In order to find the line voltage stability, there are many indices Moghavvani et al. had proposed four Voltage Collapse proximity index (VCIs) for the assessment of the line voltage stability based on the concept of maximum power transferable through a line. VCPIs consider the maximum power ($p_{r(max)}$ and $Q_{r(max)}$) transferred through a line and maximum power loss ($p_{l(max)}$ and $Q_{l(max)}$). Also there are Line collapse Proximity Index (LCPI) which proposed by Tiwari et al, and L-index which proposed by Kessel et al based on the solution of the power flow equations. The line flow index which used in this thesis is the loading index which based on real power flow loading as shown below:

$$I_{LF}=\frac{P_{Li}}{P_{Lmax}} \qquad (2.1)$$

Where:

I_{LF} = index of Line Flow.

P_{Li} = the real power loading for line i.

P_{Lmax} = the maximum real power loading in the system.

CHAPTER THREE

FUZZY LOGIC CONTROL SYSTEM

3.1 Introduction

Over the past few years, the use of fuzzy set theory, or fuzzy logic, in control systems has been gaining widespread popularity, especially in Japan. From as early as the mid- 1970s, Japanese scientists have been instrumental in transforming the theory of fuzzy logic into a technological realization. Today, fuzzy logic-based control systems, or simply *fuzzy logic controllers* (FLCs), can be found in a growing number of products, from washing machines to speedboats, from air condition units to hand-held autofocus cameras. In the present book, fuzzy logic is exemplified in the speed governing system of a synchronous generator set.

The success of fuzzy logic controllers is mainly due to their ability to cope with knowledge represented in a linguistic form instead of representation in the conventional mathematical framework. Control engineers have traditionally relied on mathematical models for their designs. However, the more complex a system, the less effective the mathematical model. This is the fundamental concept that provided the motivation for fuzzy logic and is formulated by Lofti Zadeh, the founder of fuzzy set theory, as the Principle of Incompatibility. [19]

Zadeh stated that: As the complexity of a system increases, our ability to make precise and yet significant statements about its behavior diminishes until a threshold is reached beyond which precision and significance (or relevance) become almost mutually exclusive characteristics. [20]

Fuzzy logic sometimes appears exotic or intimidating to those unfamiliar with it, but once you become acquainted with it, it seems almost surprising that no one attempted it sooner. In this sense fuzzy logic is both old and new because, although the modern and methodical science of fuzzy logic is still young, the concepts of fuzzy logic reach right down to our bones.[10]

3.2 Historical Review

The term 'fuzzy' in fuzzy logic was first coined in 1965 by Professor Lofti Zadeh, then Chair of UC Berkeley's Electrical Engineering Department. He used the term to describe multivalued sets in the seminal paper, 'Fuzzy Sets' [21]. The work in his paper is derived from multivalued logic, a concept which emerged in the 1920s to deal with Neural and Fuzzy Logic Control of Drives and Power Systems Heisenberg's Uncertainty Principle in quantum mechanics. Multivalued logic was further developed by distinguished logicians such as Jan Lukasiewicz, Bertrand Russell and Max Black. [19] At the time, multivalence was usually described by the term 'vagueness'. When Zadeh developed his theory, he introduced the term 'fuzzy'. Zadeh applied Lukasiewicz's multivalued logic to set theory and created what he called *fuzzy sets* – sets whose elements belong to it in different degrees. According to the fuzzy principle, 'everything is a matter of degree'. While conventional logic is bivalence (TRUE or FALSE, 1 or 0), fuzzy logic is multivalence (from 0 to 1). It is a shift from conventional mathematics and number crunching to philosophy and language. At the beginning, fuzzy logic remained very much a theoretical concept with little practical applications. The work Zadeh was involved in consisted mainly of the computer simulation of mathematical ideas. In the 1970s, Professor Edrahim Mamdani of Queen Mary College, London, built the first fuzzy system, a steam engine controller, and later the first fuzzy traffic lights. This led to the extensive development of fuzzy control applications and products seen today. [19]

3.3 What Is Fuzzy Logic?

Fuzzy logic is all about the relative importance of precision; how important is it to be exactly right when a rough answer will do?

Here is what some scientists have said on fuzzy:

So far as the laws of mathematics refer to reality, they are not certain. And so far as they are certain, they do not refer to reality. —Albert Einstein

As complexity rises, precise statements lose meaning and meaningful statements lose precision. —Lotfi Zadeh.

Some pearls of folk wisdom also echo these thoughts:

Don't lose sight of the forest for the trees.

Don't be penny wise and pound foolish.

Fuzzy logic is a fascinating area of research because it does a good job of trading off between significance and precision, as represents in figure 3.1.

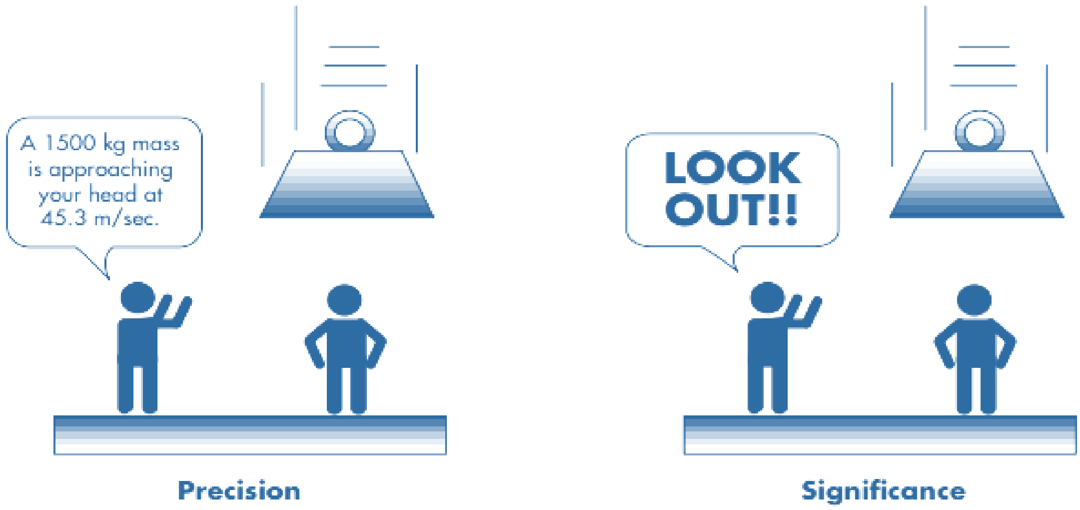


Figure 3.1: precision and significance in real world.

Fuzzy logic is a convenient way to map an input space to an output space. Between the input and the output it may put a box that does the work. What could go in the box? Any number of things: fuzzy systems, linear systems, expert systems, neural networks, differential equations, interpolated multi-dimensional lookup tables, or even a spiritual advisor, just to name a few of the possible options. Clearly the list could go on and on, as Lotfi Zadeh, who is considered to be the father of fuzzy logic, once remarked: "In almost every case you can build the same product without fuzzy logic, but fuzzy is faster and cheaper." [27]

3.4 Why Use Fuzzy Logic?

- Fuzzy logic is conceptually easy to understand. The mathematical concepts behind fuzzy reasoning are very simple. What makes fuzzy nice is the "naturalness" of its approach and not its far-reaching complexity.
- Fuzzy logic is flexible. With any given system, it's easy to massage it or layer more functionality on top of it without starting again from scratch.
- Fuzzy logic is tolerant of imprecise data. Everything is imprecise when looking closely enough, but more than that, most things are imprecise even on careful inspection. Fuzzy reasoning builds this understanding into the process rather than tacking it onto the end.
- Fuzzy logic can model nonlinear functions of arbitrary complexity. It can create a fuzzy system to match any set of input-output data. This process is made particularly easy by adaptive techniques like Adaptive Neuro-Fuzzy Inference Systems (ANFIS), which are available in the Fuzzy Logic Toolbox.
- Fuzzy logic can be built on top of the experience of experts. In direct contrast to neural networks, which take training data and generate opaque, impenetrable models, fuzzy logic lets you rely on the experience of people who already understand the system.
- Fuzzy logic can be blended with conventional control techniques. Fuzzy systems don't necessarily replace conventional control methods. In many cases fuzzy systems augment them and simplify their implementation.
- Fuzzy logic is based on natural language. The basis for fuzzy logic is the basis for human communication. This observation underpins many of the other statements about fuzzy logic. [27]

3.5 Fuzzy Sets and Fuzzy Logic

Fuzzy logic starts with the concept of a fuzzy set. A fuzzy set is a set without a crisp, clearly defined boundary. It can contain elements with only a partial degree of membership. A classical set is a container that wholly includes or wholly excludes any given element. For example, the set of days of the week unquestionably includes Monday, Thursday, and Saturday. It just as unquestionably excludes butter, liberty, and dorsal fins, and so on. Figure 3.2 below represents the meaning.

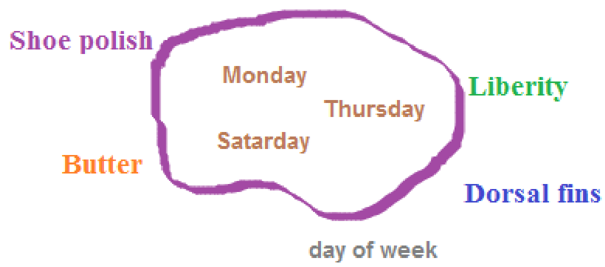


Figure 3.2: classical set.

It was Aristotle who first formulated the Law of the Excluded Middle, which says X must either be in set A or in set not-A. Another.

Classical set theory was founded by the German mathematician Georg Cantor (1845– 1918). In the theory, a *universe of discourse*, *U*, is defined as a collection of objects all having the same characteristics. A classical set is then a collection of a number of those elements. The member elements of a classical set belong to the set 100 per cent. Other elements in the universe of discourse, which are non-member elements of the set, are not related to the set at all. A definitive boundary can be drawn for the set, as depicted in Figure 3.3.

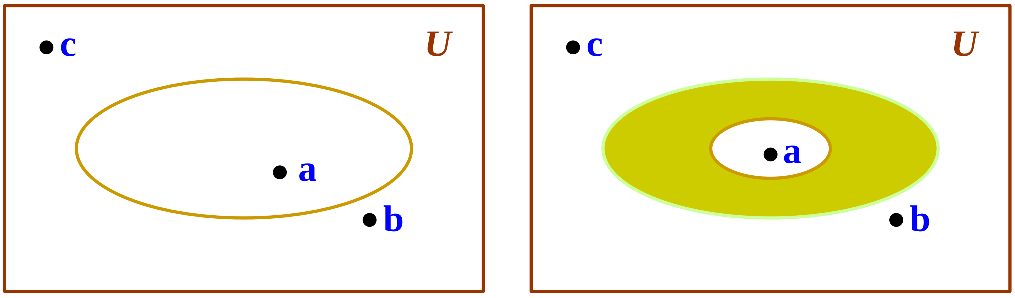


Figure 3.3: (a) classical boundary (b) fuzzy set boundary.

A *classical set* can be denoted by $A = \{x \in U \mid P(x)\}$ where the elements of A have the property P, and U is the universe of discourse. The *characteristic function* $\mu_A(x)$: → {0, 1} is defined as '0' if x is not an element of A and '1' if x is an element of A. Here U contains only two elements, '1' and '0'. Therefore, an element x, in the universe of discourse is either a member of set A or not a member of set A. There is ambiguity about, membership. For example, consider the set ADULT, which contains elements classified by the variable AGE. It can be said that an element with AGE = '5' would not be a member of the set whereas an element with AGE = '45' would be. The question which arises is, where can a sharp and discrete line be drawn in order to separate members from non-members? At AGE = '18'? By doing so, it means that elements with AGE = '17.9' are not members of the set ADULT but those with AGE = '18.1' are. This system is obviously not realistic to model the definition of an adult human. Simple problems such as this one embody the notion behind Zadeh's Principle of Incompatibility. [19]

In fuzzy set theory, the concept of characteristic function is extended into a more generalized form, known as *membership function*: $\mu_A(x)$: $U \rightarrow [0, 1]$. While a characteristic function exists in a two-element set of {0, 1}, a membership function can take up any value between the unit interval [0, 1] (note that curly brackets are used to represent discrete membership while square brackets are used to represent continuous membership). The set which is defined by this extended membership function is called a *fuzzy set*. In contrast, a classical set which is defined by the two-element characteristic function, as described earlier, is called a *crisp set*. Fuzzy set theory essentially extends the concept of sets to encompass *vagueness*. Membership to a set is no longer a matter of 'true' or 'false', '1' or '0', but a matter of degree. The degree of membership becomes important. The boundary of a fuzzy set is shown in Figure. 3.3(b). While point 'a' is a member of the fuzzy set and point 'c' is not a member, the membership of point b is ambiguous as it falls on the boundary. The concept of *membership function* is used to define the extent to which a point on the boundary belongs to the set. A *fuzzy set F* can be defined by the set of tuples F = $\{(\mu_F(x), x) \mid x \in U\}$. Zadeh proposed a notation for describing fuzzy sets therefore, the fuzzy set *F* becomes:

$$F = \int_x^U \mu_F(x)/x \text{ for a continuous universe } U \ldots \quad (3.1)$$

$$F = \sum_{x=U} \mu_F(x)/x \text{ for a discrete universe } U \ldots \quad (3.2)$$

Returning to the earlier example, an element with AGE = ‘18.1’ may now be assigned with the membership degree to the set ADULT of, say, 1.0. An element of AGE = ‘17.9’ may then have a membership degree of 0.8 instead of 0. Such gradual change in the degree of membership provides a better representation of the real world. However, the exact shape of the membership function is very subjective and depends on the designer and the context of the application. While set operations such as complement, union and intersection are straightforward definitions in classical set theory, their interpretation is more complicated in fuzzy set theory due to the graded attribute of membership functions. Zadeh proposed the following *fuzzy set operation* definitions as an extension to the classical operations:

- Complement $\forall x \in X: \mu_{A'}(x) = 1-\mu_A(x)$……………..……….. (3.3)
- Union $\forall x \in X: \mu_{A\cup B}(x) = \max[\mu_A(x), \mu_B(y)]$………… (3.4)
- Intersection $\forall x \in X: \mu_{A\cap B}(x) = \min[\mu_A(x), \mu_B(y)]$…............ (3.5)

These definitions form the foundations of the basics of fuzzy logic theory. The relationship between an element in the universe of discourse and a fuzzy set is defined by its membership function. The exact nature of the relation depends on the shape or the type of membership function used.[20]

3.6 Types of membership Functions

Figure 3.4 shows various types of membership functions which are used

Commonly in fuzzy set theory. The choice of shape depends on the individual application.

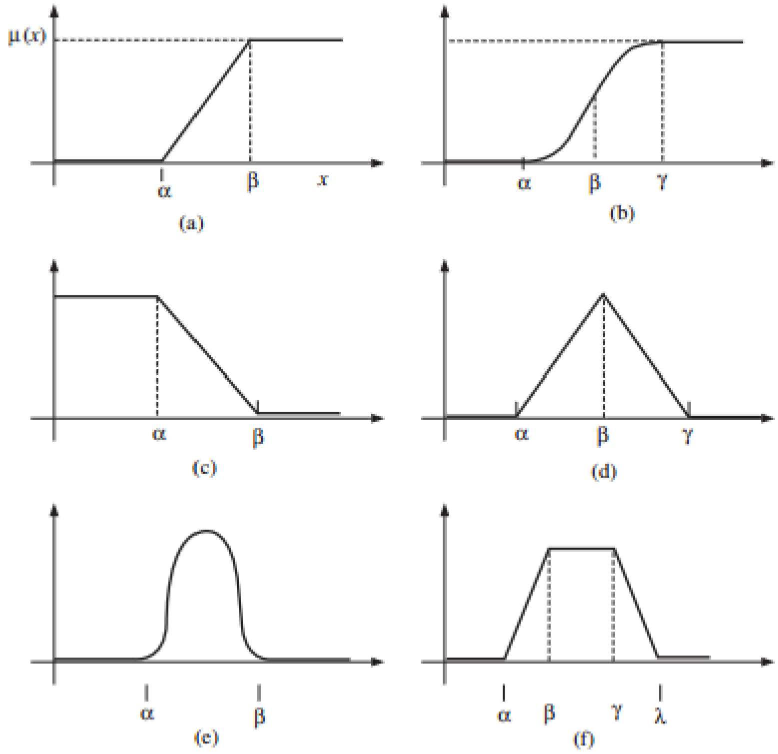


Figure 3.4 Types of membership functions.

Where:

(a) Γ-functio, (b) S-function, (c) L-function, (d) Λ- function, (e) Gaussian function (f) Π-function.

In fuzzy control applications, Gaussian or bell-shaped functions and *S*-functions are not normally used. Functions such as Γ-function, *L* function and Π-function are far more common. The definitions of the membership functions chosen to be exemplified are:

Γ-function, Γ:U →[0,1]

$$\Gamma\,(x;\alpha,\beta)=\begin{cases}0 & x<\alpha\\ (x-\alpha)/(\beta-\alpha) & \alpha\le x\le\beta\\ 1 & x>\beta\end{cases} \quad \ldots\ldots\ldots\ (3.6)$$

L-function, L:U →[0,1]

$$L(x;\alpha,\beta)=\begin{cases}1 & x<\alpha\\ (x-\beta)/(\alpha-\beta) & \alpha\le x\le\beta\\ 0 & x>\beta\end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ (3.7)$$

Λ -function, $\Lambda : U \rightarrow [0,1]$

$$\Lambda(x;\alpha,\beta,\gamma) = \begin{cases} 0 & x < \alpha \\ (x-\alpha)/(\beta-\alpha) & \alpha \le x \le \beta \\ (x-\gamma)/(\beta-\gamma) & \beta \le x \le \gamma \\ 0 & x > \gamma \end{cases} \quad \ldots\ldots.. (3.8)$$

3.7 Linguistic variables

The concept of a linguistic variable, a term which is later used to describe the inputs and outputs of the FLC, is the foundation of fuzzy logic control systems. A conventional variable is numerical and precise. It is not capable of supporting the vagueness in fuzzy set theory. By definition, a linguistic variable is made up of words, sentences or artificial language which are less precise than numbers. It provides the means of approximate characterization of complex or ill-defined phenomena. For example, 'AGE' is a linguistic variable whose values may be the fuzzy sets 'YOUNG' and 'OLD'. A more common example in fuzzy control would be the linguistic variable 'ERROR', which may have linguistic values such as 'POSITIVE', 'ZERO' and 'NEGATIVE'. [19]

3.8 Fuzzy logic operators

Logical connectives are also defined for fuzzy logic operations. They are closely related to Zadeh's definitions of fuzzy set operations. The following are four fuzzy operations which are significant for the second example presented in this book. *R* denotes the relation between the fuzzy sets *A* and *B*.

- Negation $\mu_{A'}(x) = 1 - \mu_{A'}(x)$ ……………………………..…(3.9)
- Disjunction R: A OR B $\mu_R(x) = \max[\mu_A(x), \mu_B(x)]$ ….... (3.10)
- Conjunction R: A AND B$\mu_R(x) = \min[\mu_A(x), \mu_B(x)]$ …... (3.11)
- Implication $R: (x = A) \rightarrow (y = B)$ IF *x* is *A* THEN *y* is *B* …....(3.12)

Fuzzy implication is an important connective in fuzzy control systems because the control strategies are embodied by sets of IF-THEN rules.

