POWER SYSTEM CONTINGENCY RANKING USING NEWTON RAPHSON LOAD FLOW METHOD AND ITS PREDICTION USING SOFT COMPUTING TECHNIQUES

A thesis submitted to NIT Rourkela

in partial fulfilment of the requirement for the award of the Degree of

Master of Technology

In

INDUSTRIAL ELECTRONICS

By

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Rourkela-769008 May, 2014

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CERTIFICATE

This is to certify that the thesis entitled, **"Power system contingency ranking using Newton Raphson load flow method and its prediction using soft computing techniques"** submitted by **Pritirekha Naik (Roll No. 212EE5263)** in partial fulfilment of the requirements for the award of Master of Technology Degree in Electrical Engineering with specialization in Industrial Electronics during 2013 -2014 at the National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date

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DECLARATION

I hereby declare that the investigation carried out in the thesis has been carried out by me. The work is original and has not been submitted earlier as a whole or in part for a degree/diploma at this or any other institute/University.

PRITIREKHA NAIK

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ABSTRACT

The most important requirement and need of proper operation of power system is maintenance of the system security. The security assessment analysis is done to determine and to check till what extent a power system is in operable safe condition and will not enter to the serious operation. Power system security assessment helps in monitoring and in giving up to date analysis regarding currents, bus voltages, power flows, status of circuit breaker, etc. This system assessment has been done in offline mode in which the system conditions are determined using ac power flows. The use of AC power flows is it gives information of power flows in terms of MW and MVAR , line over loadings and voltage limit violation with accurate values. Contingency selection or contingency screening is a process in which probable and potential critical contingencies are identified for which it requires consideration of each line or generator outage. For contingency screening several methods have been developed. The most widely used method for calculation of the performance index is based on the conventional method known as Newton Raphson load flow program. Contingency ranking is a procedure of contingency analysis in which contingencies are arranged in descending order, sorted out by the severity of contingency. Overall severity index (OPI) is calculated for determining the ranking of contingency. Overall performance index is the summation of two performance index , one of the performance index determines line overloading and other performance index determines bus voltage drop limit violation and are known as active power performance index PI_p and voltage performance index PI_V respectively. Here in this proposed work the contingency ranking has been done with IEEE 5 bus and 14 bus system. But the system parameters are dynamic in nature, keeps on changing and may affect the system parameters that are why there is need of soft computing techniques for the prediction purpose. Fuzzy logic approach has also been used. Two model of Artificial Neural Network namely, Multi Layer Feed Forward Neural Network (MFNN) and Radial Basis Function Network (RBFNN) have been considered. With these soft computing techniques the prediction method helps in obtaining the OPI with greater accuracy.

List of Abbreviations:

ANN	: Artificial Neural Network
NR	: Newton Raphson
MFNN	: Multi Layer Feed Forward Neural Network
RBFNN	: Radial basis function Neural network.
BPA	: Back Propagation algorithm
MFL	: Mamdani Fuzzy Logic
FL	: Fuzzy Logic
MAE	: Mean absolute error.
MSE	: Mean Square error
NN	: Neural Networks
PIp	: Active Power Performance Index
PIv	: Voltage Performance index
OPI	: Overall Performance Index
OSILL	: Overall Severity Index Line Loadings
OSIVP	: Overall severity Index Voltage Profile
LL	: Lightly Loaded
NL	: Normally loaded
FL	: Fully Loaded
OL	: over Loaded
LV	: Low Voltage
NV	: Normal Voltage
OV	: Over voltage
LS	: Low Severe
BS	: Below Severe

MS	: Most severe
AS	: Above severe
OCOSI	: Overall Composite overall severity Index
L N	: Line number
O N	: Outage number
Pre C S	: Pre contingency state
Post C S	: Post contingency state
S B	: Start bus number
E B	: End bus number
Pre C V	: Pre contingency Voltage
Post C V	: Post contingency Voltage

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION:

Power system security is the ability of power system to survive in looming disturbances conditions (contingencies), without hampering to the safety, reliability and customer service. Power system security refers to strength or robustness of any system to imminent disturbances and it depends on system operating conditions and also on contingent probable conditions. When the system is of insufficient security, it gets exposed to catastrophic and system failure. So it is of paramount importance in having a safe, reliable, continuous and economic operating condition of power system.

Power system security is the probability of system's operating conditions which should remain within the tolerable ranges. This aspect plays an important role in point of view its operations and planning. Following are few points which make the power reliability and safety over a long run. Firstly, power system should be properly designed with taking security as main concern. Secondly, regular monitoring during operation, maintaining with acceptable ranges is second most concern. Thirdly, good engineering is required to achieve these goals which mainly rely on the usage of tools used for power system analysis. The changes that are occurring in the environment have finely tuned the requirement of power system security analysis and its assessments and has also changed the analysis tools of power system.

Power system consists of numerous of electrical based devices and is a complex network in itself. And failure of any of these devices during operating condition hampers the continuity of operation, security, safety and thus leads to outages, thus influencing security of power system. Thus power system security is an important part of power system. The most important aspect is evaluation of contingency, which leads to bus limit violations, transmission line overloads during the operating conditions. Critical contingencies must be identified firstly and fast to ensure secure, reliable and continuous operation.