There are various different techniques in which fuzzy implication may be defined. These relationships are mostly derived from multivalued logic theory. The following are some of the common techniques of fuzzy implication found in literature.

- Zadeh's classical implication

  $\mu_R(x, y) = \max\{\min[\mu_A(x), \mu_B(y)], 1 - \mu A(x)\}$ ………………… (3.13)

- Mamdani's implication

  $\mu_R(x, y) = \min[\mu_A(x), \mu_B(y)]$ ……………………………….... (3.14)

  Note that Mamdani's implication is equivalent to Zadeh's classical implication when $\mu_A(x) \geq 0.5$ and $\mu_B(y) \geq 0.5$.

- Godel's implication

  $\mu R(x, y) = \begin{cases} 1 & \mu A(x) \leq \mu B(y) \\ \mu B(y) & Otherwise \end{cases}$ …………………….. (3.15)

- Lukasiewicz' implication

  $\mu_R(x, y) = \min\{1, [1 - \mu_A(x) + \mu_B(y)]\}$ ……………………..…. (3.16)

The differences in using the various implication techniques are described in [22]. It is fairly obvious by looking at the mathematical functions of the different implication techniques that Mamdani's technique is the most suitable for hardware implementation. It is also the most popular technique in control applications and is the technique used in the design example presented in the second part. [19]

3.9 Fuzzy control systems

Figure 3.5 shows the block diagram of a typical fuzzy logic controller (FLC) and the system plant as described in [23].

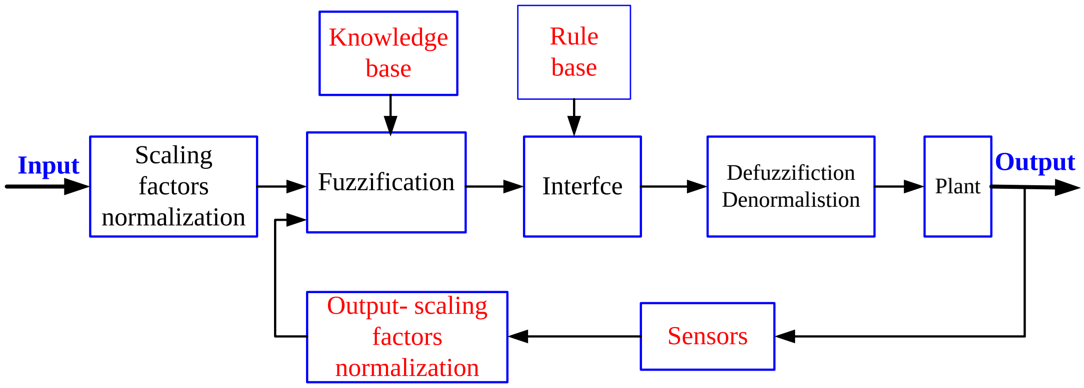


Figure 3.5: Block diagram of a typical fuzzy logic controller.

There are five principal elements to a fuzzy logic controller:

• Fuzzification module (fuzzier).

• Knowledge base.

• Rule base.

• Inference engine.

• Defuzzification module (defuzzifier).

Automatic changes in the design parameters of any of the five elements creates an adaptive fuzzy controller. Fuzzy control systems with fixed parameters are non-adaptive. Other non-fuzzy elements which are also part of the control system include the sensors, the analogue–digital converters, the digital–analogue converters and the normalization circuits. There are usually two types of normalization circuits: one maps the physical values of the control inputs onto a normalized universe of discourse and the other maps the normalized value of the control output variables back onto its physical domain. [19]

3.9.1 Fuzzifier

The fuzzification module converts the crisp values of the control inputs into fuzzy values, so that they are compatible with the fuzzy set representation in the rule base. The choice of fuzzification strategy is dependent on the inference engine, i.e. whether it is composition based or individual-rule-firing based. [24]

3.9.2 Knowledge base

The knowledge base consists of a database of the plant. It provides all the necessary definitions for the fuzzification process
such as membership functions, fuzzy set representation of the input–output variables and the mapping functions between the physical and fuzzy domain. [19]

3.9.3 Rule base

The rule base is essentially the control strategy of the system. It is usually obtained from expert knowledge or heuristics and expressed as a set of IF-THEN rules. The rules are based on the fuzzy inference concept and the antecedents and consequents are associated with linguistic variables. For example:

IF *error* (e) is *Positive Big* (PB) THEN *output* (u) is *Negative Big* (NB)

Rule antecedent Rule consequent

Error (e) and *output* (u) are linguistic variables while *Positive Big* (PB) and *Negative Big* (NB) are the linguistic values. The rules are interpreted using a fuzzy implication technique. In fuzzy control theory, this is normally Mamdani's implication technique. [19]

3.9.4 Defuzzifier

The FLC will process the input data and map the output to one or more of these linguistic values (LU^1 to LU^5). Depending on the conditions, the membership functions of the linguistic values may be clipped. Figure 3.6 shows an output condition with two significant (clipped above zero) output linguistic values. The union of the membership functions forms the fuzzy output value of the controller.

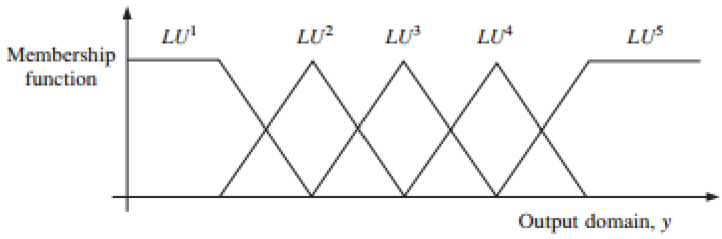


Figure 3.6: Membership function of the output linguistic values.

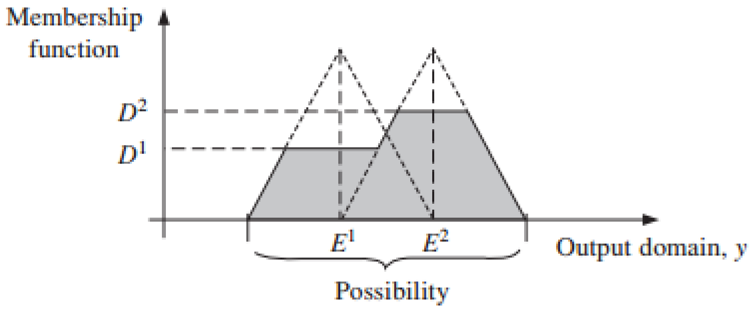


Figure 3.7: Possibility distribution of an output condition.

This is represented by the shaded area in figure. 3.7, and is expressed by the fuzzy set equation:

$$S = \bigcup_{i=1}^{k} S_i,\ \mu_s(y) = \max_i [\mu_{S_i} (y)],\ i=1, 2, \ldots K \ldots\ldots (3.17)$$

Where:

S = is the union of all the output linguistic values.

S_i = is an output linguistic value with clipped membership function.

k = is the total number of output linguistic values defined in the universe of discourse.

In most cases, the fuzzy output value S has very little practical use as most applications require non-fuzzy (crisp) control actions. Therefore, it is necessary to produce a crisp value to represent the possibility distribution of the output. The mathematical procedure of converting fuzzy values into crisp values is known as "defuzzification". A number of defuzzification methods have been suggested. The different methods produce similar but not always the same results for a given input condition. The choice of defuzzification methods usually depends on the application and the available processing power. The defuzzification method used in the example presented in the second part is the weighted average method. This method requires relatively little processing power and is ideal for FPGA implementation where 'area space' is a major consideration. However, it is only valid for symmetrical membership functions. Each membership function is assigned with a weighting, which is the output point where the membership value is maximum. Based on the diagram in figure 3.6, the defuzzification process can be expressed by:

$$f(y) = \frac{\sum \mu(y).y}{\sum \mu(y)} \qquad (3.18)$$

By using the weighted average method becomes:

$$f(y) = \frac{\sum_{m=1}^{n} E^{D}}{\sum_{m=1}^{n} D} \qquad (3.19)$$

Where:

$f(y)$ = is the crisp output value

E^D = is the crisp weighting for the linguistic value LU^D.

D = is the membership value of y with relation to the linguistic value LU. The crisp defuzzifier output is used as it is or via an interfacing block, to control the plant.

3.10 Implementation of fuzzy controller

3.10.1 Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox for use with MATLAB is a tool for solving problems with fuzzy logic. The Fuzzy Logic Toolbox is a collection of functions built on the MATLAB numeric computing environment. It provides tools for creating and editing fuzzy inference systems within the framework of MATLAB, also it can integrate fuzzy systems into simulations with Simulink, and can even submit the programmer to build stand-alone C programs that call on fuzzy systems which was built with MATLAB. This toolbox relies heavily on graphical user interface (GUI) tools to help in accomplishing the work, although submit working entirely from the command line if user prefer.

The toolbox provides three categories of tools:

- Command line functions.
- Graphical, interactive tools.

• Simulink blocks and examples.

The first category of tools is made up of functions that can call from the command line or from the user's own applications. Many of these functions are MATLAB M-files, series of MATLAB statements that implement specialized fuzzy logic algorithms. It can view the MATLAB code for these functions using the statement type: *function_name* the toolbox function can changed by copying and renaming the M-file, then modifying the copy. The toolbox can also extended by adding the user's own M-files. Secondly, the toolbox provides a number of interactive tools that the user access many of the functions through a GUI. Together, the GUI- based tools provide an environment for fuzzy inference system design, analysis, and implementation. The third category of tools is a set of blocks for use with the Simulink simulation software. These are specifically designed for high speed fuzzy logic inference in the Simulink environment.

Because of the integrated nature of MATLAB's environment, It is possible to create tools to customize the Fuzzy Logic Toolbox or harness it with another toolbox, such as the Control System, Neural Network, or Optimization Toolbox, to mention only a few of the possibilities as shown in figure 3.8.

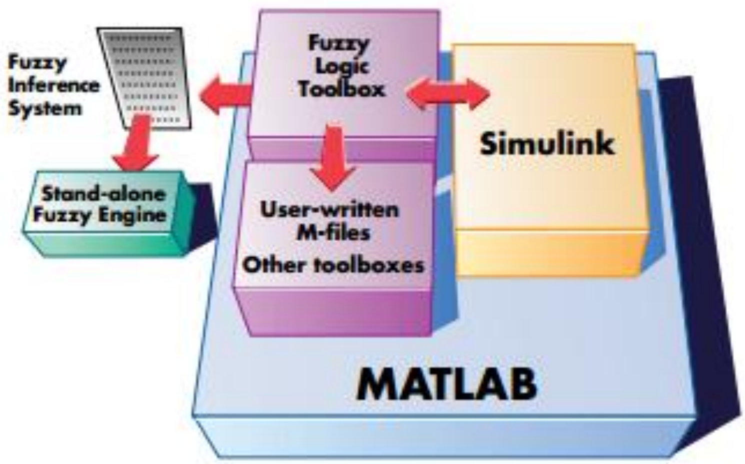


Figure 3.8: Integrality environment of fuzzy toolbox in MATLAB.

3.10.2 Membership Functions in the Fuzzy Logic Toolbox

The Fuzzy Logic Toolbox includes eleven built-in membership function (MF) types. These eleven functions are, in turn, built from several basic functions: piecewise linear functions, the Gaussian distribution function, the sigmoid curve, and quadratic and cubic polynomial curves.

The simplest membership functions are formed using straight lines. Of these, the simplest is the triangular membership function, and it has the function name "trimf". It’s nothing more than a collection of three points forming a triangle. The trapezoidal membership function, "trapmf", has a flat top and really is just a truncated triangle curve. These straight line membership functions have the advantage of simplicity, they are shown in figure (3.9).

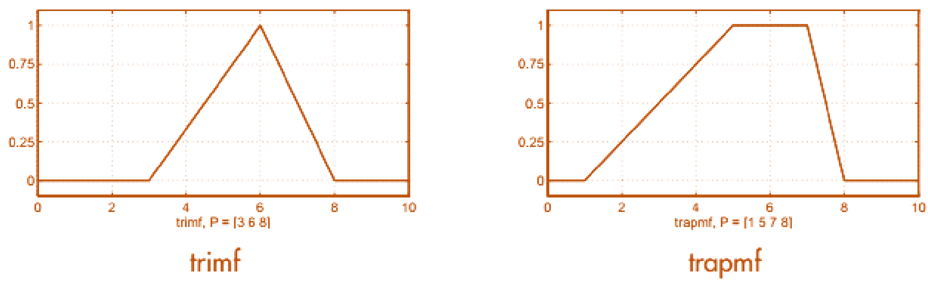


Figure 3.9: Triangular and trapezoidal MF in fuzzy toolbox.

Two membership functions are built on the Gaussian distribution curve: a simple Gaussian curve and a two-sided composite of two different Gaussian curves. The two functions are "gaussmf" and "gauss2mf". The generalized bell membership function is specified by three parameters and has the function name "gbellmf". These membership functions are shown in figure3.10.

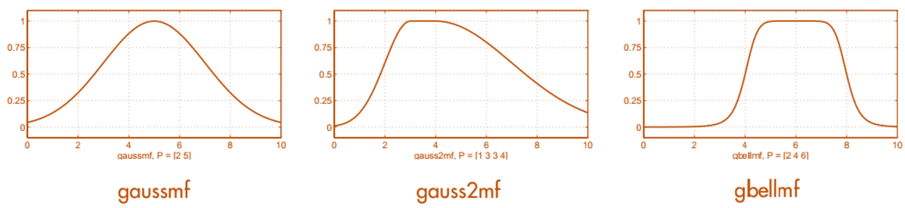


Figure 3.10: Gaussian and generalized bell MF in fuzzy toolbox.

Although, these membership functions have the advantages of being smooth and nonzero at all points, they are unable to specify asymmetric membership functions, which are important in certain applications.so, sigmoidal membership functions were defined , which are either open left or right. Asymmetric and close. So, in addition to the basic "sigmf", also there difference between two sigmoidal functions, "dsigmf", and the product of two sigmoidal functions "psigmf". These sigmoidal membership functions are shown in figure 3.11.

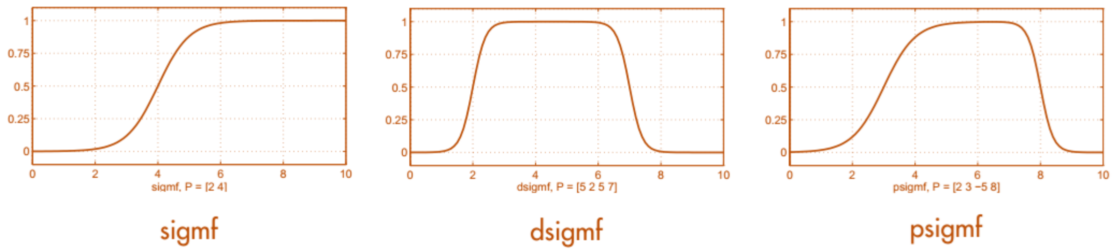


Figure 3.11: Sigmoidal membership functions in fuzzy toolbox.

Polynomial based curves account for several of the membership functions in the toolbox. Three related membership functions are the Z, S, and Pi curves, all named because of their shape. The function "zmf" is the asymmetrical polynomial curve open to the left, "smf" is the mirror-image function that opens to the right, and "pimf" is zero on both extremes with a rise in the middle. These polynomial curves are shown in figure 3.12.

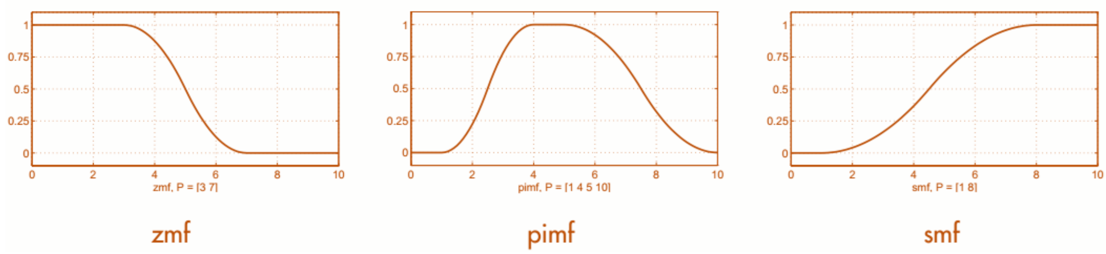


Figure 3.12: Polynomial membership functions in fuzzy toolbox.

3.10.3 Fuzzy logic Operators in Fuzzy Logic Toolbox

The most important thing to realize about fuzzy logical reasoning is the fact that it is a superset of standard Boolean logic. Figure (3.13) illustrates the relations between standard Boolean logic and fuzzy logic operations in the toolbox. Given these three functions, we can resolve any construction using fuzzy sets and the fuzzy logical operation AND, OR, and NOT.

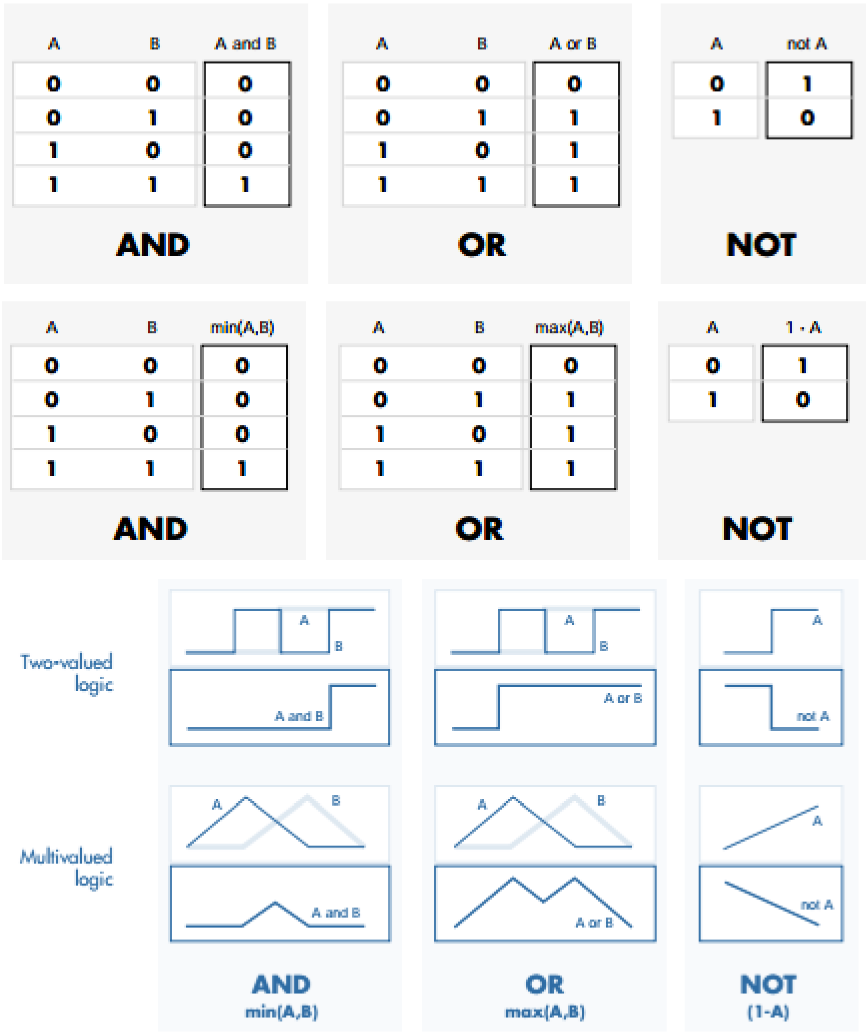


Figure 3.13: Developing binary logic operations in fuzzy logic.

3.10.4 If -Then Rules

If-then rule statements are used to formulate the conditional statements that comprise fuzzy logic. A single fuzzy if-then rule assumes the form: *"if x is A then y is B "*.

Where: A and B are linguistic values defined by fuzzy sets on the ranges (universes of discourse) X and Y, respectively. The if-part of the rule “x is A” is called the antecedent or premise, while the then-part of the rule “y is B” is called the consequent or conclusion.

Interpreting if-then rules is a three-part process:

1. Fuzzify inputs: Resolve all fuzzy statements in the antecedent to a degree of membership between 0 and 1. If there is only one part to the antecedent, this is the degree of support for the rule.
2. Apply fuzzy operator to multiple part antecedents: If there are multiple parts to the antecedent, apply fuzzy logic operators and resolve the antecedent to a single number between 0 and 1. This is the degree of support for the rule.
3. Apply implication method: Use the degree of support for the entire rule to shape the output fuzzy set. The consequent of a fuzzy rule assigns an entire fuzzy set to the output represented by a membership function that is chosen to indicate the qualities of the consequent. If the antecedent is only partially true, (i.e., is assigned a value less than 1), then the output fuzzy set is truncated according to the implication method. This three part process is shown in figure 3.14.

In general, one rule by itself doesn't do much good. What's needed are two or more rules that can play off one another. The output is fuzzy set. Finally the resulting set is defuzzified, to a single number.

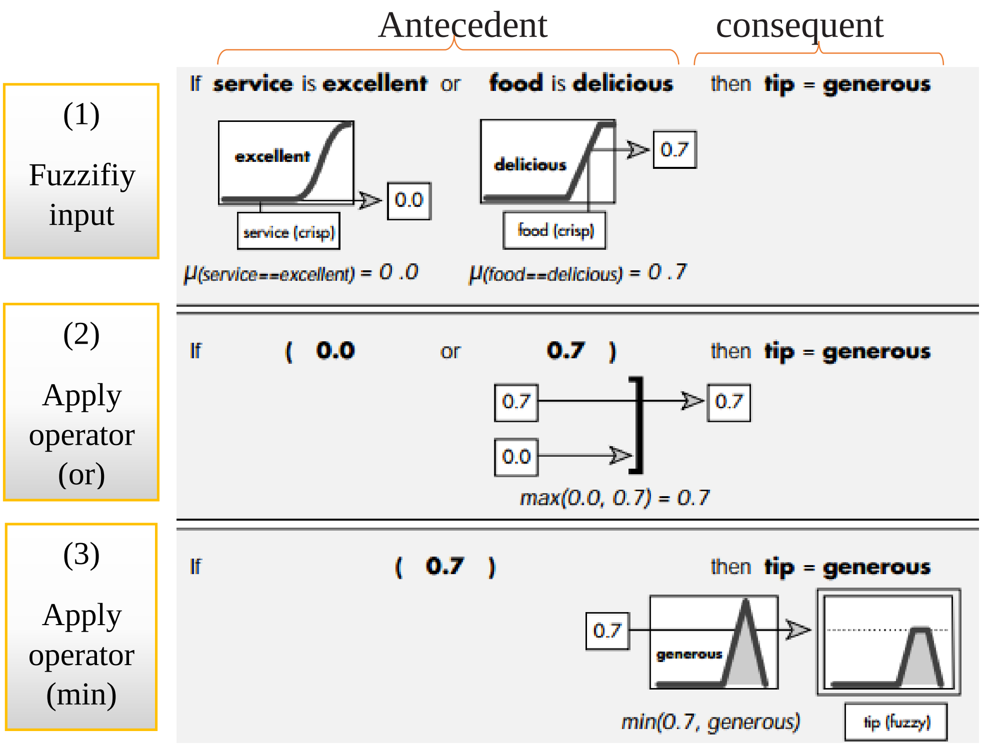


Figure 3.14: Interpreting if-then rules.

3.10.5 Fuzzy Interface Systems

Fuzzy inference is the process of formulating the mapping from a given input to an output using involves all of the pieces that are described earlier: membership functions, fuzzy logic operators, and if-then rules.

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems.

There are two types of fuzzy inference systems that can be implemented in the Fuzzy Logic Toolbox: Mamdani-type and Sugeno-type. These two types of inference system vary somewhat in the way outputs are determined. Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. Mamdani's effort was based on Lotfi Zadeh's 1973 paper on fuzzy algorithms for complex systems and decision processes.

In Mamdani-type inference the output membership functions to be fuzzy sets. After the aggregation process, there is a fuzzy set for each output variable that needs defuzzification. It's possible, and in many cases much more efficient, to use a single spike as the output membership function rather than a distributed fuzzy set. This is sometimes known as a singleton output membership function, and it can be thought of as a pre-defuzzified fuzzy set. It enhances the efficiency of the defuzzification process because it greatly simplifies the computation required which finds the centroid of a two-dimensional function. Rather than integrating across the two-dimensional function to find the centroid, we use the weighted average of a few data points. Sugeno-type systems support this type of model. In general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

3.10.6 Building Systems with the Fuzzy Logic Toolbox

There are five primary Graphical User Interference (GUI) tools for building, editing, and observing fuzzy inference systems (FIS) in the Fuzzy Logic Toolbox:

1) The Fuzzy Inference System or FIS Editor.
2) The Membership Function Editor.
3) The Rule Editor.
4) The Rule Viewer.
5) The Surface Viewer.

In addition to these five primary GUIs, the toolbox includes the graphical adaptive neural fuzzy inference systems (ANFIS) Editor GUI, which is used for building and analyzing Sugeno-type adaptive neural fuzzy inference systems.

The five GUIs are dynamically linked, in that changes the user makes to the FIS using one of them, can affect what user can see on any of the other open GUIs. Any or all of them can open for any given system. These five GUIs are shown in figure (3.15) and the following section represents a brief description for each one.

FIS Editor

The FIS Editor handles the high level issues for the system: How many input and output variables? What are their names? The Fuzzy Logic Toolbox doesn't limit the number of inputs. However, the number of inputs may be limited by the available memory of your machine. If the number of inputs is too large, or the number of membership functions is too big, then it may also be difficult to analyze the FIS using the other GUI tools. Figure 3.16 represents the FIS editor in fuzzy toolbox.

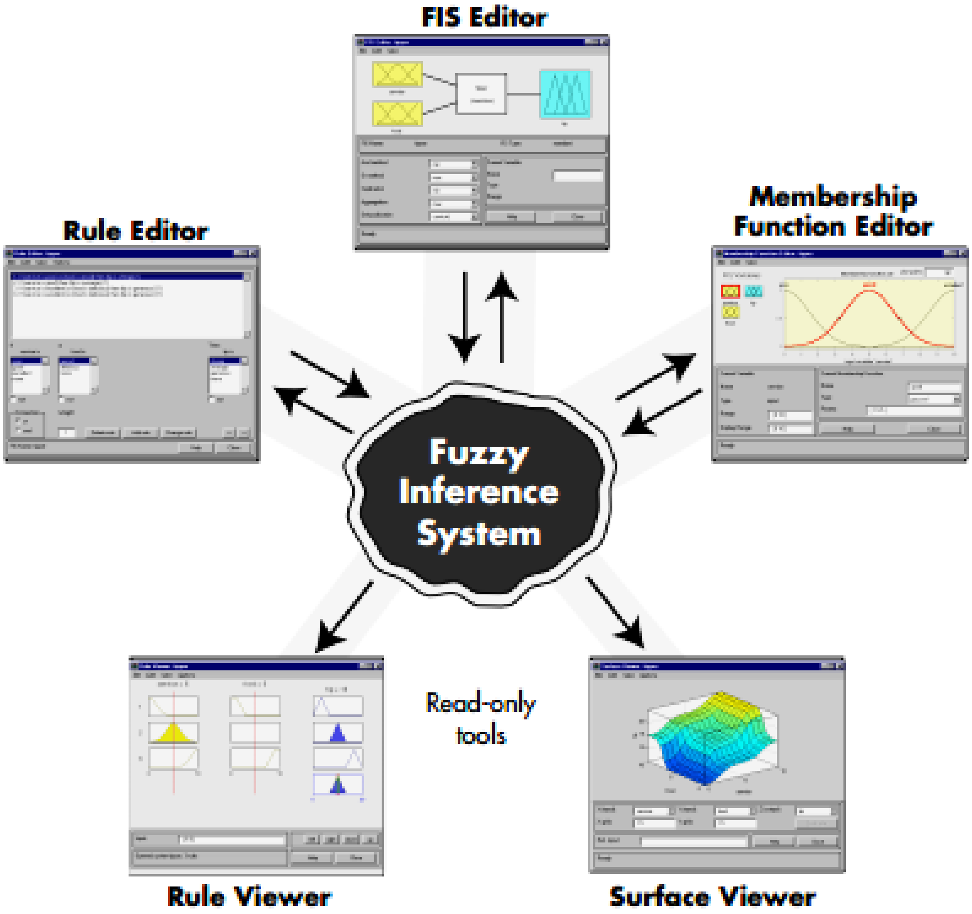


Figure 3.15: GUIs in fuzzy logic toolbox.

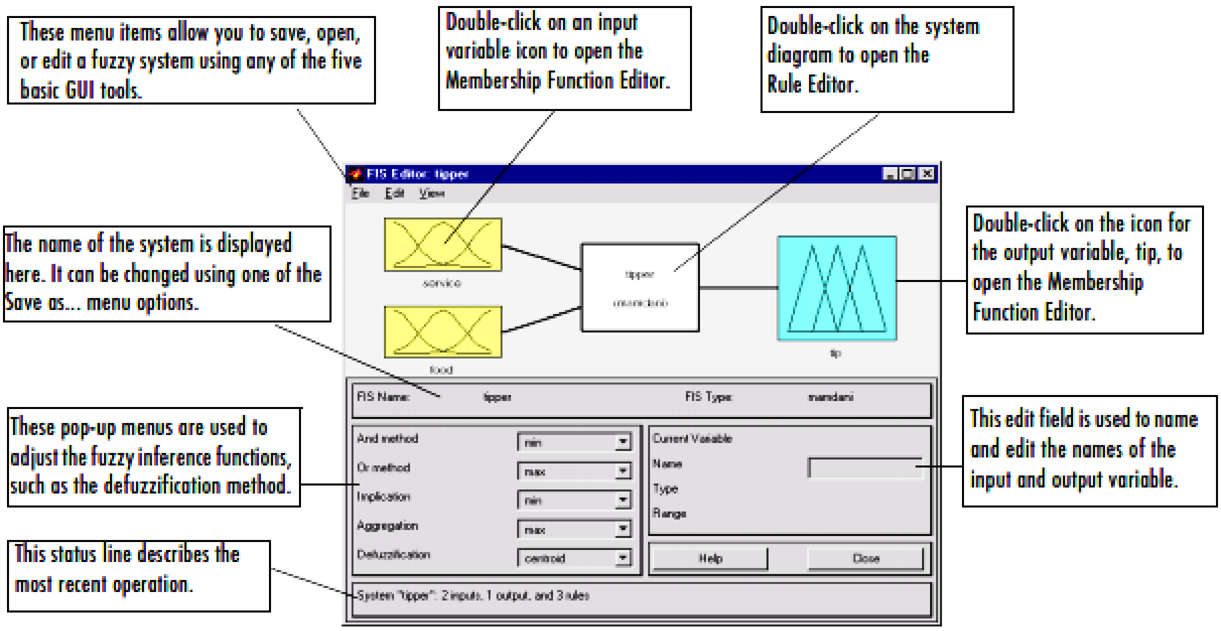


Figure 3.16: FIS editor in fuzzy logic toolbox.

The Membership Function Editor

The membership function editor is used to define the shapes of all the membership functions associated with each variable. Figure 3.17 shows how to set the membership function editor.

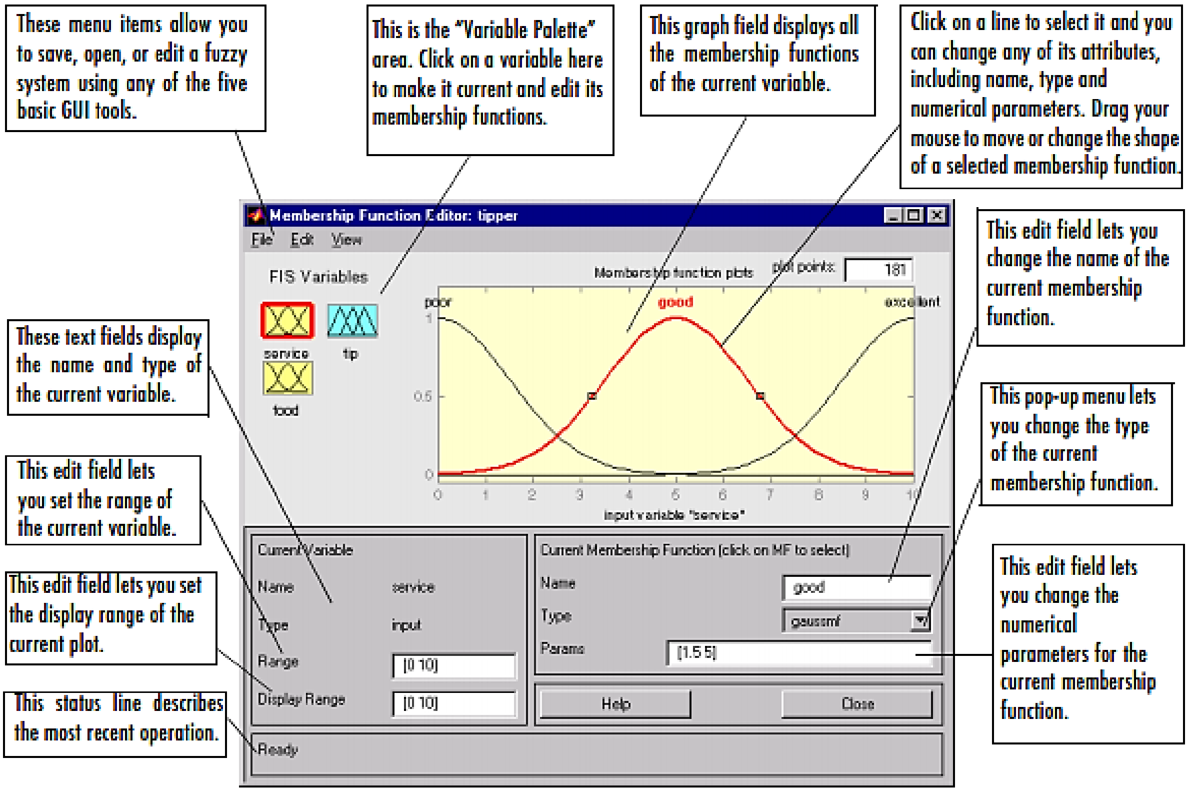


Figure 3.17: Membership function editor.

The Rule Editor

The Rule Editor is for editing the list of rules that defines the behavior of the system. Constructing rules using the graphical rule editor interface is based on the descriptions of the input and output variables defined with the FIS Editor, this can be shown in figure 3.18.

The Rule Viewer

The Rule Viewer displays a roadmap of the whole fuzzy inference process. The Rule Viewer is a MATLAB-based display of the fuzzy inference diagram. It used as a diagnostic, it can show (for example) which rules are active, or how individual membership function shapes are influencing the results. Since it plots every part of every rule. This described in figure 3.19.

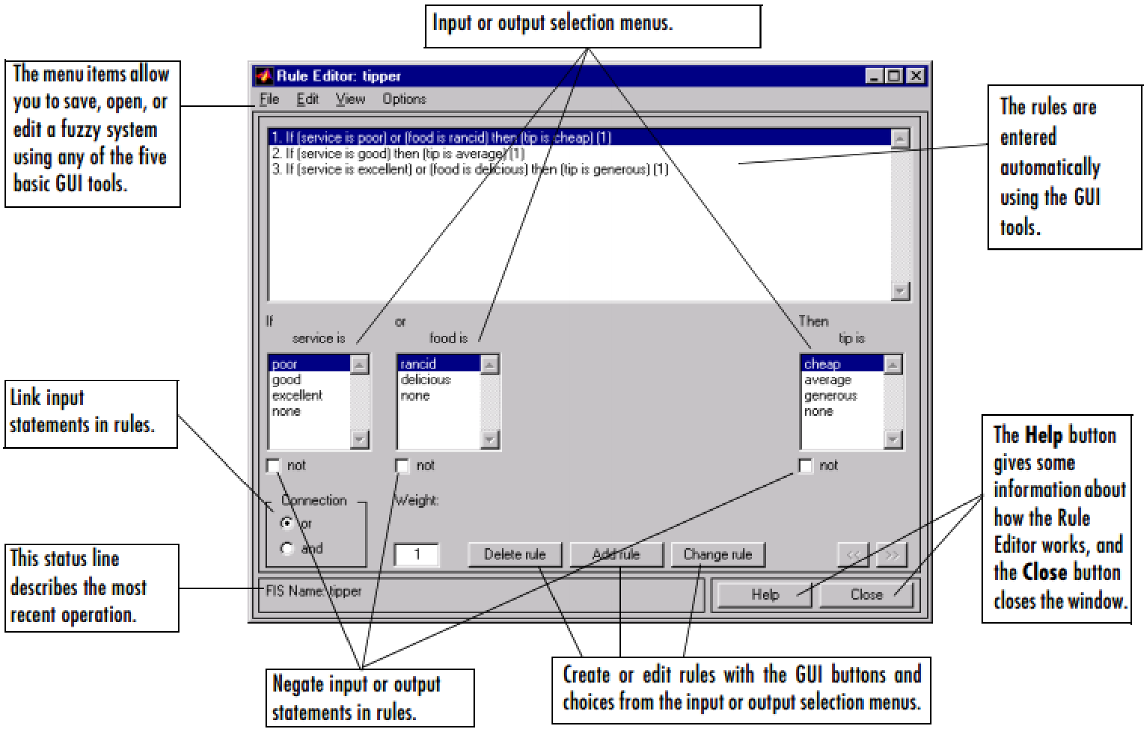


Figure 3.18: The rule editor in fuzzy toolbox.