As a major and important part of power system security , operational engineers need to study the effect of outages and contingency on power system in terms of severity. Power flow or load flow are important part of this analysis. They are required to have proper operation, scheduling, and controlling of existing and operating power system and also on proper planning for future expansion.

Contingency selection or contingency screening is a process in which probable and potential critical contingencies are identified for which it requires consideration of each line or generator outage. This method is very time consuming as it does not suit real time requirement, as real time systems are large systems and requires lot of time for computation. To solve this problem a number of algorithms have been developed which are classified into two methods. One of those method is the Performance Index (PI) which is based on calculation the PI values and ranking them accordingly to quantify the severity for each case. The other method is based on approximate power flow which is used to eliminate those critical contingencies. This method is known as screening method.

There are number of methods for evaluation of contingency of power system. AC load flow and mathematical calculations are mostly used in most of the methods.

For contingency screening several methods have been developed. The most widely used method for calculation of the performance index is based on the conventional method known as Newton Raphson load flow program [7]. The modern power system is a complex network and due to its complexity and large scale networks, contingency analysis should be powerful and computation should be fast. The most important point for contingency or outage is that all possible outages does not affect overload in lines and transformers, and does not affect voltage drops in different nodes of system. Therefore it is not required to consider all possible outages for computer simulation purpose. It is necessary to specify the outages which can cause the most of overloads and voltage drops in the system for contingency screening. Such critical and potential contingencies should be quickly identified for further evaluation process in detailed manner. thus contingency selection is defined as the process of identifying these critical contingencies. Thus contingency selection/screening or contingency ranking is projected so in order to rank those outages which will violate the normal operating condition. Contingency selection methods are based on Performance Index (PI), that may represent a line overloading or bus voltage drop limit violation. Then sorting of performance index is done in such a way contingencies are ranked according to their severity. In these last few years, a lot of work has been done in this part which consists of selection of the potential contingencies cases by using ranking methods or screening methods. Bounding methods [3], Distribution methods [7], Expert and new method for contingency selection [7-12], Neural

Network [15-20] and other latest mathematical techniques have been used in the indirect calculation of MW flow violation ranking. The recent developments using Artificial Neural Network have brought lot of advancement in the speed of contingency screening [18].

1.2 LITERATURE REVIEW:

Power system operation and planning is the most important part of power system security. The importance of security assessment is necessary for secure, reliable, and safe power system operation and its importance is presented in[1-2]. This assessment helps in taking prior steps to keep the system secure and thus to keep the system parameters of the power system within the operation limits. It not only provides the system condition, operability and planning but also prevents failure of operation of power system during any failure of equipment. Thus helps in keeping the system secure and reliable and continuous without any interruptions. The paper has introduced the challenges faced for the practical implementation of security analysis algorithm. The changes in the line flow due to an outage in generator or transmission line is predicted based on distribution factors [3-4]. The use of AC power flow has been discussed in [3]. Contingency, its analysis, involves selection and contingency screening .The complete bounding methods used for AC contingency screening reduces the computational barrier is described in[5]. The method of concentric relaxation for contingency evaluation has been described in [6] by the author. Calculation of performance index for contingency selection criteria has been introduced in [8] by Ejebe and Wollenberg. Sorting of contingencies is done in the descending order of the values of their performance index (PI), and thus helps in ranking according to the severity.

Contingency analysis problem has been solved by using fuzzy logic. The post contingency has been studied by Newton Raphson load flow method [9]. These qualities have been assigned a degree of severity. Fuzzy logic is applied to contingency selection problem for voltage ranking where the post contingent quantities are used to rank the contingencies [8-10].

[15]The artificial neural network for non linear adaptive filtering and control, its ability to predict solutions from the past trends, its enormous data processing capability, and its ability to provide fast response in mapping data makes them fast and promising tool for power system's security analysis and its contingency ranking. Use of artificial neural networks (ANN) for various application of power systems such as transient stability analysis, load forecasting has been introduced in[16-18]. The determination of voltage stability margin

using ANN has been discussed in[19]. A review from [17] illustrates the types of neural networks which have been used for determining the weights and minimizing the error by various researchers. The collective use of supervised and unsupervised learning in power system analysis has been used to overcome the slow rate of convergence and local minima problem faced in multilayer perceptron neural network using back propagation training [16]. The counter propagation network which has been used [20] for the identification of coherency existing between load buses.

The radial basis function (RBF) neural network is highly efficient for function approximation and it involves two hybrid stage learning scheme. Structural simplicity, no local minima, fast training are the advantages of using Radial basis function neural network [19]. Radial Basis Function (RBF) neural network is used for estimating line loading and bus voltage following a contingency in bulk power system as RBF has non linear mapping capability [20].

1.3 MOTIVATION/OBJECTIVE OF THE WORK:

Power system is said to be in secure condition if system's operating point remains in the acceptable ranges, given whatever the probabilities of changes in the system (contingencies) and its environment. The need of power system security assessment is to have a power system which is sufficiently reliable, secure, safe, and continuous even in case of credible contingencies. It is the foremost and important task of operational engineers to predict such outages/contingencies (disturbances) and to initiate preventive action control actions (as economic as possible so that system integrity and continuity of power supply is maintained.

The objective of this thesis is to have a secure, reliable power system for which contingency ranking is done. Contingency ranking is done by calculating the performance indices for the critical transmission line outages using conventional load flow method i.e. Newton Raphson load flow method, and to do its prediction using soft computing techniques: fuzzy logic, MLFNN and radial basis function N N. The objective here is to find the contingency ranking and conduct the prediction employing fuzzy logic, MLFNN and RBF and to compare the prediction methods used.