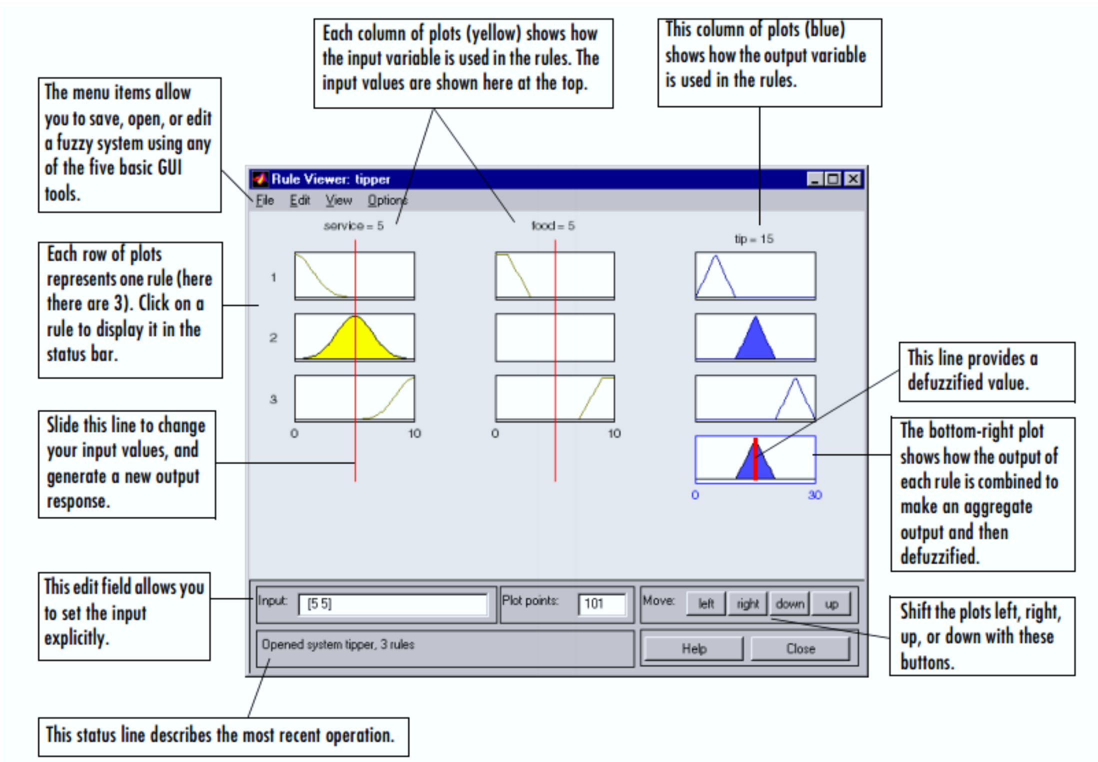


Figure 3.19: The rule viewer in fuzzy logic toolbox.

The Surface Viewer

The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs-that is, it generates and plots an output surface map for the system. The Rule Viewer and Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools [27]. Figure 3.20 below, shows the internal construction of the surface viewer.

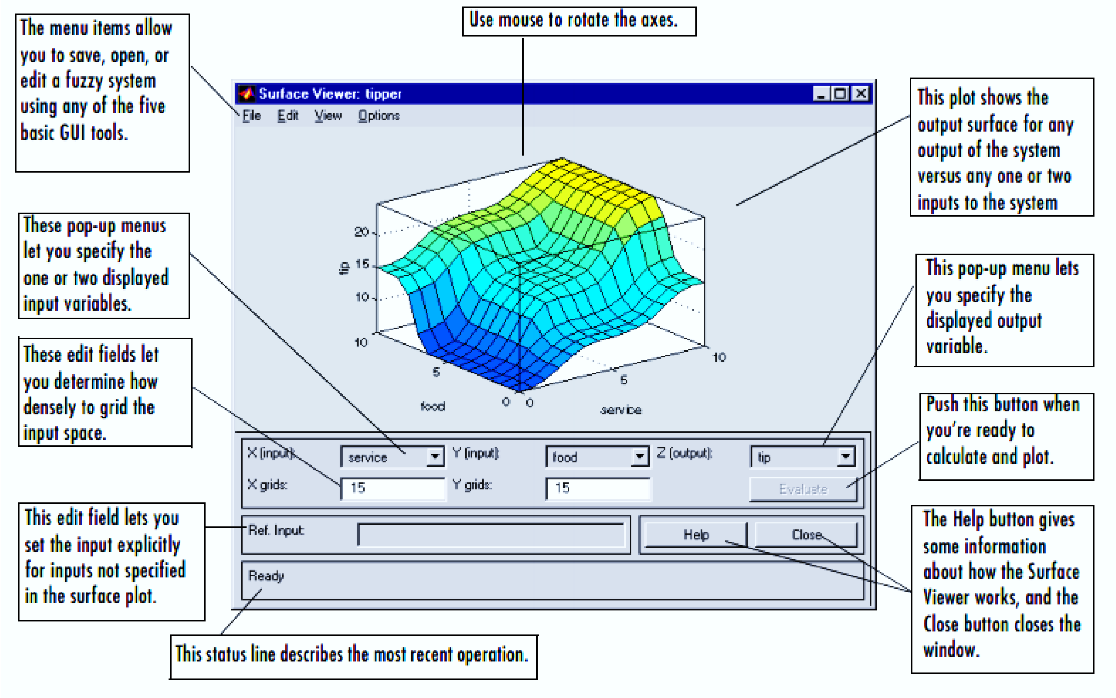


Figure 3.20: The surface viewer in fuzzy toolbox.

3.11 Fuzzy Logic In Power And Control Applications

Over the past two decades, there has been a tremendous growth in the use of fuzzy logic controllers in power systems as well as power electronic applications. A recent series of tutorials in the *IEE* Power Engineering Journal [25], [26] which focused entirely on the applications of fuzzy logic in power systems is evidence of its growing significance in the field. Current applications in power systems include power system stability control, power system stability assessment, line fault detection and process optimization for generation, transmission and distribution. Fuzzy logic is also used in motion control, control of wind turbines [23], motor efficiency optimization and waveform estimation. The advantages of using fuzzy logic in such applications include the following:

• Fuzzy logic controllers are not dependent on accurate mathematical models. This is particularly useful in power system applications where large systems are difficult to model. It is also relevant to smaller applications with significant non-linarites in the system.

• Fuzzy logic controllers are based on heuristics and therefore able to incorporate human intuition and experience. There are numerous ways to build and implement a fuzzy logic system. It can either be based on a fuzzy logic development shell or built using software programming languages such as C++ or even Java. [19]

CHAPTER FOUR

SIMULATION RESULTS AND DISCUTION

4.1 National Sudanese Grid Description

The single line diagram of the national network is shown in figure 4.1 and network characteristics are shown in table 4.1 The network consist of eighty two (82) busbars. The network busbars operate in various four voltage levels (500,220, 110, and 66kV) which forms the main part of the transmission system in the Sudanese electrical network.

The total number of transmission lines is eighty one (81) and the transmission line charge supplies the required reactive power with total line length of 5469.735 km.

The data was taken at normal load condition with total loading of 1553.3 MW and 1083.3 MVAr and the total generation of 1603.517 MW, and 227.008 MVAr.

The total generation in the grid is generated from seven power plants in Sudan (Merwi, Garri, Rosieres, Sennar, Kosti, Khartoum north, and Girba) and the eighth generator is the tie line feeder from Ethiopia to Port Sudan power plant.

Table 4.1: National Sudanese network characteristics.

Number of Buses.	82
Number of Lines.	81
Number of Generators.	8
Number of Transformers.	15
Total connected Loads.	53

This study focus on ranking of contingencies on the national Sudanese network. This objective must be achieved basically on fuzzy interface system, it was achieved primarily on NELAN software program and the results were represents on table 4.2, which they were taken as reference to compare them with those which was taken from fuzzy logic approach.

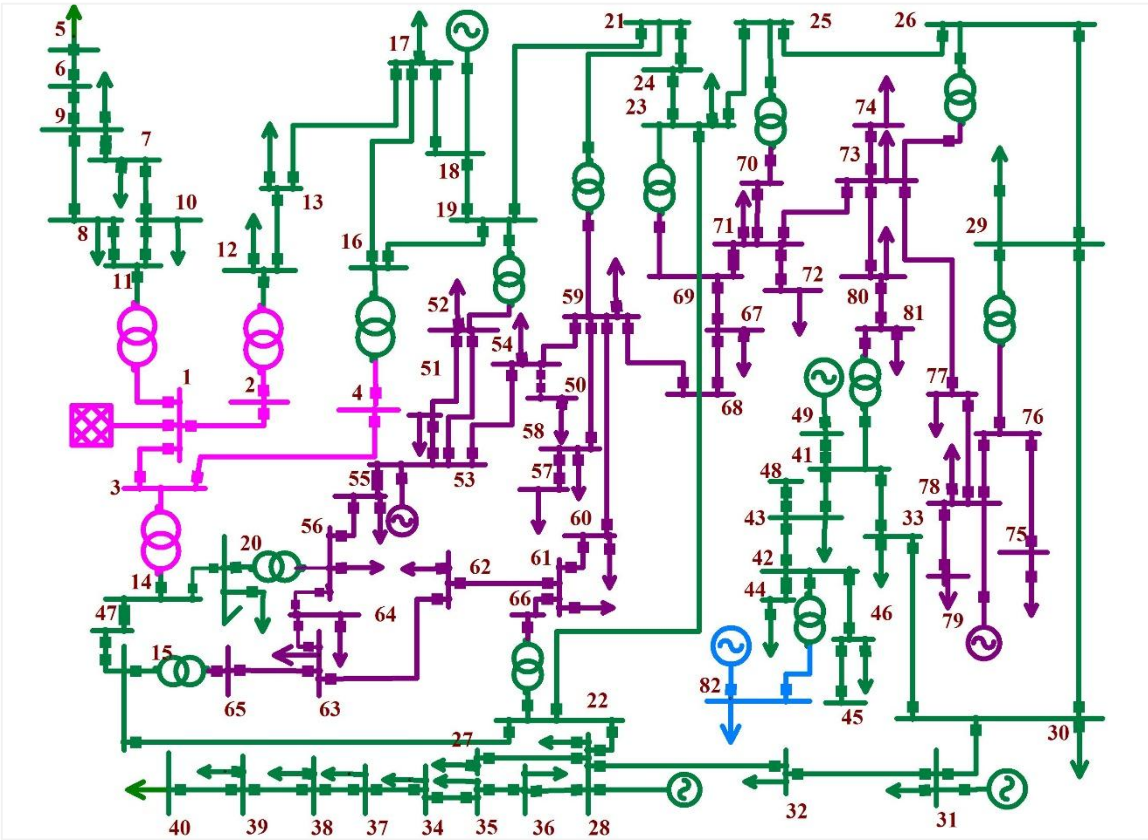


Figure 4.1: Single line diagram of national Sudanese grid.

■ 500 kV, ■ 220kV, ■ 110kV, ■ 66Kv

4.2 National Grid (CA) Results Using NEPLAN Software.

The base case results of the national Sudanese network contingency analysis are shown in table 4.2.

Table 4.2: NEPLAN results of the contingency analysis for the national grid.

Contingency	Violated Element	Element Type	Zone of Violated Element	Viola-tion	Base Case Value	Zone Viola -tion KV	Zone Rated kV	Ranking
Element/Mode				%				
23	36	Line	Zone 1	142.63	58.11	**-**	110	1
23	35	Line	Zone 1	142.59	59.07	-	110	2
NHAS TR	43	Line	Zone 1	115.77	13.49	-	110	3
39	40	Line	Zone 1	113.3	62.19	-	110	4
26	51	Line	Zone 1	113.17	85.54	-	110	5
SHU-WAW2	6	Node	North	112.96	102.04	248.512	220	6
63	65	Node	Omdurman	112.53	98.58	123.783	110	7
32	65	Node	Omdurman	112.09	98.58	123.299	110	8
25	43	Line	Zone 1	111.71	13.49	-	110	9

61	66	Node	Khartoum	111.37	100.35	122.507	110	10
SHU-WAW2	9	Node	North	111.31	102.56	244.882	220	11
SHU-WHL	5	Node	North	111.31	98.92	244.882	220	12
12	4	Node	Khar. North	111.24	97.99	556.2	500	13
78	75	Node	White Nile	110.84	101.97	121.924	110	14
78	76	Node	Blue Nile	110.79	102.01	121.869	110	15
37	66	Node	Khartoum	110.72	100.35	121.792	110	16
51	75	Node	White Nile	110.65	101.97	121.715	110	1
51	76	Node	Blue Nile	110.6	102.01	121.66	110	18
SHU-WHL	6	Node	North	110.12	102.04	242.264	220	19
KLX TR	35	Line	Zone 1	108.78	59.07	-	110	20
MAR TR	51	Line	Zone 1	108.73	85.54	-	110	21
25	40	Line	Zone 1	108.19	62.19	-	110	22
KLX TR	36	Line	Zone 1	107.93	58.11	-	110	23
19	25	Line	Blue Nile	106.2	61	-	110	24
48	51	Line	Zone 1	104.67	85.54	-	110	25
73	51	Line	Zone 1	102.12	85.54	-	110	26
MAR TR	43	Line	Zone 1	100.9	13.49	-	110	27
19	47	Node	Omdurman	90	100.02	198	220	28
54	60	Node	Khartoum	89.99	94.41	98.989	110	29
GER-14Gen	12	Node	North	89.99	92.4	197.978	220	30
40	67	Node	Khartoum	89.95	92.03	98.945	110	31
54	69	Node	Khartoum	89.88	92.4	98.868	110	32
KHN-5Gen	25	Node	Gezera	89.83	95.74	197.626	220	33
25	60	Node	Khartoum	89.79	94.41	98.769	110	34
NHAS TR	69	Node	Khartoum	89.77	92.4	98.747	110	35
26	80	Node	White Nile	89.76	100.49	98.736	110	36
25	69	Node	Khartoum	89.71	92.4	98.681	110	3
KHN-5Gen	20	Node	Omdurman	89.7	100.45	197.34	220	38
19	68	Node	Khartoum	89.7	93.55	98.67	110	39
54	59	Node	Khartoum	89.7	94.4	98.67	110	40
7	8	Node	North	89.69	104.43	197.318	220	41
NHAS TR	67	Node	Khartoum	89.63	92.03	98.593	110	42
25	69	Node	Khartoum	89.61	92.4	98.571	110	43
19	15	Node	Omdurman	89.61	98.44	197.142	220	44
KHN-5Gen	22	Node	Khartoum	89.6	98.12	197.12	220	45
54	68	Node	Khartoum	89.56	93.55	98.516	110	46
21	64	Node	Omdurman	89.56	95.76	98.516	110	47
25	67	Node	Khartoum	89.5	92.03	98.45	110	48
36	69	Node	Khartoum	89.5	92.4	98.45	110	49
25	59	Node	Khartoum	89.49	94.4	98.439	110	50
MAR TR	73	Node	Gezera	89.47	102.91	98.417	110	51
68	69	Node	Khartoum	89.44	92.4	98.384	110	52
35	69	Node	Khartoum	89.44	92.4	98.384	110	53
18	12	Node	North	89.42	92.4	196.724	220	54
23	69	Node	Khartoum	89.37	92.4	98.307	110	55
25	68	Node	Khartoum	89.36	93.55	98.296	110	56
53	23	Node	Khartoum	89.33	98.31	196.526	220	57
54	67	Node	Khartoum	89.29	92.03	98.219	110	58
23	67	Node	Khartoum	89.28	92.03	98.208	110	59
59	69	Node	Khartoum	89.13	92.4	98.043	110	60
25	67	Node	Khartoum	89.12	92.03	98.032	110	61
39	26	Node	Zone 1	88.97	95.59	195.734	220	62
21	56	Node	Rever Nile	88.89	96.42	97.779	110	63

53	25	Node	Gezera	88.88	95.74	195.536	220	64
36	68	Node	Khartoum	88.88	93.55	97.768	110	65
KHN-5Gen	15	Node	Omdurman	88.86	98.44	195.492	220	66
36	67	Node	Khartoum	88.86	92.03	97.746	110	67
53	14	Node	Omdurman	88.82	100.51	195.404	220	68
23	26	Node	Zone 1	88.81	95.59	195.382	220	69
35	67	Node	Khartoum	88.81	92.03	97.691	110	70
68	67	Node	Khartoum	88.8	92.03	97.68	110	71
10	2	Node	North	88.77	100.31	443.85	500	72
20	61	Node	Khartoum	88.52	95.16	97.372	110	73
59	68	Node	Khartoum	88.51	93.55	97.361	110	74
59	67	Node	Khartoum	88.49	92.03	97.339	110	75
53	47	Node	Omdurman	88.42	100.02	194.524	220	76
1	67	Node	Khartoum	88.34	92.03	97.174	110	77
69	67	Node	Khartoum	88.32	92.03	97.152	110	78
21	55	Node	Khar. North	88.24	97.5	97.064	110	79
26	73	Node	Gezera	88.17	102.91	96.987	110	80
53	22	Node	Khartoum	88.1	98.12	193.82	220	81
20	69	Node	Khartoum	88.03	92.4	96.833	110	82
53	20	Node	Omdurman	87.78	100.45	193.116	220	83
19	69	Node	Khartoum	87.74	92.4	96.514	110	84
19	67	Node	Khartoum	87.45	92.03	96.195	110	85
39	25	Node	Gezera	87.32	95.74	192.104	220	86
20	67	Node	Khartoum	87.23	92.03	95.953	110	87
9	9	Node	North	87.21	102.56	191.862	220	88
53	15	Node	Omdurman	87.14	98.44	191.708	220	89
23	25	Node	Gezera	87.13	95.74	191.686	220	90
9	6	Node	North	86.52	102.04	190.344	220	91
20	60	Node	Khartoum	86.42	94.41	95.062	110	92
20	68	Node	Khartoum	86.38	93.55	95.018	110	93
17	12	Node	North	86.07	92.4	189.354	220	94
13	12	Node	North	86.07	92.4	189.354	220	95
8	9	Node	North	86.05	102.56	189.31	220	96
GDF TR	80	Node	White Nile	86.01	100.49	94.611	110	97
20	59	Node	Khartoum	85.92	94.4	94.512	110	98
KHN-5Gen	66	Node	Khartoum	85.85	100.35	94.435	110	99
17	13	Node	North	85.67	96.88	188.474	220	100
13	13	Node	North	85.67	96.88	188.474	220	101
8	6	Node	North	85.35	102.04	187.77	220	102
41	80	Node	White Nile	85.08	100.49	93.588	110	103
13	12	Node	North	85.05	92.4	187.11	220	104
5	12	Node	North	85.05	92.4	187.11	220	105
NHAS TR	71	Node	Gezera	84.62	103.17	93.082	110	106
NHAS TR	70	Node	Gezera	84.5	103.49	92.95	110	107
NHAS TR	72	Node	Gezera	84.21	102.84	92.631	110	108
10	12	Node	North	83.82	92.4	184.404	220	109
17	51	Node	Khar. North	83.61	96.63	91.971	110	110
9	5	Node	North	83.23	98.92	183.106	220	111
20	54	Node	Khar. North	83.03	98.48	91.333	110	112
53	66	Node	Khartoum	83.02	100.35	91.322	110	113
20	50	Node	Khartoum	82.71	98.21	90.981	110	114
KHN-5Gen	65	Node	Omdurman	82.05	98.58	90.255	110	115
8	5	Node	North	82.04	98.92	180.488	220	116
KHN-5Gen	69	Node	Khartoum	81.65	92.4	89.815	110	117

10	9	Node	North	81.36	102.56	178.992	220	118
10	6	Node	North	80.6	102.04	177.32	220	119
KHN-5Gen	67	Node	Khartoum	80.59	92.03	88.649	110	120
53	69	Node	Khartoum	79.73	92.4	87.703	110	121
25	71	Node	Gezera	79.73	103.17	87.703	110	122
25	70	Node	Gezera	79.6	103.49	87.56	110	123
53	51	Node	Khar. North	79.56	96.63	87.516	110	124
7	9	Node	North	79.43	102.56	174.746	220	125
25	72	Node	Gezera	79.29	102.84	87.219	110	126
53	65	Node	Omdurman	79.14	98.58	87.054	110	127
7	6	Node	North	78.63	102.04	172.986	220	128
KHN-5Gen	68	Node	Khartoum	78.48	93.55	86.328	110	129
53	67	Node	Khartoum	78.46	92.03	86.306	110	130
KHN-5Gen	61	Node	Khartoum	78.02	95.16	85.822	110	131
KHN-5Gen	63	Node	Omdurman	77.99	95.85	85.789	110	132
KHN-5Gen	62	Node	Omdurman	77.75	95.47	85.525	110	133
10	7	Node	North	77.57	102.16	170.654	220	134
KHN-5Gen	59	Node	Khartoum	77.32	94.4	85.052	110	135
KHN-5Gen	64	Node	Omdurman	77.29	95.76	85.019	110	136
KHN-5Gen	60	Node	Khartoum	77.27	94.41	84.997	110	137
10	5	Node	North	77.2	98.92	169.84	220	138
KHN-5Gen	56	Node	Rever Nile	77.19	96.42	84.909	110	139
KHN-5Gen	51	Node	Khar. North	76.42	96.63	84.062	110	140
KHN-5Gen	55	Node	Khar. North	76.4	97.5	84.04	110	141
KHN-5Gen	53	Node	Khar. North	76.33	100	83.963	110	142
KHN-5Gen	54	Node	Khar. North	75.97	98.48	83.567	110	143
KHN-5Gen	50	Node	Khartoum	75.62	98.21	83.182	110	144
7	7	Node	North	75.48	102.16	166.056	220	145
53	68	Node	Khartoum	75.23	93.55	82.753	110	146
7	5	Node	North	75.19	98.92	165.418	220	147
53	63	Node	Omdurman	74.84	95.85	82.324	110	148
53	61	Node	Khartoum	74.53	95.16	81.983	110	149
53	62	Node	Omdurman	74.51	95.47	81.961	110	150
53	56	Node	Rever Nile	74.32	96.42	81.752	110	151
53	64	Node	Omdurman	74.24	95.76	81.664	110	152
53	55	Node	Khar. North	73.53	97.5	80.883	110	153
53	60	Node	Khartoum	73.5	94.41	80.85	110	154
53	59	Node	Khartoum	73.47	94.4	80.817	110	155
53	54	Node	Khar. North	70.01	98.48	77.011	110	156
53	50	Node	Khartoum	69.63	98.21	76.593	110	157
GDF TR	81	Node	East	64.18	101.65	70.598	110	158
41	81	Node	East	62.68	101.65	68.948	110	159

The above results of contingency analysis was taken for National Gird at normal load .The contingency analysis results in NEPLAN depends on the voltage violation. The results represent 159 cases includes system lines, generators, and transformers, where the total number of elements in the network are 186 but some of the lines locate as partial networks or not feeded lines. So, the NPELAN gives the results of the cases which they are operating (ON). The results shown the voltage at the base case, zone voltage level of the each contingency, and the violated of zone's voltage during outage of the contingency. Also, the results show the most affected element in each case (violated element), its value of violation (%), and ranking of contingency according to his violation level.

NEPLAN achieves ranking of violation according to where the violation occurs, i.e the outage of one element, causes voltage violation in the other element of the network, the element which a case of contingency ranked according to its voltage violation, is called the violated element. Hence, a one case of contingency may has more than ranking in NEPLAN because it causes voltage violation in many element and NEPLAN takes the higher values of violation. Hence, the element may have more ranking according the violated element consideration. For instance, line 23-which connected between busbar 61and 62- has two ranking in the results, the first one according to the violation which it causes in line 36 and the other ranking according to the violation which it causes at line 35. Also, line SHU-WAW2 has ranking according to violation at busbar 6 and another ranking according to violation at busbar 9.

There are about 27 contingences have high value of voltage violation above than (%100), those are separated with blue line from that which there have violation level less than (%100) in table 4.2.

It is worth to mention that the violated element effects on the other element which they are located in its zone, and the most affected elements, those which have physical related coherent with it.

4.3 Fuzzy Logic Approach.

A membership function of trapezoidal type "trapmf" was created on the Mamdani model membership function editor at (FIS) toolbox in order to find the severity indices for the buses, i.e severity indices of Voltage Profile (SI_{VP}), also another membership function with the same type was created to find the Severity Indices of Line Flow (SI_{LF}). These two membership functions (the voltage profile membership function, and the line flow membership function) were set as shown in Figures (4.2, and 4.3).

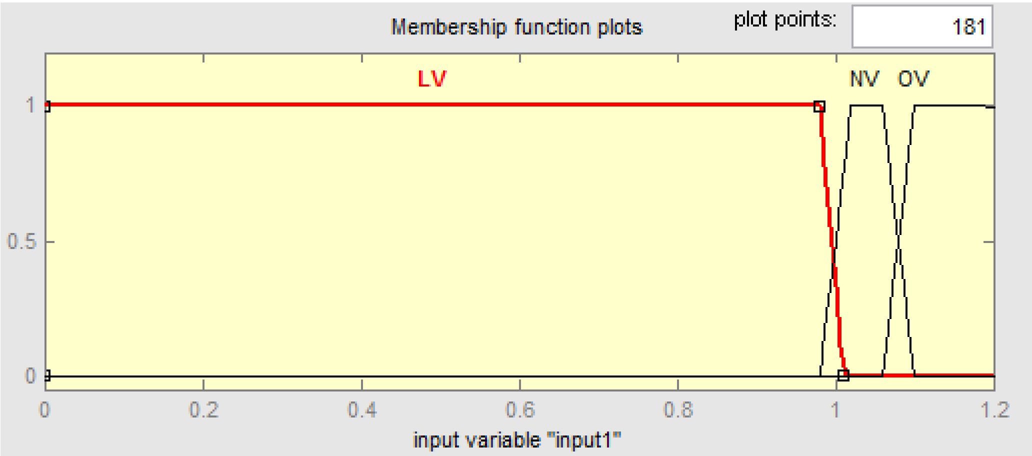


Figure 4.2: Voltage profile membership function.

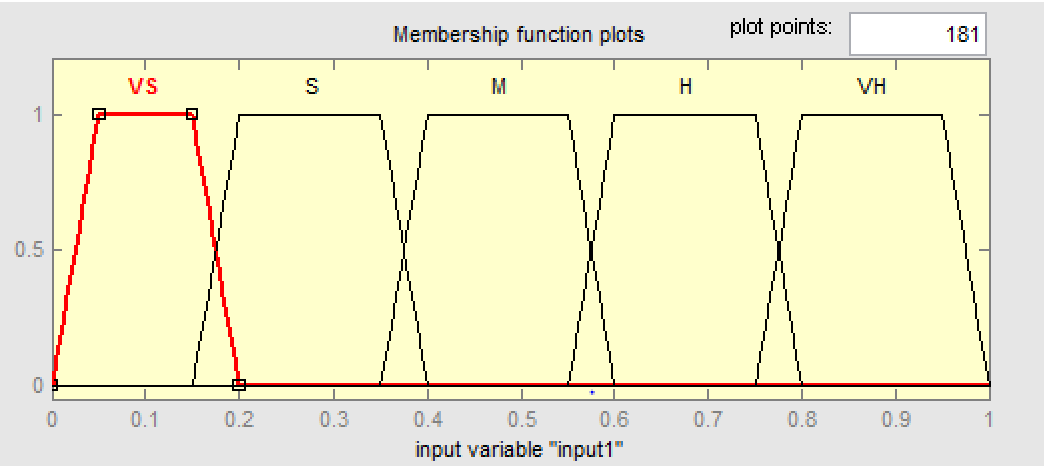


Figure 4.3: Line flow membership function.

The output for the two membership functions is represented the severity index of each one, which is shown on figures (4.4, and 4.5) respectively.

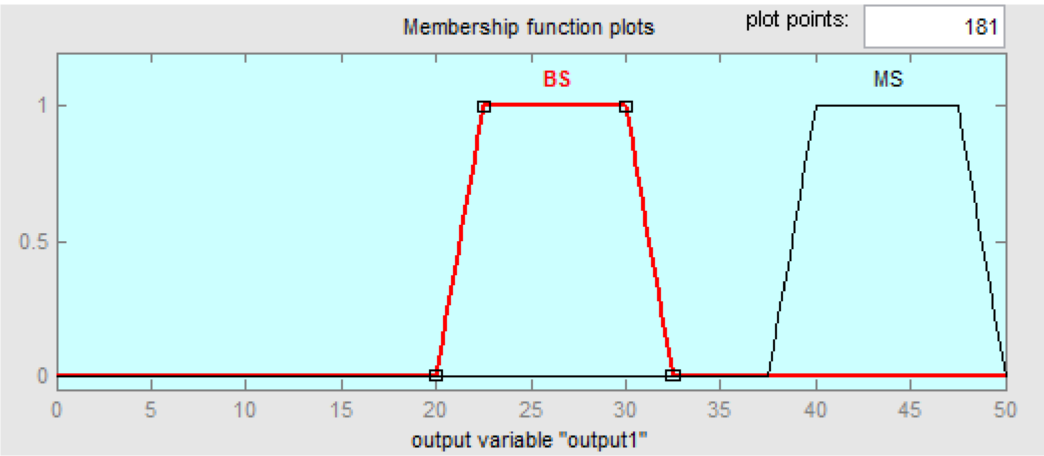


Figure 4.4: Severity index of voltage profile membership function.

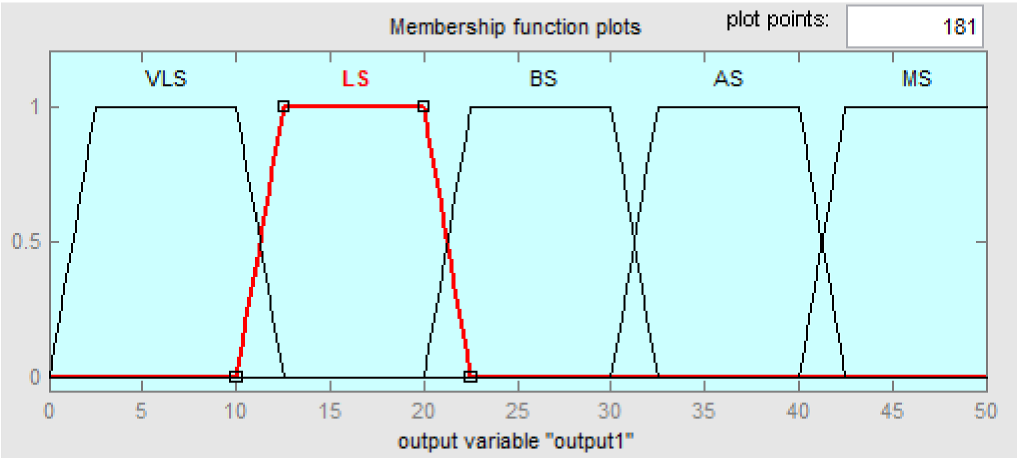


Figure 4.5: Severity index of line flow membership function.

The fuzzification process completes by setting the if-then rules as the required setting in table 4.3 below.

Table 4.3: Fuzzy Rules.

<table>
<tr><th colspan="5">Input</th><th colspan="5">Output</th></tr>
<tr><td colspan="5">Voltage profile</td><td colspan="5">SI_{VP}</td></tr>
<tr><td colspan="2">LV</td><td colspan="2">NV</td><td>OV</td><td colspan="2">MS</td><td colspan="2">BS</td><td>MS</td></tr>
<tr><td colspan="5">Line flow index</td><td colspan="5">SI_{LF}</td></tr>
<tr><td>VS</td><td>S</td><td>M</td><td>H</td><td>VH</td><td>VLS</td><td>LS</td><td>BS</td><td>AS</td><td>MS</td></tr>
</table>

Where:

LV= Low Voltage.

NV= Normal Voltage.

OV= Over Voltage.

MS= More Severe.

BS= Below Severe.

VS= Very Small.

S = Small.

M= Medium.

H= High.

AS= Above Severe.

VH= Very High.

LS= Less Severe.

VLS= Very Less Severe.

This rules were set on the rule editor of both voltage profile and line flow membership functions as shown in figures (4.6, and 4.7).

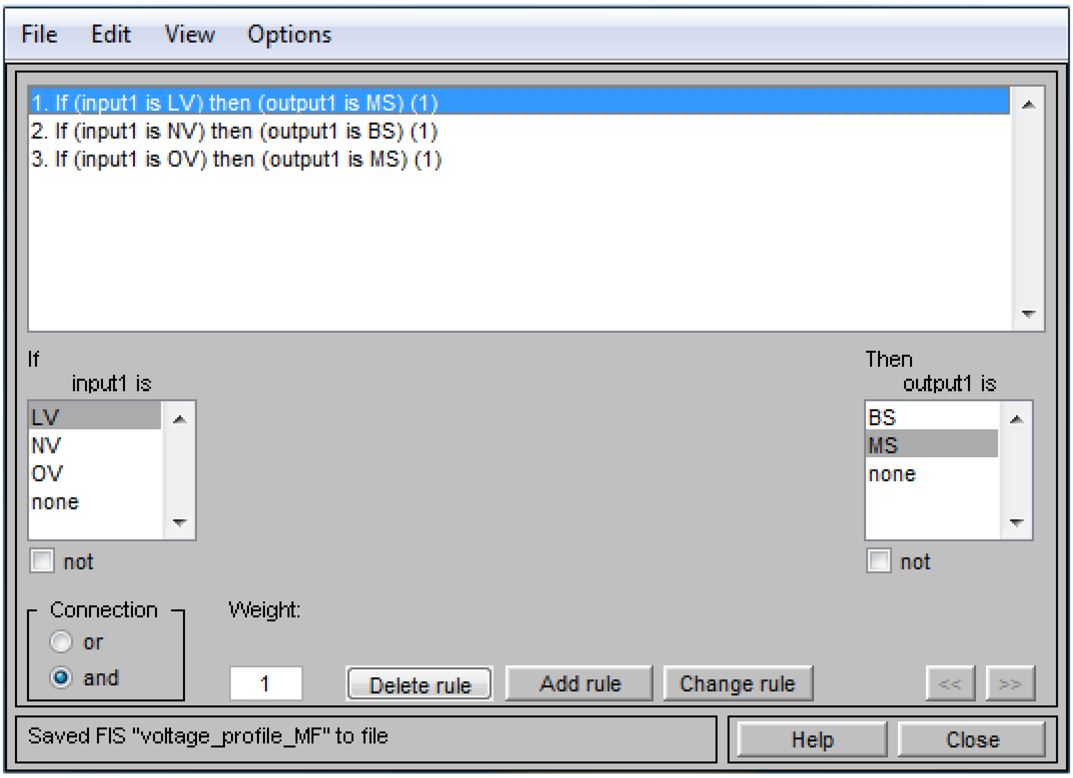


Figure 4.6: The rules editor of voltage profile membership function.

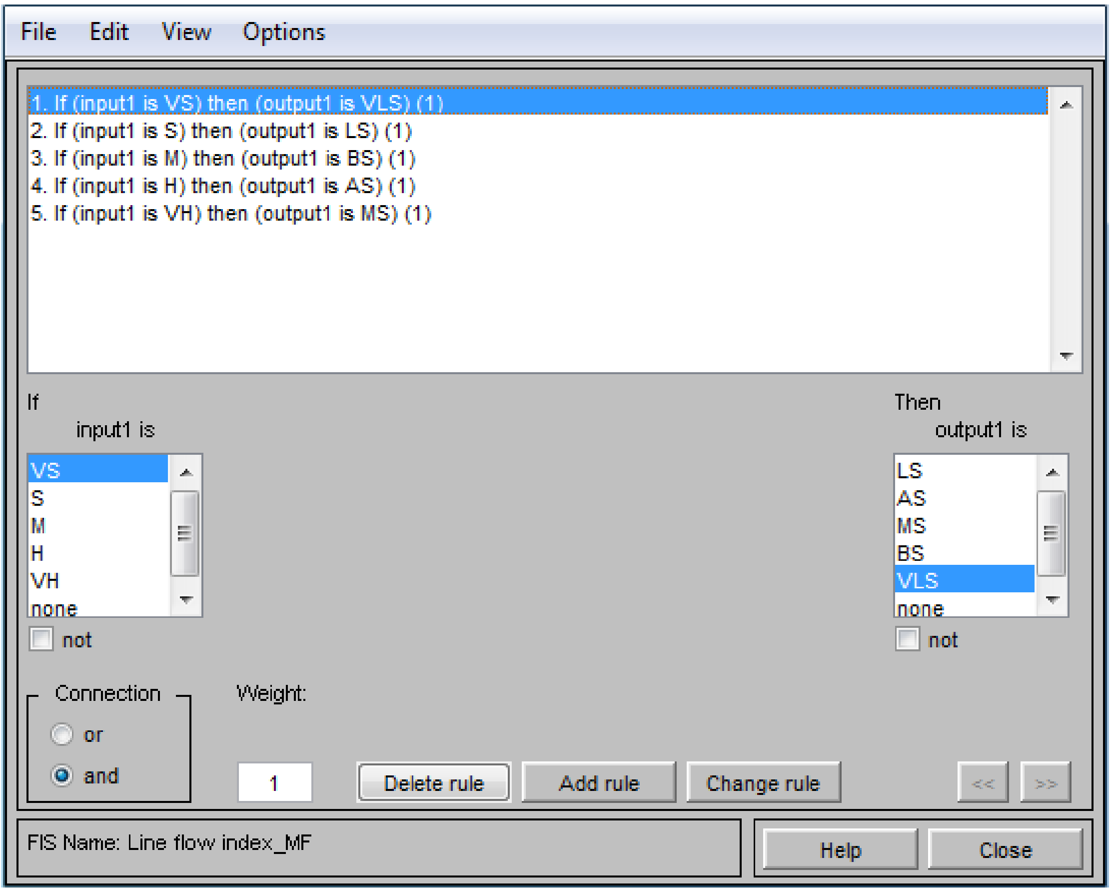


Figure 4.7: The rules editor of line flow membership function.

These rules are illustrates perfectly on the rule viewer as shown in figures (4.8, and 4.9).

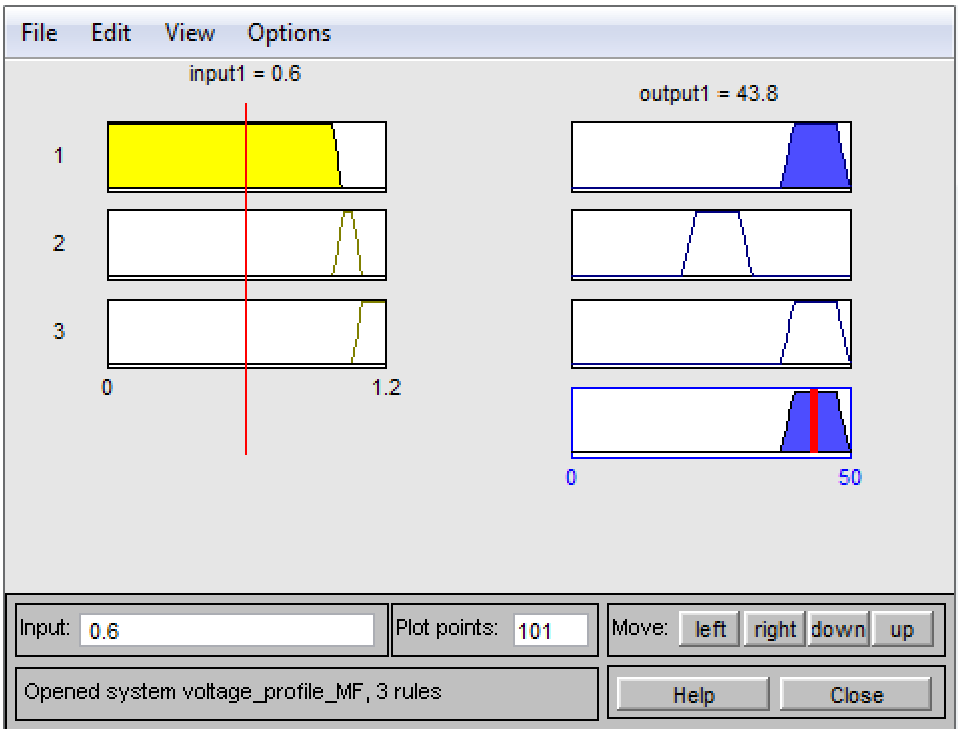


Figure 4.8: The rules viewer of voltage profile membership function.