1.4ORGANIZATION OF THESIS:

The work carried out in this thesis is summarized into 6 chapters. Chapter 1 deliberates on the outline of problem and the need of power system contingency, brief literature review, objective of work, and organization of thesis. Chapter 2 includes contingency analysis, and its creation selection and evaluation and brief detail about Newton Raphson load flow method; in chapter3 contingency ranking is done by calculating the active and reactive power performance indices using Newton Raphson load flow method and the results for various systems. In chapter 4 contingency ranking has been done by using fuzzy logic approach and the results for various bus systems has been obtained. In chapter 5 contingency analyses has been done by using two methods of Artificial N N, MLFNN and Radial Basis Function NN and corresponding results for various tests system and the comparisons for three methods of prediction techniques have been discussed. The conclusion and scope for the future work are detailed in chapter 6.

Chapter 2
Contingency ranking and Newton Raphson Method

2.1 INTRODUCTION:

Power system consists of numerous of electrical equipments and failure of any of these leads to power failure and affects the system parameters to go beyond its operating limits. It may lead to obstruct the secure operations and reliability of power systems. Power system needs to be operationally secure i.e. with minimal probability of blackout and equipment damage the power system is said to be normal when the power flows and bus voltages are within operating and acceptable limits despite there are changes in load and or in available generation.

Ejebe and Wollenberg introduced the concept of contingency. The unpredictable events in the power system operations are termed as “contingency”. Contingency in a power system leads to instability of entire power system, and affects the reliability, security and continuity**.** An outage refers to the temporary suspension of power. And contingency can be defined as the possible circumstance or outage which is possible but cannot be predicted with certainty. A contingency is basically an outage of a generator, transformer and or line, and its effects are monitored with precise security limits.

From this perspective, security is the probability of a power system’s operating point remaining in a viable state of operation.

The rapidly increasing and unending demand for electric energy has made the task more difficult and challenging for power engineers, since they have to decide and think so as to have an efficient, secure and reliable power dispatch to the consumer without any interruption.

2.2 CONTINGENCY ANALYSIS:

Contingency analysis is one of the most talked issue in security assessment of any power system because with the existing complex infrastructure and with no extensive development of power stations, it is obvious that most of existing power systems can not cope with the increase in demand. Contingency analysis should be performed for the unexpected and severe events that may occur in power system and preventing other related cascade accidents.

The contingency analysis for a considered power system model involves the simulation of individual contingency. In order to make the contingency analysis easier, it comprises of three basic steps. They are as follows:

1) Contingency creation: it is the first step of analysis. It consists of all set of possible contingencies that may occur in a power system. This process comprises of creating contingencies lists.
2) Contingency selection: it is the second step and it is the process which involves selection of severe contingencies from the list that may lead to bus voltage and power limit violations. Here in this process contingency list is minimized by elimination of least severe contingency and taking into account of most severe ones. The severity of contingencies is found by index calculation for this process.
3) Contingency evaluation: it is the third step and the most important one as it involves necessary control action and necessary security actions which are needed in order to mitigate the effects of most severe contingencies in a power system.

   Performance index (PI) is the method which is used for quantifying the severity and ranking those contingencies in the order of their severity.

For calculating those performance indexes various iterative methods can be used.

2.3 POWER FLOW SOLUTION:

Power flow studies are necessary for control and planning of an existing power system and also for planning its future expansion. Determining of active and reactive power flow for each line and calculation of magnitude and phase angle of voltages at each bus is a challenging thing.

While solving the power flow problem, assumption is taken as, power system is a single phase model and is operating under balanced condition. With each bus four quantities are associated. These are voltage magnitude |V|, phase angle (δ), real power P and reactive power Q. The system buses are divided into three categories: they are as follows:

SLACK BUS:

This bus is also known as swing bus. This bus is used as reference where the magnitude and phase angle of the voltages are only specified. This bus finds the difference between the scheduled loads and generated power which are caused by the losses in the networks.

LOAD BUSES:

The magnitude of bus voltage and the phase angle of the bus voltage are unknown. The active and the reactive power is specified. These buses are also known as P-Q buses.

REGULATED BUSES:

These are also known as generator buses, or voltage controlled buses. Real power and voltage magnitude are specified at these buses. The phase angle of the voltages and the reactive powers are to be determined. These buses are known as P-V buses.

The mathematical formulation of the power flow or the load flow problem results into nonlinear algebraic equations which can only be solved by iterative techniques.

There are various iterative techniques.

- Gauss Siedel power flow solution:
- Fat decoupled power flow solution:
- Newton Raphson load flow solution:

2.4 NEWTON RAPHSON LOAD FLOW METHOD:

The Newton-Raphson method is the most preferred for load flow solutions because of its various advantages. It has potent convergence characteristics compared to other alternative processes and has low computation. The sparsity-programmed ordered elimination is used for solving sparse network equations with less time. The NR approach is useful for large networks as because computer storage requirements are judicious and increases with size of problem almost linearly. The method is very sensitive to good start condition. The use of a suitable start condition reduces the time for computation remarkably, as well as ensures for the fast convergence. There is no requirement of determining acceleration factors, and iteration does not get affected by the choice of slack bus, and network modifications require quite less computational effort.

The NR method has great flexibility and generality, hence enables easy and efficient involvement of representational needs, such as on load tap changing and phase-shifting devices, area interchanges, functional loads and remote voltage control. The NR load flow forms the central method for various recently methods developed to optimize the power system operation, its sensitivity analysis, system-state assessments, modelling of linear-network, evaluation of security and analysis of transient-stability, it is well appropriate for online computation. NR formulation is also required for the system with large angles across line and with control device which influences reactive and real power.

Now considering a typical bus of the power system, the current entering the bus I is given by equation:

The power flow equation are formulated the polar form for the bus admittance matrix Y as:

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \tag{2.1}$$

Expressing it in form of polar :

$$I_i = \sum_{j=1}^{n} |V_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{2.2}$$

The current is expressed in terms of active and reactive power at bus I as:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{2.3}$$

Substituting for I_i from equation (2.3) in equation (2.2), we get:

$$P_i - jQ_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |V_{ij}||V_j| \angle \theta_{ij} + \delta_j \tag{2.4}$$

Separating the real and imaginary parts of power:

$$P_i = \sum_{j=1}^{n} |V_{ij}||V_j||V_i| \cos(\theta_{ij} - \delta_i + \delta_j) \tag{2.5}$$

$$Q_i = \sum_{j=1}^{n} |V_{ij}||V_j||V_i| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.6}$$

Expanding the equation (2.5) and (2.6) in Taylor's series about the initial estimate and neglecting the higher order terms, we get:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta P_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{pmatrix} \\ \hline \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2^{(k)}} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n^{(k)}} \end{pmatrix} & \begin{pmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{pmatrix} \end{array} \right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix} \tag{2.7}$$

The Jacobian matrix gives the linearized relationship between small changes in $\Delta\delta_i^{(k)}$ and voltage magnitude $\Delta\left[V_i^k\right]$ with small changes in real and reactive power ΔP_i^k and ΔQ_i^k

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{2.8}$$

The diagonal and off diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq i} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \tag{2.9}$$

$$\frac{\partial P_i}{\partial \delta_i} = -|V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) \quad j \neq i \tag{2.10}$$

Similarly we can find the diagonal and off diagonal elements for J_2, J_3 and J_4.

The terms ΔP_i^k and ΔQ_i^k are the difference between the scheduled and calculated values which are known as power residuals, and is given by:

$$\Delta P_i^k = P_i^{sch} - P_i^{(k)} \tag{2.11}$$

$$\Delta Q_i^k = Q_i^{sch} - Q_i^{(k)} \tag{2.12}$$

Using the values of power residuals and Jacobian matrix, $\delta_i^{(k)}$ and $\left|V_i^{(k)}\right|$ are calculated from the equation from equation (2.7) to complete particular iteration and the new values calculated as shown below are used for next iteration [2].

The new estimates for bus voltages are

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{2.13}$$

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta\left|V_i^{(k)}\right| \tag{2.14}$$

Chapter 3

Contingency ranking using Newton Raphson Method

3.1 INTRODUCTION:

Here in this chapter algorithm for Newton Raphson method, contingency ranking using NR method has been discussed. This conventional method had been proposed on two IEEE buses, 5 bus and 14 bus system. The results obtained using this method had been used further in determing the performance indices, active power performance index and voltage power performance index. After obtaining the performance indices, the contingency ranking is done with the overall performance index which is the summation of these two performance indices. The one with higher overall performance index is ranked first and is arranged in descending order quantifying the severity of contingency.

3.2 ALGORITHM FOR N R METHOD:

The procedure for N R load flow method is described as follows:

1. P_i and Q_i are specified for the load buses, the values of voltage magnitudes and phase angles are set equal to the values of slack bus values, 1.0 and 0.0 i.e, $|V_i|$ =1.0 and δ_i =0.0. for voltage- regulated buses, where $|V_i|$ and P_i^{sch} are specified, phase angle are set equal to the slack bus angle, or 0,i.e., δ_i =0 .
2. For load buses $P_i^{(k)}$ and $Q_i^{(k)}$ are calculated from the equations. And ΔP_i^k and ΔQ_i^k are calculated.
3. From voltage controlled buses $P_i^{(k)}$ and ΔP_i^k are calculated from equations respectively.
4. The elements of Jacobian matrix $(J_1, J_2 J_3, J_4)$ are calculated.
5. The linear simultaneous equation is solved directly by optimally or ordered triangular factorization and Gaussian elimination.
6. Computation of new voltage and phase angles.
7. The process is repeated until the residuals ΔP_i^k and ΔQ_i^k are less than the specified accuracy.

3.3 CONTINGENCY RANKING APPROACH:

The Contingency analysis with the use of AC power flow gives the advantage that it provides power flows in terms of MW, MVAR and bus voltage magnitudes. Using the AC power flow overloads and accurate voltage limit violations. In the present work, for the contingency ranking outages of each line has been considered. Performance indices (PI) are considered for ranking the severity of a particular contingency. Conventional power flow methods are used in calculating the indices in an offline mode. After obtaining the values obtained using conventional method are sorted out in descending manner and the highest value of PI is ranked first.