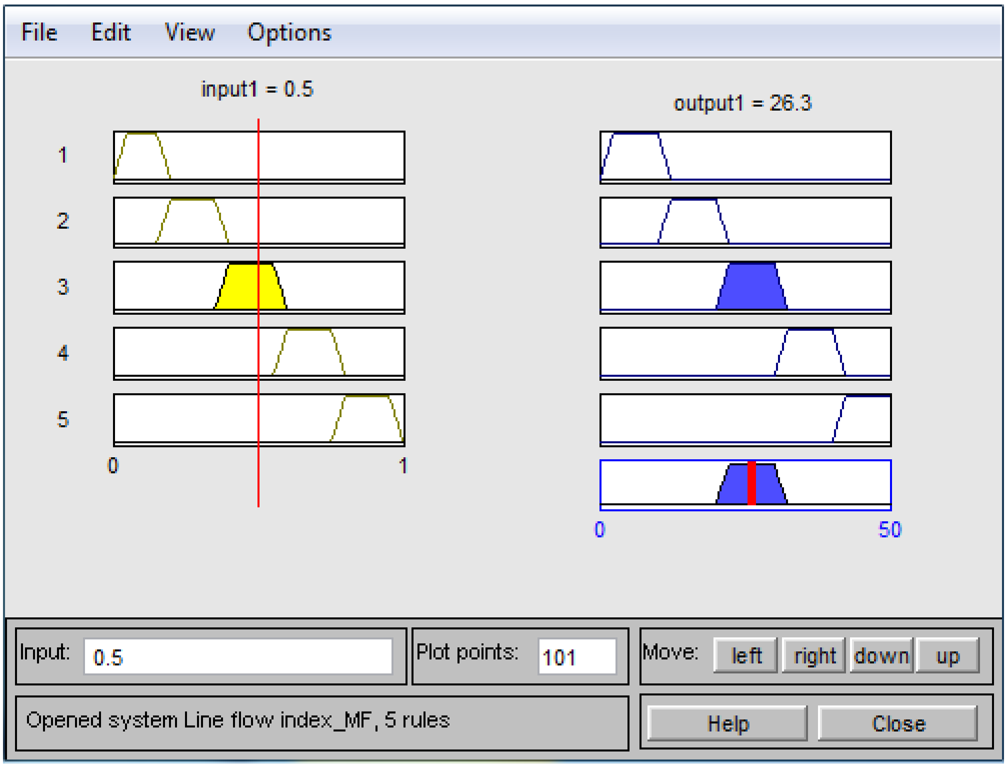


Figure 4.9: The rules viewer of line flow membership function.

To defuzzifiy the output which represents the severity indices for voltage profile and line flow (SI_{VP} and SI_{LF}), to evaluate them as numbers the two membership functions were inserted into two FIS blocks. The FIS block of voltage profile is shown in figure (4.10), the linguistic variables for this block are the voltage profile data of the system, and the linguistic values are the severity indices of the voltages. The fuzzy logic controller of the block includes the voltage profile membership function which designed previously on Mamdani membership function editor, it was inserted in the block as shown in figure (4.11). The same action was applied to line flow membership function as shown in figures (4.12) and (4.13).

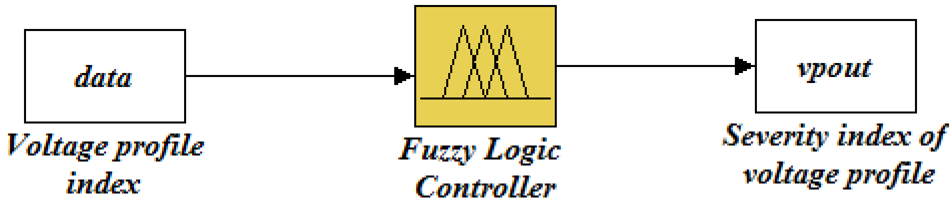


Figure 4.10: Voltage Profile FIS block.

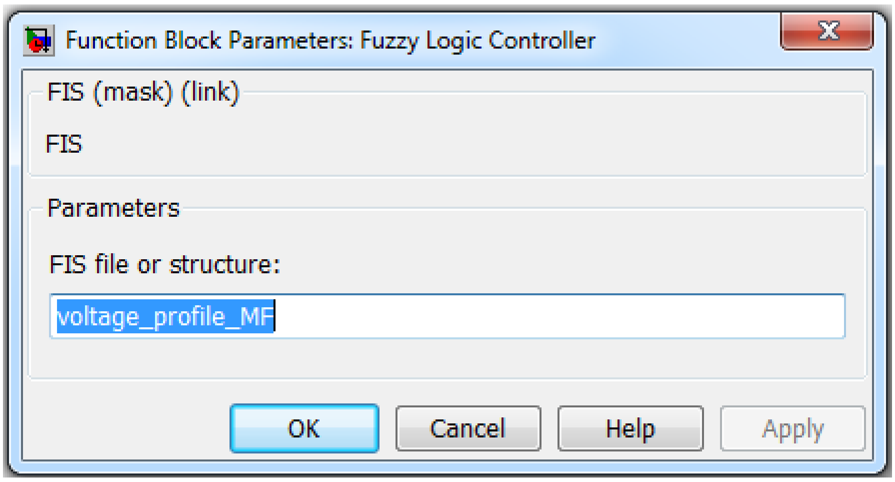


Figure 4.11: Parameters setting on fuzzy logic controller at Voltage Profile FIS block.

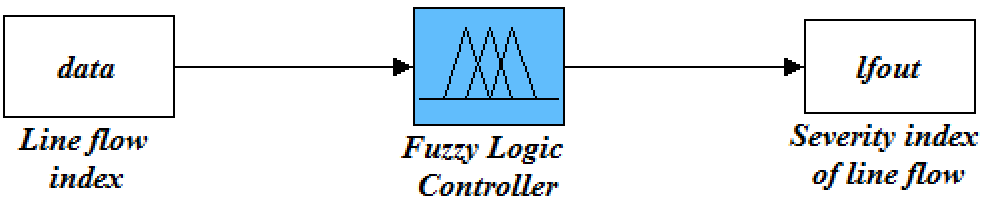


Figure 4.12: Line flow FIS block.

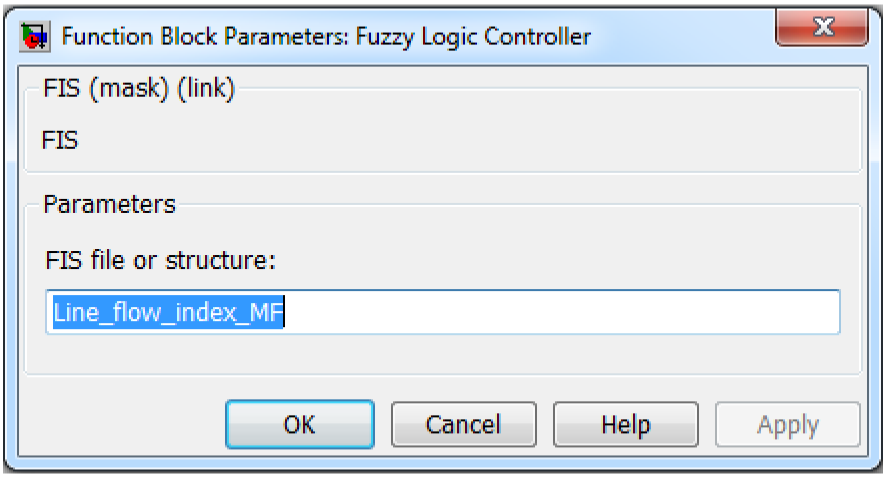


Figure 4.13: Parameters setting on fuzzy logic controller at Line flow FIS block.

The two outputs from two blocks represents the summation of the severity indices of voltage profile and summation of severity indices of line flow ($\sum SI_{VP}$, $\sum SI_{LF}$). The summation of these two outputs (i.e. $\sum$ ($\sum SI_{VP}$, $\sum SI_{LF}$), is forming the composite index (CI) which express the total severity index for the common contingency case. Figure (4.14) gives detailed description for the fuzzy approach to find the total severity index for contingency case (composite index (CI)).

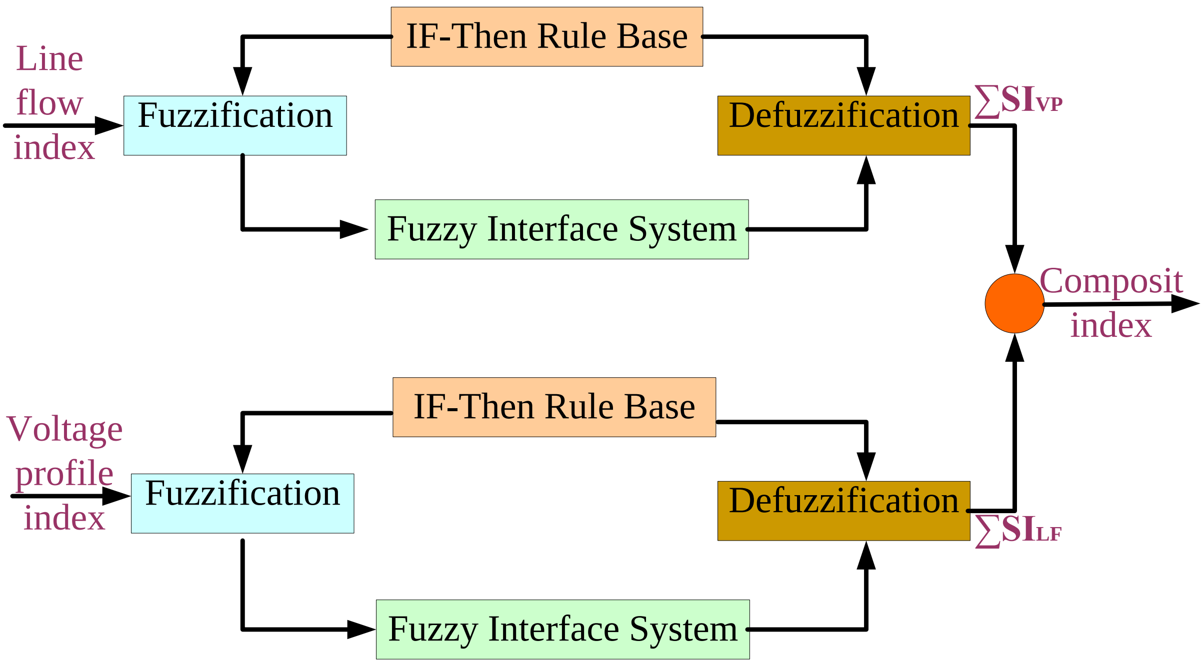


Figure 4.14: Fuzzy logic base algorithm.

4.4 National Grid (CA) Results Using Fuzzy Logic Approach

For purpose of simplicity, five contingencies of national grid was taken on consideration these five cases are clarified in table (4.4).

Table 4.4: Reference data for the five contingencies under consideration

Contingency NO.	Type of Contingency	From	To	Violation %	Violated Element	Ranking
1	Line 23	Bus 61	Bus 62	142.63	Line36	1
2	Line37	Bus66	Bus61	110.72	Node66	2
3	Line 20	Bus53	Bus54	88.52	Node61	3
4	Line26	Bus59	Bus60	88.17	Node73	4
5	Line 10	Bus1	Bus2	83.82	Node12	5

4.4.1 Contingency [1] Analysis (Line 23 outage)

Table 4.5: Severity Indices for voltage profiles.

Node Name	Voltage profile (p.u)	SI_{VP}
61	0.9240	43.75
21	0.9245	43.75
63	0.9272	43.75
62	0.9413	43.75
54	0.9507	43.75
53	0.9509	43.75
58	1.0443	43.75
55	0.9572	43.2685
26	0.9575	43.2042
56	0.9591	42.2508
25	0.9595	41.3088
58	0.9609	40.6618
11	1.0384	40.6618
57	0.9624	40.6618
64	1.0371	40.6618
65	1.0339	39.7147
48	0.9665	39.6324
52	0.9665	39.6324
10	1.0315	39.6324
67	1.0307	39.6324
13	0.9694	37.9946
66	1.0306	37.6856
29	0.972	37.6856
9	1.0256	37.6856
51	0.9764	37.6856
7	1.0216	35.5912
6	1.0204	35.5912
69	1.0203	35.5912
68	1.0199	35.5912
3	0.9807	35.1786
4	0.983	34.8444
73	1.017	34.549

47	0.9835	34.549
22	0.9844	34.549
23	0.9861	34.549
50	0.9861	34.549
70	1.0126	34.549
15	0.9879	34.1867
16	0.9884	34.121
5	0.9892	33.8188
59	0.9896	33.445
30	0.9900	33.0653
14	1.0087	32.6796
43	0.9916	32.2876
20	1.0083	31.8893
42	0.9918	31.4844
60	1.0081	30.9167
32	1.0079	30.9167
36	1.0072	26.25
72	1.0062	26.25
24	0.9941	26.25
35	1.0054	26.25
40	1.0046	26.25
2	1.0039	26.25
45	1.0038	26.25
12	0.9964	26.25
19	0.9971	26.25
27	0.9974	26.25
39	1.0026	26.25
44	0.9975	26.25
17	0.9978	26.25
37	1.0019	26.25
41	0.9986	26.25
46	0.9986	26.25
34	0.9987	26.25
33	0.9988	26.25
38	1.0006	26.25
1	1.00	26.25
18	1.00	26.25
28	1.00	26.25
31	1.00	26.25
49	1.00	26.25
71	1.00	26.25
$\sum SI_{VP}$		**2539.404**

The results of voltage profile at line23 contingency, was taken for its highest violation (142.63%) which occurs at line 36. From the results of the voltage profile it is clear that the highest values of the severity index of voltage profile (43.75) appear on nodes 61 and 62 (the two nodes which the contingency of line 23 connected between them) and this value represent also on the nodes which are closely connected to node 61 and node 62. It is worth to mention that the value of (43.75) classified (MS) on the membership function editor at the fuzzy set. Also it can be noticed that the severity index for node 59 and node 68 –the two nodes which the violated element (line 36) connected between them; these two nodes have severity index voltage profile of (33.4450, and 35.5912) respectively which is lesser than that of nodes 61 and 62 and they are classified (BS) at the fuzzy set of membership function editor.

Table 4.6: Severity Indices for Line Flow index

Line Name	L.F index	SI_{LF}
36	0.8645	13.7797
25	0.8589	13.0675
24	0.6227	12.3651
26	0.5798	12.1934
35	0.5736	12.1934
32	0.5637	11.5047
31	0.5637	10.816
34	0.5619	10.3066
22	0.5612	10.3066
30	0.5581	9.6066
20	0.5425	8.8968
22	0.5391	8.3654
17	0.4806	8.3654
16	0.4783	7.9602
18	0.4169	7.7078
14	0.4161	7.6124
15	0.375	7.1147
13	0.3693	6.8377
51	0.3622	6.4728
44	0.3598	6.25
41	0.3589	6.25
78	0.3578	6.25
43	0.3433	6.25
38	0.3408	6.25
53	0.333	6.25
52	0.3122	6.25
1	0.2714	6.25
3	0.2713	6.25
37	0.2683	6.25
74	0.2638	6.25
39	0.2621	6.25
19	0.262	6.25
10	0.2604	6.25
4	0.2568	6.25
75	0.2565	6.25
76	0.2565	6.25
2	0.2552	6.25

71	0.2541	6.25
49	0.2444	6.25
42	0.2398	6.25
41	0.2371	6.25
45	0.2371	6.25
61	0.2367	6.25
63	0.2365	6.25
56	0.2364	6.25
59	0.2236	6.25
57	0.2234	6.25
69	0.2202	6.25
67	0.2193	6.25
50	0.2192	6.25
5	0.2186	6.25
68	0.2076	6.25
62	0.1965	6.25
64	0.1947	6.25
60	0.1866	6.25
65	0.183	6.25
70	0.1823	6.25
6	0.1801	6.25
$\sum SI_{L.F}$		**429.2228**

From the line flow index results it is apparent that the highest value of the severity index line flow (13.7797) is for line 36 (the violated element on case line23 outage) and the other lines which neighboring to line 36 have values of severity index line flow near to that for line 36, and the reverse thing can be said about those lines which they are far connected from the violated element -line 36- (i.e. they have the lesser values of severity index of line flow).

By returning to the membership function editor, these fuzzy sets are classified into (LS) range on the membership function editor what means that the outing of on these lines (line 36 and its neighbors) must not cause a severe on the network on other words, the network settle secure in case of one of these lines outage, this can be checked from NPELAN results, for example, line 36 contingency has a violation of (89.50%) and this falls under the severity line of the system. From the defuzzificaton results above, the value of the composite index for line 23 (CI_{line23}) contingency is:

$CI_{line23} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line23} = 2539.4040+429.2228$ = **2968.6268**....(4.1)

The results of voltage profile and line flow severity indices for line23 contingency, are represent at the two graphs on figures (4.15) and (4.16).

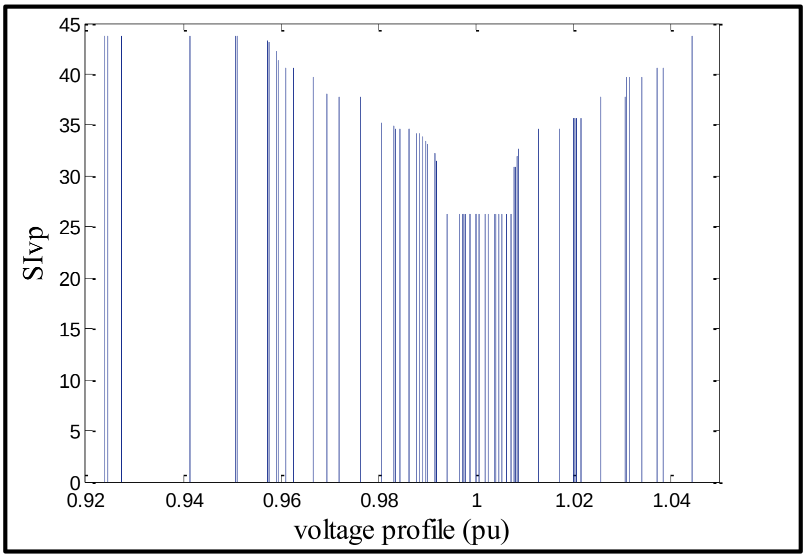


Figure 4.15: Severity index voltage profile (SI_{VP}) at line23.