There are two types of performance index [9] which are mainly used for contingency analysis. They are:

Active Power performance index (PI_P): This is the index which helps in determining the extent of line over loads.

$$PI_P = \sum_{l=1}^{N_L} (W/2n)(P_l/P_l^{max})^{2n} \tag{3.1}$$

Where,

P_l is the MW power flow of line l

P_l^{max} is the MW capacity of line l

N_L is the number of lines of the system

W is the real non-negative weighting factor, and value is (= 1)

n is exponent of penalty function and value is (=1)

$$P_l^{max} = (V_i * V_j)/X \tag{3.2}$$

Where,

V_i is the voltage at bus i^{th} obtained from the NR solution

V_j is the voltage at bus j^{th} obtained from the NR solution

X is the reactance of the line connecting i^{th} bus and j^{th} bus.

Voltage performance index (PI_V): This is the index which helps in determining bus voltages limit violation.

$$PI_V = \sum_{i=1}^{N_B} (W/2n)\{(|V_i| - |V_i^{sp}|)/\Delta V_i^{lim}\}^{2n} \qquad (3.3)$$

Where,

$|V_i|$ is the voltage magnitude at i^{th} bus.

$|V_i^{sp}|$ is the specified (rated) voltage magnitude at i^{th} bus.

ΔV_i^{lim} is the deviation limit of the voltage.

n is the exponent of penalty function and value is (=1)

N_B is the number of buses in the system taken.

W the real non-negative weighting factor and the value is (= 1)

Bus voltages are also influenced by the reactive power which is produced by the generating units and PI_V provides information regarding severity of abnormal voltages till the reactive power are within the limits or not. During a case of a contingency and if the reactive power reaches to their limits, and under this circumstance taking reactive power limits standard AC load flow calculates the bus voltages and therefore there is deviation of voltage from their scheduled voltage at generator buses. Hence, for the voltage analysis under contingency involves the reactive power constraints of the generators also.

The generalized formula is represented by eqn.(18):

$$PI_V = \sum_{i=1}^{N_B} (W/2n)\{(|V_i| - |V_i^{sp}|)/\Delta V_i^{lim}\}^{2n} + \sum_{i=1}^{N_G} (W/2n)\{Q_i/Q_i^{max}\}^{2n} \qquad (3.4)$$

Where,

Q_i is the produced reactive power at ith bus

Q_i^{max} is the reactive power production limit.

N_G is the number of generating units in the system.

W is the real non-negative weighting factor and its value is (= 1)

In this proposed present work, system's performance index PI_{VQ} has not been considered. The proposed approach for contingency ranking has considered only PI_P and PI_V.

3.4 ALGORITHM FOR CONTINGENCY ANALYSIS USING NEWTON RAPHSON METHOD:

The algorithm for contingency analysis using Newton Raphson load flow solution is as follows:

Step 1: Read the given system's line data and bus data.

Step 2: Without considering the line contingency perform the load flow analysis for base case.

Step 3: Simulating a line outage or line contingency, i.e. removing a line and proceeding to the next step.

Step 4: Load flow analysis is done for this particular outage, then calculation of the active power flow is done in the remaining lines and value P^{max} is found out .

Step 5: The active power performance index (PI_P) is found, which indicates the active power limit violation of the system model taken.

Step 6: subsequently for the particular line contingency; voltages of all the load buses are calculated.

Step 7: Then voltage performance index (PI_V) is being calculated which indicates the voltage limit violation at all the load buses due to the line contingencies.

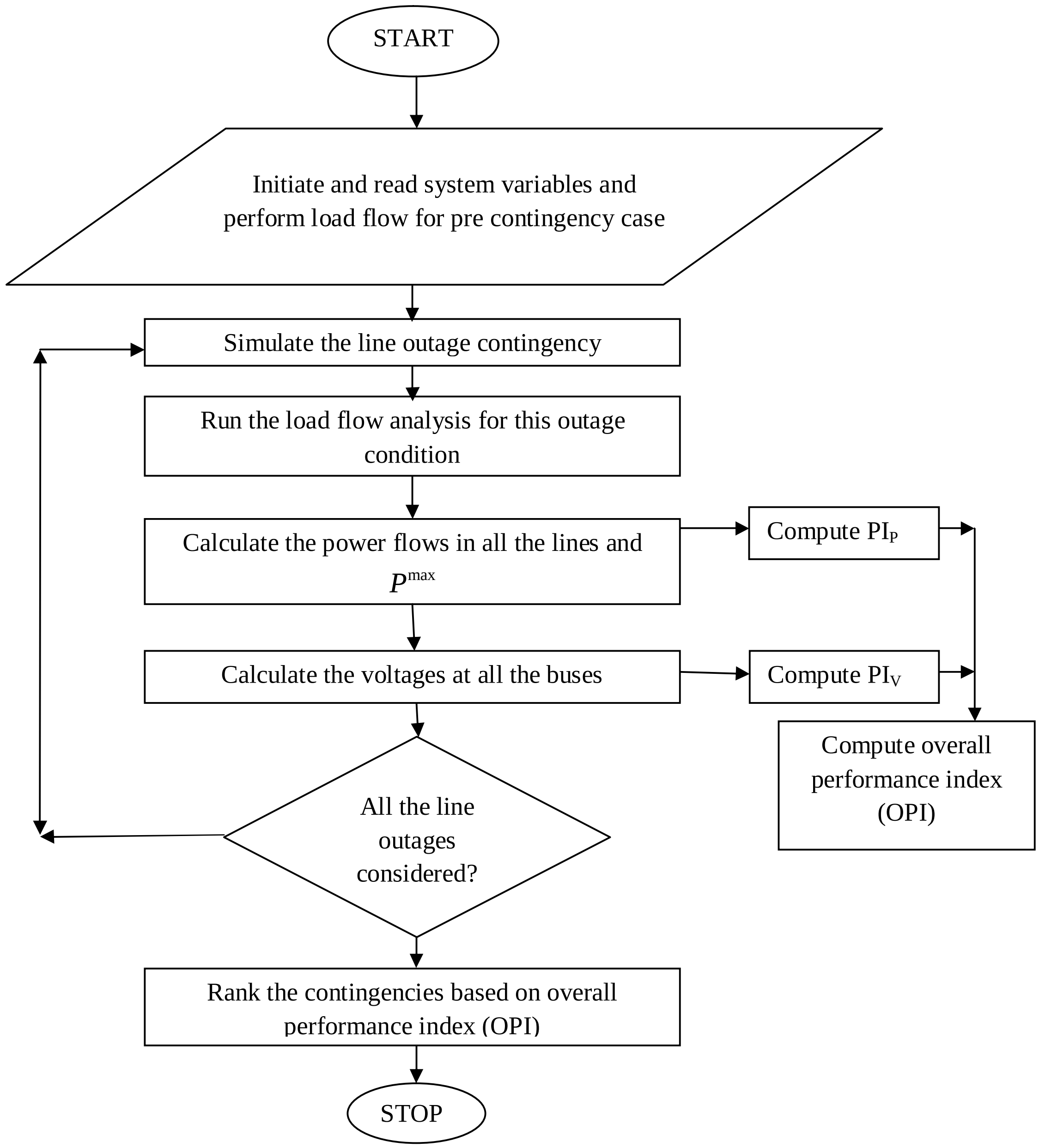
Step 8: Computation of overall performance index is done by adding PI_P and PI_V for each line outage of the system.

Step 9: Steps 3 to 8 for all line outages is repeated to obtain the PI_P and PI_V. for all line outages.

Step 10: Then contingencies is ranked based on the overall performance index (OPI) which is calculated according to the values of the performance indices obtained.

Step 11. Do the power flow analysis for the most severe contingency case and obtain the results.

3.5 Flow chart of the algorithm:



3.6 RESULTS AND DISCUSSIONS:

The main aim here is to obtain contingency analysis using calculated values of active and reactive performance indices i.e.,PI_p and PI_V. The contingency ranking is done in the order of their severities which uses the performance index (PI). The computation of performance indices are calculated based on the load flow analysis carried out using conventional method

Newton Raphson method under MATALB environment. The most severe contingent is chosen from the contingency list and the corresponding power flows and line flows are analyzed for the considered power system. The study has been carried out for the following standard systems.

- ❖ 5 bus system
- ❖ 14 bus system

(i)5 bus system:

Fig.3.1,shows a 5 bus system which consists of bus-1 as slack bus and bus-2, 3, 4, 5 as load buses. There are seven transmission lines for 5 bus system and active power flows on transmission lines were obtained using NR load flow method. In Fig 3.1. the active power flows and bus voltages are shown by considering the base case and this is is called as the pre-contingency state.

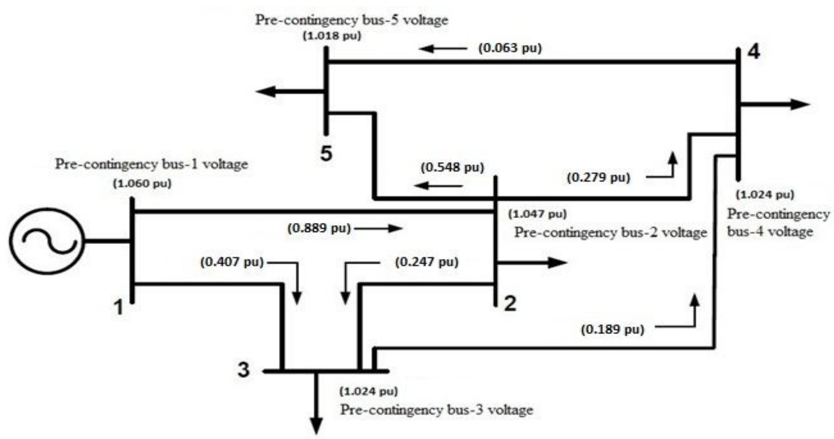


Figure 3. 1: Pre Contingency state of 5 bus system

By considering the line outage for each line at a time, the load flow analysis is done. The active power and reactive power performance indices PI_p and PI_V are calculated considering the outage of only one line sequentially and the calculated indices are summarized. Contingency ranking is done in the decreasing order of the severity. The higher the value of OPI ranks first and indicates that it has highest severity and poses great danger in terms of instability.. it also indicates that power system operating condition can go beyond the limits of operation if not taken care of and can cause a great damage to operation and may cause human loss. Fig. 3.1 and 3.2 represents the graphical representation of these performance indices for each outage cases and the contingency ranking based on the overall performance indices has been shown.