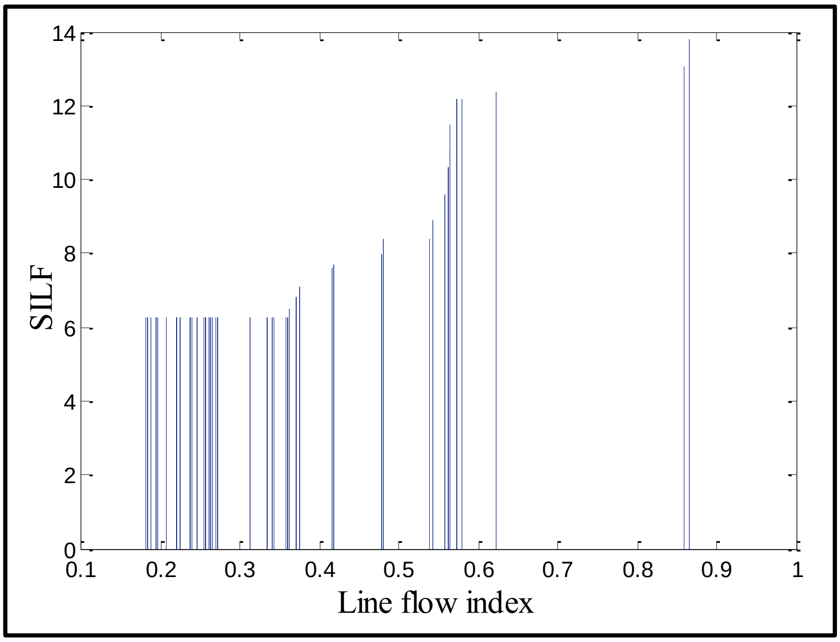


Figure 4.16: Severity index line flow (SI_{LF}) at line23.

4.4.2 Contingency [2] Analysis (Line 37 outage)

Table 4.7: Severity Indices for voltage profiles

Node Name	Voltage profile (p.u)	SI_{VP}
66	1.1072	43.75
67	0.9222	43.75
61	0.924	43.75
69	0.9272	43.5381
68	0.9295	43.3185
60	0.9315	43.0995

12	0.9332	43.0704
59	0.9337	42.8811
62	0.9429	42.1534
63	0.9489	41.3856
64	0.9502	40.6618
8	1.0443	40.6618
70	1.0423	40.6618
56	0.9603	40.6618
71	1.0391	39.8897
26	0.9611	39.6324
11	1.0384	39.6324
72	1.0359	39.6324
25	0.9642	39.6324
73	1.0345	38.4455
51	0.9666	37.6856
10	1.0315	37.6856
13	0.9689	37.6856
55	0.9727	37.6856
29	0.974	35.5912
9	1.0256	35.5912
7	1.0216	35.5912
76	1.0207	35.5912
3	0.9796	35.1266
6	1.0204	34.8024
75	1.0203	34.549
50	0.9802	34.549
65	0.9805	34.549
4	0.9817	34.549
81	1.0181	34.549
54	0.9828	34.549
77	1.0150	34.1981
14	1.0127	33.8419
16	0.9878	33.7135
20	1.011	33.4803
5	0.9892	33.1131
80	1.0092	32.7403
30	0.9913	32.3616
47	1.0085	31.9769
32	1.0079	31.5862
44	0.9922	30.9167
42	0.9924	30.9167
23	0.9926	26.25
36	1.0072	26.25
35	1.0054	26.25
15	0.9949	26.25
24	0.9949	26.25
40	1.0046	26.25
21	0.9955	26.25
19	0.9962	26.25
22	0.9965	26.25

2	1.0031	26.25
27	1.0026	26.25
39	1.0026	26.25
17	0.9977	26.25
46	0.998	26.25
37	1.0019	26.25
34	0.9987	26.25
41	0.9992	26.25
48	0.9992	26.25
38	1.0006	26.25
33	0.9998	26.25
1	1.00	26.25
18	1.00	26.25
28	1.00	26.25
31	1.00	26.25
53	1.00	26.25
78	1.00	26.25
$\sum SI_{VP}$		**2494.3840**

The violated element at line37 contingency is node 66 with violation of (110.72%) this is clearly apparent on the voltage profile of node 66 that has a same value in p.u (1.1072) which is directly effects on the value of severity index voltage profile where it is the highest at node 66. Since line37 connected between node 66 and node 61, it is expected for the highest value of the severity index voltage profile to be cumulated on nodes 66 and node 61 and the near nodes around them.

The severity index for buses 61, 62, and their neighbors have a value of (43.75) and it is clearly noticed that this value locate at fuzzy set on membership function range of (MS). Also there are many bus have severity index voltage profile in the same range of (MS).

One of the observable points in this contingency that the violated element (node 66) appears with its nominal violation at table 4.7 on contrast with the pervious contingency (line23), the violated element (line 36) its violation does not appear on table 4.6, this is for the reason that NEPLAN program achieves the ranking process by paying attention to the voltage violation which happens in the elements of the system when case of contingency occurs. Since, violated element at contingency line23 was a line, so its violation in the table does not appear oppose to this case of contingency where the violated element was a node not a line. The same saying is proper for the following three contingencies.

Table 4.8: Severity Indices for Line Flow index.

Line Name	L.F index	$SI_{L.F}$
23	0.9201	37.6230
29	0.8852	13.9569
27	0.8795	13.2364
31	0.7209	12.5259
32	0.7175	12.1934
26	0.6969	12.1934
19	0.6962	11.4991
54	0.6284	10.8047
40	0.6186	10.3066
51	0.6105	10.3066
35	0.6105	9.6008
36	0.6059	8.8851
20	0.5873	8.3654
17	0.5121	8.3654
18	0.5098	7.6615
33	0.419	7.6061
34	0.4183	7.6059
15	0.4175	6.8247
78	0.4166	6.7964
1	0.4094	6.4571
53	0.407	6.25
30	0.396	6.25
49	0.3906	6.25
4	0.3664	6.25
74	0.3659	6.25
77	0.3659	6.25
50	0.3653	6.25
73	0.333	6.25
39	0.3236	6.25
22	0.323	6.25
5	0.3206	6.25
14	0.3191	6.25
13	0.3122	6.25
24	0.3088	6.25
56	0.3087	6.25
16	0.2685	6.25
7	0.2675	6.25
28	0.2625	6.25
11	0.2568	6.25
55	0.2552	6.25

41	0.2416	6.25
6	0.2388	6.25
52	0.2351	6.25
9	0.2339	6.25
71	0.232	6.25
43	0.232	6.25
75	0.2315	6.25
5	0.2308	6.25
42	0.2299	6.25
70	0.2256	6.25
12	0.2206	6.25
10	0.2196	6.25
45	0.2119	6.25
2	0.2005	6.25
80	0.1938	6.25
60	0.1892	6.25
3	0.1851	6.25
48	0.1847	6.25
$\sum SI_{L.F}$		**428.9414**

From the results of severity index line flow for line37 contingency, it is clear that the most severe line in this case is line23 which has severity index of 37.623.As known previously that line23 -which was taken in contingency NO.1, is partially connected with line37 through bus 61 hence, it is normally to appear with highest value of severity index which locates in range of (AS) and (MS) at fuzzy set on membership function editor. Where the other lines have values of severity index start from 13.9569 and less which as generally locate in range of (LS) and (VLS) at fuzzy set on membership function editor.

From tables 4.7 and 4.8, the composite index for line37 (CI_{line37}) contingency is:

$CI_{line37} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line37} = 2494.3840 + 428.9414 =$ **2923.3254**....(4.2)

The results of voltage profile and line flow severity indices for line37 contingency, are represent at the graphs on figures (4.17) and (4.18) .

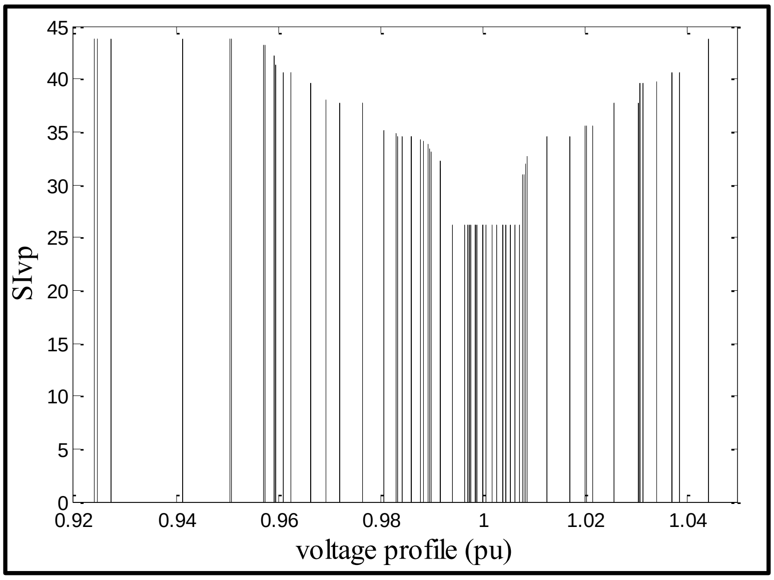


Figure 4.17: Severity index voltage profile (SI_{VP}) at line37.

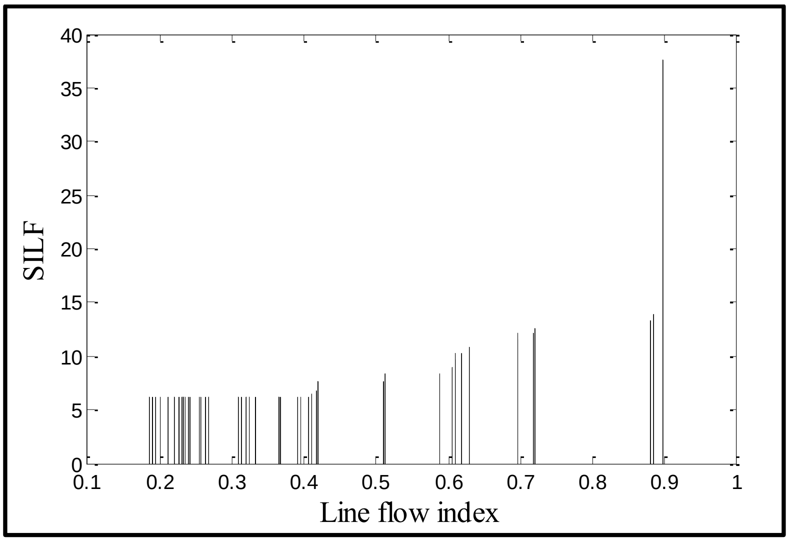


Figure 4.18: Severity index line flow (SI_{LF}) at line37.

4.4.3 Contingency [3] Analysis (Line 20 outage)

Table 4.9: Severity Indices for voltage profiles

Node Name	Voltage profile (p.u)	SI_{VP}
53	0.8271	43.75
54	0.8303	43.75
59	0.8592	43.75
68	0.8638	43.75
60	0.8642	43.75
67	0.8723	43.75
69	0.8803	43.75
61	0.8852	43.75
62	0.9038	43.75
63	0.9131	43.75
64	0.9198	43.75

12	0.9234	43.75
56	0.9387	43.75
25	0.9397	43.75
26	0.9423	43.75
65	0.9439	43.75
66	0.951	43.75
8	1.0443	43.75
22	0.9578	43.75
55	0.9597	42.9947
15	0.9607	42.273
23	0.9607	42.162
11	1.0384	41.3381
29	0.9633	40.6618
51	0.9635	40.6618
13	0.968	40.6618
10	1.0315	40.6618
3	0.9711	39.8331
24	0.9718	39.6324
4	0.9731	39.6324
9	1.0256	39.6324
21	0.975	39.6324
47	0.978	39.2267
7	1.0216	39.0524
6	1.0204	37.6856
16	0.9802	37.6856
76	1.0187	37.2539
75	1.0183	35.5912
20	0.9825	35.5912
19	0.9826	34.9178
14	0.9834	34.7761
30	0.9841	34.6337
73	1.015	34.549
70	1.0141	34.549
27	0.9861	34.549
81	1.0128	34.549
5	0.9892	34.3968
44	0.9892	34.2437
71	1.0107	34.0895
42	0.9894	33.9344
32	1.0079	33.7782
72	1.0074	33.6209
36	1.0072	33.4627
80	0.9938	33.3033
33	0.9943	33.143
35	1.0054	32.9815
46	0.995	32.9049
40	1.0046	32.8189
41	0.9957	32.6553
48	0.9957	32.4905
17	0.9968	32.3246

2	1.0027	32.1576
39	1.0026	31.9895
77	1.0026	31.8201
$\sum SI_{VP}$		**2461.7530**

From results at table 4.9, node 53 and 54 have the highest severity index (43.75) because they base node that the contingency case (line 20) connected between them. The other nodes which they possess the same severity index are the more closely connected nodes to node 53 and node 54. The other nodes of the system have a severity index varied from [42.9947-to-31.8201] in descending arrangement, it is observable that in this case there are many nodes have severity index in range of (MS).

Table 4.10: Severity Indices for Line Flow index

Line Name	L.F index	$SI_{L.F}$
23	0.7806	12.8837
27	0.7752	12.2429
26	0.7195	12.1934
28	0.681	12.1934
24	0.6313	11.5632
25	0.6291	10.933
36	0.5947	10.3066
35	0.5931	10.3066
37	0.5282	9.6664
1	0.5253	9.074
40	0.5253	9.0181
34	0.5237	8.3654
33	0.5064	8.3654
32	0.504	8.3654
29	0.4993	8.3654
30	0.498	8.3654
19	0.4956	8.3654
17	0.495	8.1471
18	0.491	7.6772
21	0.4905	7.4992
53	0.4801	6.9708
74	0.4785	6.8809
73	0.4686	6.6041
78	0.4674	6.25
14	0.4435	6.25
4	0.4433	6.25
31	0.4314	6.25
77	0.4301	6.25
5	0.3861	6.25
39	0.3836	6.25

22	0.3781	6.25
13	0.3747	6.25
50	0.3422	6.25
49	0.3364	6.25
54	0.333	6.25
55	0.3212	6.25
56	0.3206	6.25
16	0.3163	6.25
75	0.3145	6.25
7	0.3122	6.25
11	0.2937	6.25
41	0.2868	6.25
63	0.2868	6.25
9	0.2846	6.25
43	0.2821	6.25
42	0.2786	6.25
64	0.2786	6.25
66	0.2775	6.25
14	0.2571	6.25
67	0.2568	6.25
45	0.2552	6.25
12	0.2551	6.25
47	0.2474	6.25
48	0.2467	6.25
81	0.2446	6.25
10	0.2394	6.25
2	0.2348	6.25
80	0.2236	6.25
$\sum SI_{L.F}$		**451.853**

The above results in table 4.10, indicate that most of the severity indices of the lines are located within range of (VLS) and a few lines are in range of (LS) in the fuzzy set. It can be noticed here line23 is the first effected line because of its direct connection with node61 (the violated element) although its severity index in this case (12.8837) located within (LS) range because this contingency has an impact of system voltage stability higher than the effect on lines loading, this had already noticed in the results of voltage profile in table 4.9 that most of buses ware located in (MS) range which means that this contingency makes a problem in system voltage stability. From tables 4.9 and 4.10, the composite index for line20 (CI_{line20}) contingency is:

$CI_{line20} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line20} = 2461.7530 + 451.8530$ **=** **2913.6060**....(4.3)

The results of voltage profile and line flow severity indices for line20 contingency, are represent at the graphs on figures (4.17) and (4.18).

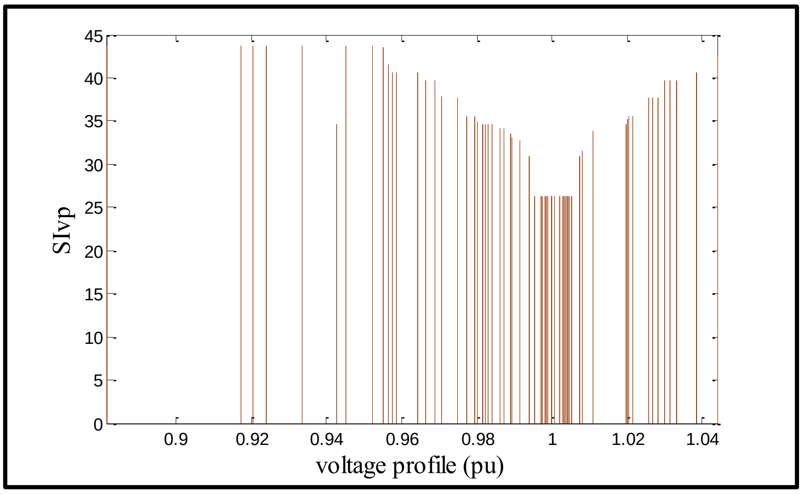


Figure 4.19: Severity index voltage profile (SI_{VP}) at line20.

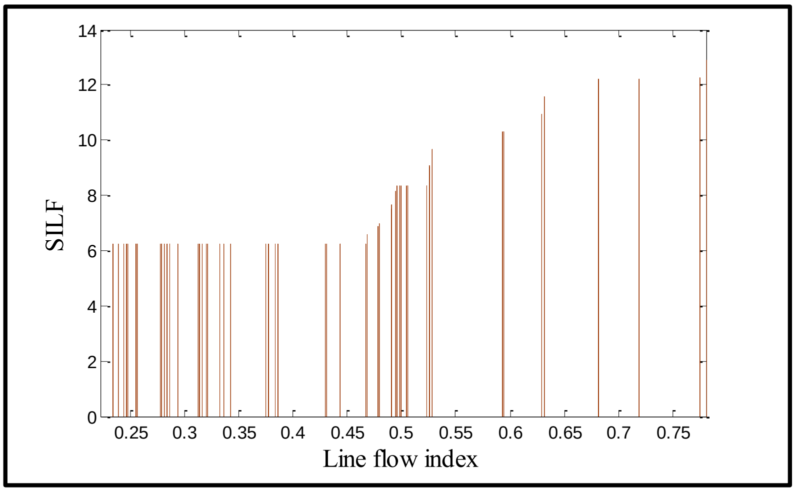


Figure 4.20: Severity index Line flow index (SI_{LF}) at line20.

4.4.4 Contingency [4] Analysis (Line 26 outage)

Table 4.11: Severity Indices for voltage profiles.