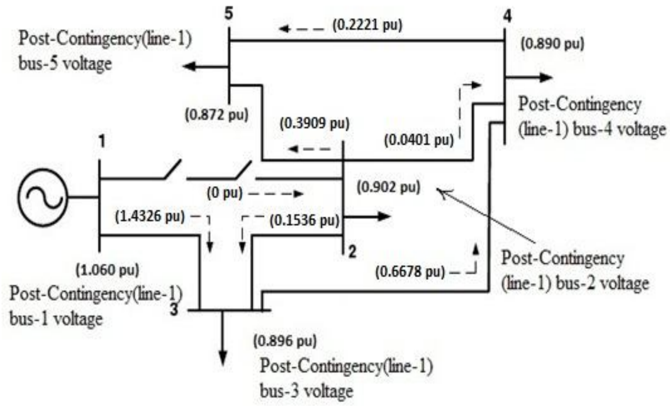


Figure 3. 2: Post contingency state of 5 bus system.

Table3. 1:BUS VOLTAGES IN THE PRE CONTINGENCY STATE AND POST CONTINGENCY STATE

Bus	Pre-contingency	Post-contingency
1	1.0601	1.0601
2	1.0470	0.9020
3	1.0240	0.8960
4	1.0240	0.8900
5	1.0181	0.8720

Table3. 2:ACTIVE POWER FLOWS IN THE PRE AND POST CONTINGENCY STATE

L N	S N	E N	Pre CS (pu)	Post CS (pu)
1	1	2	0.8890	0
2	1	3	0.4070	1.4336
3	2	3	0.2470	0.1537
4	2	4	0.2790	0.0402
5	2	5	0.5480	0.3909
6	3	4	0.1890	0.6676
7	4	5	0.0630	0.2223

Table3. 3: PERFORMANCE INDICES,OVERALL PERFORMANCE INDEX AND CONTINGENCY RANKING

O N	PI_P	PI_V	OPI	Ranking
1	0.1074	1.8052	1.9126	1
2	0.0418	0.2390	0.2808	5
3	0.0418	0.3194	0.3612	7
4	0.0451	0.3128	0.3578	6
5	0.1212	0.2818	0.4030	3
6	0.0406	0.3387	0.3793	4
7	0.0417	0.3548	0.3965	2

Line outage contingencies are considered for each line and one at a time, and the load flow analysis is carried out for the outages individually. The Active Power Performance indices and Voltage Performance indices has been calculated for each line outage. The active power flows and bus voltages for line outage-1 have been shown in Fig *2*. The pre contingency state and post contingency state for the bus voltage is shown in Table. 2.1, The Table 2.2, show the pre contingency state and post contingency state for the active power flows, while Table 2.3, shows active power performance index and voltage performance index for each line outages and their ranking corresponding to highest overall performance index. From the Table 2.3 , it is observed that line outage number 1 has the highest OPI, overall performance index because of contribution of high value of PI_v for that particular line outage(because for line outage no. -1 the bus voltages has violated the minimum voltage limit (0.950 pu), while in other outage cases the bus voltages lies below or above nominal voltage i.e.(1 pu) but remains within maximum voltage limit range (1.05 pu) and so PI_v can be seen above 1.0 based on bus voltages considered) and hence it is ranked as first.

From the results we can conclude that Performance indices calculated indicates how much severe a possible line outage is and thus defines the severity of each line outage in the system. The performance index with highest value indicates the severity of that particular line outage and also indicates that it has got maximum chances of making system parameters to operate beyond the operating limits. Thus it helps the operational engineers of power system to take necessary and prior actions to mitigate the problem and thus helps in guiding to have a safe, secure, reliable and continuous supply from the power system.

(ii)14 bus system:

The data obtained from the data sheet of 14 bus system gives data of bus and line .The IEEE 14 bus system are detailed in appendix B. it consists of 1 slack bus, 9 load buses, 4 generator buses. Three synchronous compensators which are used for only reactive power support. The active power flow in each transmission lines that has been obtained by using newton Raphson load flow method which corresponds to base case load condition. This system has total number of 20 transmission lines, and consider one line outage for each line contingency. The performance indices are summarized. The system IEEE-14 bus system consist of bus-1(slack bus), bus-2,6,8(generator bus) and bus-3,4,5,7,9,10,11,12,13,14(load bus). It has 20 transmission lines and using NR load flow method active power flows for 20 transmission lines are obtained method.

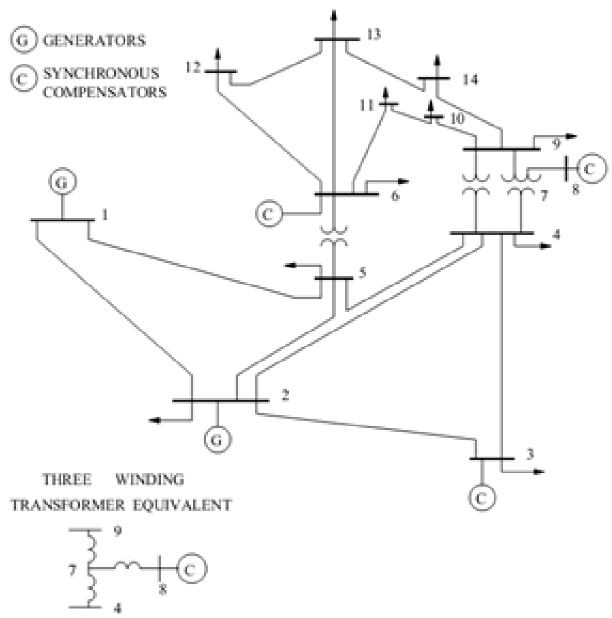


Figure 3. 3: IEEE 14 BUS TEST SYSTEM.