Node Name	Voltage profile (p.u)	SI_{VP}
60	0.9171	43.75
63	0.9205	43.75
61	0.924	43.75
62	0.9334	43.75
73	0.8817	43.75
59	0.9451	43.75
58	0.9523	43.75
68	0.955	43.5252
21	0.9552	43.3207
64	1.0443	42.5161
25	0.9565	41.5199

58	0.9576	40.6618
57	0.9587	40.6618
67	1.0384	40.6618
52	0.9641	40.6618
48	0.9663	39.6632
64	1.0333	39.6324
10	1.0315	39.6324
13	0.9689	39.6324
65	1.03	39.6324
29	0.9707	37.8918
67	1.0282	37.6856
66	1.0267	37.6856
9	1.0256	37.6856
51	0.975	37.6856
3	0.9773	35.5912
7	1.0216	35.5912
4	0.9795	35.5912
6	1.0204	35.5912
69	1.0201	35.1786
22	0.98	34.8444
68	1.0196	34.549
47	0.9816	34.549
23	0.9824	34.549
15	0.9831	34.549
53	0.9425	34.549
50	0.9842	34.549
11	0.986	34.1867
16	0.9871	34.171
70	1.011	33.8188
30	0.9891	33.445
5	0.9892	33.0653
24	0.9913	32.6796
43	0.9913	32.2876
42	0.9915	31.8893
32	1.0079	31.4844
36	1.0072	30.9167
27	0.9939	30.9167
35	1.0054	26.25
19	0.9952	26.25
40	1.0046	26.25
27	0.9955	26.25
60	1.0043	26.25
72	1.0042	26.25
14	1.0039	26.25
20	1.0033	26.25
2	1.0032	26.25
44	0.9971	26.25
39	1.0026	26.25
17	0.9976	26.25
33	0.9981	26.25

37	1.0019	26.25
41	0.9981	26.25
46	0.9981	26.25
34	0.9987	26.25
45	0.999	26.25
38	1.0006	26.25
1	1.00	26.25
18	1.00	26.25
28	1.00	26.25
31	1.00	26.25
49	1.00	26.25
71	1.00	26.25
$\sum SI_{VP}$		**1708.767**

From the results in table 4.11, it is shown that the violated element node 73 has the highest value of the severity index voltage profile, it is also seen that the other nodes which have the same value of severity index are those nodes which locate in the same area. The other nodes have severity index in range of (BS).

Table 4.12: Severity Indices for Line Flow index

Line Name	L.F index	$SI_{L.F}$
27	0.8514	13.9569
24	0.8458	13.2305
25	0.696	12.5144
36	0.6928	12.1934
23	0.6445	12.1934
28	0.6143	11.4934
33	0.6136	10.7934
73	0.6016	10.3066
37	0.496	10.3066
29	0.4936	9.595
35	0.4862	8.8733
34	0.4763	8.3654
22	0.4763	8.3654
31	0.4707	8.0236
21	0.4177	7.9307
32	0.417	7.5998
30	0.3963	7.1418
39	0.3941	6.8118
78	0.3883	6.6823
15	0.3829	6.25
18	0.3722	6.25
17	0.3713	6.25
78	0.3673	6.25
74	0.3651	6.25

14	0.333	6.25
19	0.3122	6.25
16	0.3035	6.25
4	0.3032	6.25
1	0.3031	6.25
49	0.298	6.25
50	0.2887	6.25
52	0.2884	6.25
54	0.2832	6.25
43	0.2809	6.25
46	0.2809	6.25
42	0.2802	6.25
47	0.2754	6.25
48	0.2686	6.25
40	0.2686	6.25
41	0.2665	6.25
51	0.2568	6.25
53	0.2552	6.25
75	0.251	6.25
77	0.2494	6.25
76	0.2483	6.25
10	0.2483	6.25
62	0.2331	6.25
12	0.2313	6.25
67	0.2293	6.25
65	0.229	6.25
62	0.2284	6.25
66	0.2284	6.25
61	0.2203	6.25
80	0.2123	6.25
81	0.2106	6.25
63	0.2105	6.25
11	0.2088	6.25
2	0.2082	6.25
$\sum SI_{L.F}$		**344.5316**

From the results of line flow for contingency line20, the most severity indices are located within range of (VLS) and some of results locate in the range of (LS) in fuzzy set. So, it can be noticed that the summation of severity index line flow (SI_{LF}) is lesser than the previous cases. Hence, the effect of the severity index line flow on the composite index of line26 (CI_{line26}) is less than the severity index profile, the composite index for contingency is:

$CI_{line26} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line26} = 1708.767 + 344.5316 =$ **2053.2986**....(4.4)

The results of voltage profile and line flow severity indices for line 26 contingency, are represent at the graphs on figures (4.21) and (4.22) below.

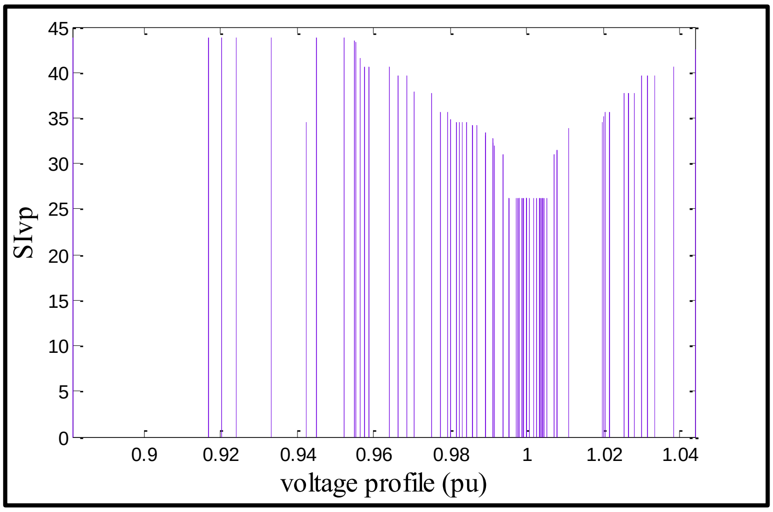


Figure 4.21: Severity index voltage profile (SI_{VP}) at line26.

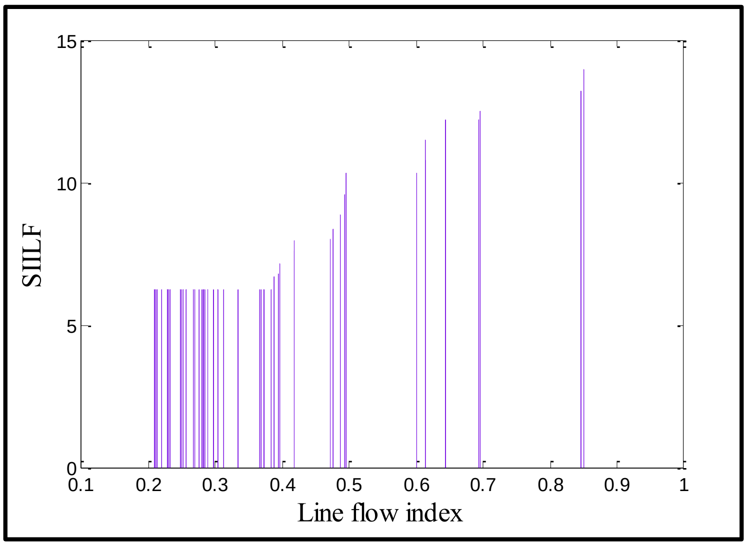


Figure 4.22: Severity index line flow (SI_{LF}) at line26.

4.4.5 Contingency [5] Analysis (Line 10 outage)

Table 4.13: Severity Indices for voltage profiles

Node Name	Voltage profile (p.u)	SI_{VP}
12	0.8382	43.75
2	0.8877	42.0605
1	0.9179	40.6618
10	0.9215	39.8611
13	0.9311	39.6324
68	0.9335	37.6856
59	0.9422	36.5625
60	0.9422	35.5912

61	0.9494	34.549
62	0.9523	33.4375
26	0.954	30.9167
25	0.9549	30.1389
64	0.9552	26.25
8	1.0443	26.25
63	0.956	26.25
3	0.9611	26.25
14	1.0384	26.25
56	0.9621	26.25
4	0.9624	26.25
51	0.9658	26.25
70	1.0322	26.25
10	1.0315	26.25
29	0.9699	26.25
71	1.0291	26.25
73	1.0271	26.25
55	0.9737	26.25
72	1.0257	26.25
9	1.0256	26.25
22	0.9763	26.25
15	0.9775	26.25
7	1.0216	26.25
6	1.0204	26.25
23	0.9796	26.25
76	1.0199	26.25
75	1.0195	26.25
50	0.9818	26.25
65	0.9826	26.25
81	1.0161	26.25
54	0.9845	26.25
16	0.9847	26.25
30	0.9886	26.25
5	0.9892	26.25
77	1.0103	26.25
24	0.9898	26.25
44	0.9911	26.25
42	0.9913	26.25
$\sum SI_{VP}$		**812.3472**

The violated element in contingency line10 is node 12 which has violation of (83.82%) this is the value is apparent on the voltage profile of node 12. In this case the most of the buses have a severity index within range of (BS) on the fuzzy set classification at membership function editor. Hence, this means that the outage of line10 doesn't have a severe effects on the system voltage stability, this can be checked from the results of NEPLAN that line 10 contingency lays under the severity line of the system.

Table 4.14: Severity Indices for Line Flow index.

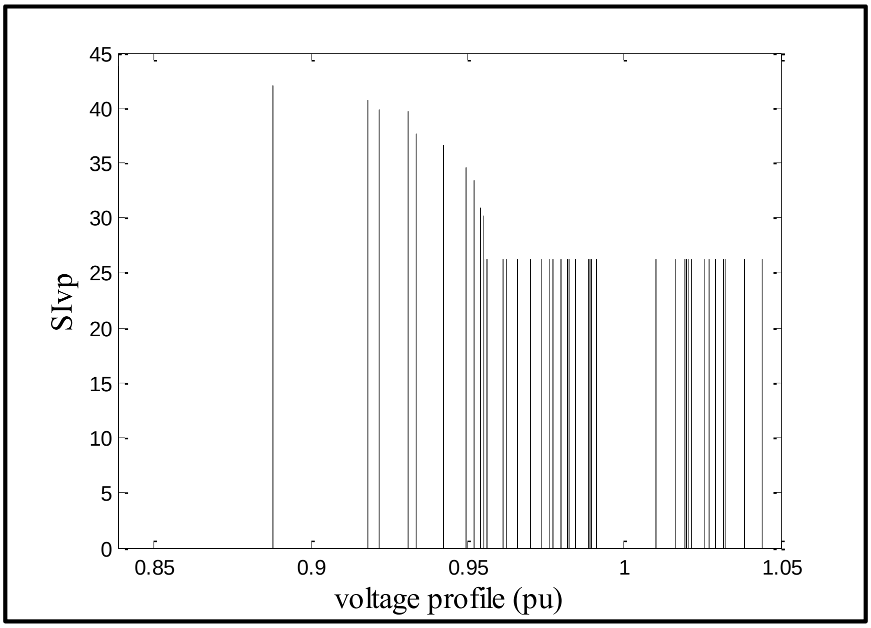
Line Name	L.F index	$SI_{L.F}$
4	0.8445	25.1293
6	0.8389	25
8	0.6303	25
3	0.6297	25
2	0.6296	25
5	0.6261	25
7	0.6195	25
9	0.6091	25
14	0.5995	25
75	0.5995	25
12	0.5941	25
11	0.5774	25
16	0.4829	24.1346
78	0.4805	24.1346
18	0.4176	22.1934
17	0.4169	22.1934
19	0.4061	20.3066
21	0.4036	20.3066
20	0.3985	18.3654
35	0.3928	18.3654
32	0.3571	16.25
31	0.3549	16.25
33	0.333	16.25
76	0.3268	16.25
77	0.3253	16.25
73	0.3201	16.25
74	0.3159	16.25
70	0.3159	16.25
43	0.3145	16.25
40	0.3122	16.25
39	0.3024	16.25
37	0.3024	16.25
49	0.2995	16.25
44	0.2975	16.25
42	0.2958	16.25
48	0.2952	16.0468
47	0.2792	15.4229
50	0.2735	14.813
62	0.2568	14.5611
71	0.2552	14.2167
69	0.2523	14.1346
67	0.2498	14.1346
56	0.2303	14.1346
53	0.2299	13.566

30	0.2286	13.0036
29	0.2165	12.768
57	0.2152	12.1934
52	0.2119	12.1934
54	0.2102	12.1934
51	0.209	12.1934
55	0.2086	10.3066
63	0.208	10.3066
66	0.2071	10.3066
65	0.2054	10.3066
59	0.205	8.3654
60	0.2049	6.25
64	0.1974	6.25
79	0.1830	6.25
$\sum SI_{L.F}$		**987.7966**

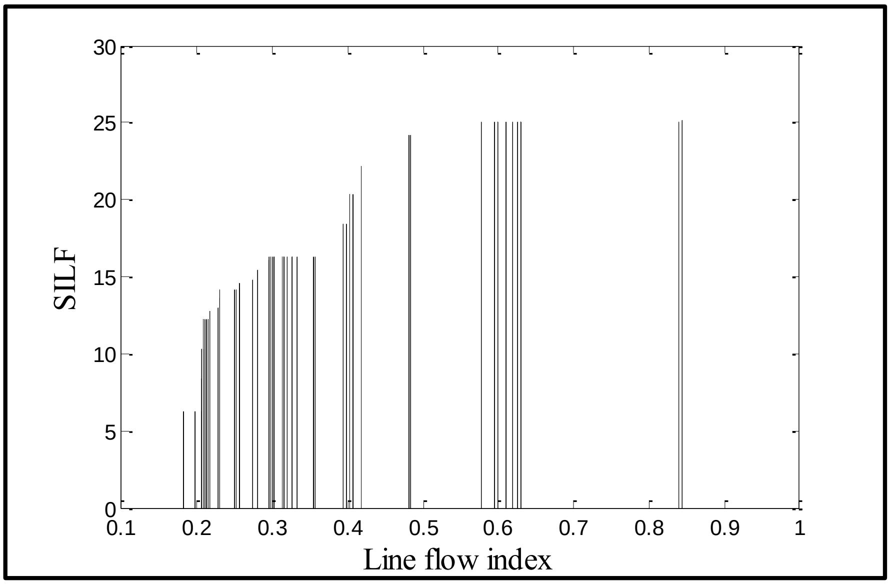
From results in table 4.14 it can be noticed that higher values of severity index was distributed around the lines which are closely connected to bus1 and 2 (the buses which line 10 connected between them), these values of severity index are located within range of (BS) in the fuzz set. The values of severity index for the other lines are varied within range of (LS) and (VLS). It is worth to mention here, that the severity index voltage profile for this case of contingency is taken values located within three different ranges (BS, LS, and VLS) this is which leads to the summation of severity index line flow for this case of contingency to become high than the other previous cases which their ($\sum SI_{LF}$) was varied into two ranges or less. On the other hand the summation of the severity index voltage profile ($\sum SI_{VP}$) for line 10 outage wasn't been a high value as it was been in the previous contingences. Hence, in this case the value of ($\sum SI_{LF}$) has the higher effect in the composite index, the composite index for line10 contingency (CI_{line10}) is:

$CI_{line10} = \sum (\sum SI_{VP} + \sum SI_{LF})_{line10} = 812.3472 + 987.7966 =$ **1800.1438**....(4.4)

The results of voltage profile and line flow severity indices for line 10 contingency, are represent at the graphs on figures (4.23) and (4.24).



Figures 4.23: Severity index voltage profile (SI_{VP}) at line10.



Figures 4.24: Severity index line flow (SI_{LF}) at line10.

The results of ranking process for the five selected contingences through fuzzy approach are shown in table 4.15.

Table 4.15: Ranking of selected contingencies through fuzzy approach.

Cont. NO.	Type of Contingency	$\sum SI_{VP}$	$\sum SI_{L.F}$	CI $\sum(\sum SI_{VP},\sum SI_{LF})$	Ranking
1	Line 23	2539.4040	429.2228	2968.6268	1
2	Line37	2494.3840	428.9414	2923.3254	2
3	Line 20	2461.7530	451.8530	2913.6060	3
4	Line26	1708.7670	344.5316	2053.2986	4
5	Line 10	812.3472	987.7966	1800.1438	5

4.5 Results Comparison

In the previous sections, the results of ranking national Sudanese grid contingency was arranged in NELPAN, and some selected contingency cases was taken to represent the proposed approach for ranking network contingencies in fuzzy logic control system or (FIS). AS discussed previously NEPLAN software program ranks the contingency depending on the voltage violation level (%violation), where fuzzy approach ranking depend on the composite index (CI) which has two base components, the total value of severity index for voltage profile ($\sum SI_{VP}$) and the total value of severity index for line flow ($\sum SI_{LF}$). The fuzzy approach was applied in five selected contingences and the result are compares with those which were given from NELAN program as shown in table 4.16.

Table 4.16: Compression of contingencies results.

Cont. NO.	Type of Contingency	Violation (%)	Ranking	CI $\sum(\sum SI_{VP},\sum SI_{LF})$	Ranking
1	Line 23	142.63	1	2968.6268	1
2	Line37	110.72	2	2923.3254	2
3	Line 20	88.52	3	2913.6060	3
4	Line26	88.17	4	2053.2986	4
5	Line 10	83.82	5	1800.1438	5

From the table it is shown that any one of the selected contingencies has the same ranking within both NEPLAN program and FIS.

The process of ranking in NEPLAN program is so fast when it compared with that on the fuzzy logic but the fuzzy controller gives more accurate results. Also, the using of composite index in computation process makes the fuzzy logic controller more popular because it includes both values ($\sum SI_{VP}$) and ($\sum SI_{LF}$) in its evaluation, what means that it takes the effect of both- voltage violation in buses and power flow in lines- on its consideration to achieve the ranking process so, it more reliable than NEPLAN program which ranks the network contingency according to their voltage violation only.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In this thesis, the contingency ranking for single line outage (N-1) was proposed in fuzzy logic approach. The reference data was taken from NEPLAN software program.

NEPLAN program which used to simulate the national Sudanese network, gives the ranking depending on the maximum violation which occur in the contingency case, i.e. gives the severity index of the element outage by the violation which occur at the other elements on the network. Hence, the higher the violated element is the most severe one and the rise versa.

Fuzzy logic controller represents system ranking depending on the composite index, where the most severe line outage possesses the higher value of the composite index and the lower composite index expresses the less severe element.

Composite index gives detailed information about the severity of the network, it consists of two indices (voltage profile index and line flow index) so; it more accrue and processioned. Hence, it gives details about the source of severity by noting the more high value of the two indices which form the composite index. Fuzzy logic controller also divide the severe level of the system (below severe, above severe, most severe, less severe, etc.) and assist to propose optimal solution for system security.

The severity of the system with composite index may refer to voltage problem if the summation of voltage profile in the composite index has the higher value, this means that the system may be less severe by improving the system voltage by one of the compensation techniques. On the other hand the severity of the system may refer to line loading if the summation of line flow has the higher effect, this means that; the system require load shading or any power improvement techniques.

Fuzzy process does not relate to the cohesion of the network, even if he NELAN techniques pay attention to the connection of the element which others, i.e. the most violated element in one of the outage cases has an impact on its neighbor element.

5.2 Recommendations

- The proposed fuzzy logic approach can be extended to apply actually in the Sudanese gird to give and accrue results of ranking for the system because of its reliability and accuracy.
- It is more suitable to suggest the fuzzy logic approach for studying the voltage stability of the power system.
- The results which was taken from the fuzzy logic interface system may suggest for interfacing with Artificial Neural Network (ANN) in the MATLAB through an Adaptive Neuro-Fuzzy Interface System (ANFIS) function in MATLAB Toolbox by using Sugeno- model system instead of Mamdani model which used in simulation.
- The ranking of the system contingency may achieved also with other intelligent systems such Genetic Algorithm (GA), individual Artificial Neural Network (ANN) control system.
- An advanced analysis can be achieved on the system by using the static and dynamic analysis of the machine at both steady state cases and during contingency cases.

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