Pre-contingency state is that case where active power flows and voltages of the system are found for the base case. Load flow analysis is done for each line outage and is done with the consideration of line outage one at time. The active Power Performance and voltage Performance indices are calculated for each line outage .

The Table 3.4 shows the bus voltages of the sysytem in the pre and post contingency state for line outage-4, The Table 3.5, shows the active power flow during the pre contingency and post contingency state for line outage-4, while Table 3.6, shows the active power performance and voltage performance index for each outage and their ranking.

Table3. 4:BUS VOLTAGES IN THE PRE CONTINGENCY STATE AND POST CONTINGENCY STATE WITH LINE OUTAGE-4.

Bus No.	Pre-CV (pu)	Post-CV (pu)
1	1.060	1.060
2	1.045	1.045
3	1.010	1.010
4	1.016	1.003
5	1.020	1.008
6	1.070	1.060
7	1.051	1.039
8	1.090	1.070
9	1.035	1.022
10	1.033	1.021
11	1.048	1.036
12	1.054	1.043
13	1.047	1.037
14	1.022	1.010

Table3. 5:ACTIVE POWER FLOWS IN PRE CONTINGENCY AND POST CONTINGENCY STATE WITH LINE-4 OUTAGE

LN	S B	E B	Pre CS (pu)	Post CS pu	L N	S B	E B	Pre CS(pu)	Post CS(pu)
1	1	2	1.569	1.427	11	6	11	0.081	0.096
2	1	5	0.757	0.919	12	6	12	0.080	0.082
3	2	3	0.732	0.904	13	6	13	0.182	0.190
4	2	4	0.560	0	14	7	8	0	0
5	2	5	0.417	0.670	15	7	9	0.273	0.258
6	3	4	0.237	0.074	16	9	10	0.045	0.031
7	4	5	0.605	0.969	17	9	14	0.088	0.079
8	4	7	0.273	0.258	18	10	11	0.045	0.059
9	4	9	0.155	0.147	19	12	13	0.018	0.020
10	5	6	0.456	0.480	20	13	14	0.063	0.072

Table3. 6: PERFORMANCE INDICES AND CONTINGENCY RANKING

O N	PI_P	PI_V	OPI	Rank	O N	PI_P	PI_V	OPI	Rank
1	0.6413	0.7727	1.4141	16	11	0.4815	0.9773	1.4588	15
2	0.4511	0.8686	1.3198	19	12	0.4749	1.0453	1.5202	4
3	0.6306	0.8388	1.4694	11	13	0.5181	1.0002	1.5183	6
4	0.4709	0.8545	1.3254	18	14	0.4766	0.7967	1.2733	20
5	0.4531	0.8755	1.3286	17	15	0.5401	0.9529	1.4930	8
6	0.4386	1.0403	1.4788	9	16	0.4784	1.0550	1.5334	3
7	0.4609	1.0065	1.4674	12	17	0.4793	1.0730	1.5523	1
8	0.5369	1.0095	1.5464	2	18	0.4712	0.9949	1.4661	13
9	0.4503	1.0157	1.4660	14	19	0.4693	1.0499	1.5192	5
10	0.7056	0.7996	1.5053	7	20	0.4739	1.0036	1.4775	10

From the Table 3.6, it can be seen that with the line number-17 as outage has the highest overall performance index (OPI) because of high value of PI_v (because for the line outage number -17 the bus voltages violated the minimum limit of voltage i.e. (0.7727 pu), while in for other outage cases for the same system the bus voltages are found to be below or above the nominal voltage (1 pu) but lies within maximum voltage limit (1.0730 pu) and so PI_v is above 1.0 based on the bus voltages considered, hence it is ranked as first.

3.7 CONCLUSION:

From the results we can conclude that Performance indices calculated indicates how much severe a possible line outage is and thus defines the severity of each line outage in the system. The performance index with highest value indicates the severity of that particular line outage and also indicates that it has got maximum chances of making system parameters to operate beyond the operating limits. Thus it helps the operational engineers of power system to take necessary and prior actions to mitigate the problem and thus helps in guiding to have a safe, secure, reliable and continuous supply from the power system.

Chapter 4
Contingency ranking using Fuzzy logic

4.1 INTRODUCTION:

The Fuzzy logic system (FLS) is a logic system which represents reasons and knowledge in a fuzzy manner for reasoning under uncertainty or describes in imprecise manner for human interpretation [7]. Not like Boolean logic and classic logic which assumes that entire fact is either true or false, but fuzzy logic allows Boolean logic to tackle with vague and imprecise expressions of human understanding. Not like the classic logic systems, it models the reasoning for imprecision model that plays important role in ability of human knowledge to understand an estimated or inexact answer for a question which is based on store of knowledge which is approximate, not complete or totally unreliable. It is the best approach and way to go for fuzzy logic when it is too difficult to encode a mathematical model which may exist or does not exist and when it is very much difficult to do evaluation for real time operation. Knowledge of human experts forms the base of the accuracy of fuzzy logic systems (FIS). Therefore it is as good as like validity of rules. In this chapter fuzzy logic system which is based on certain rules is used for power system contingency ranking, but before that a small description, overview of fuzzy logic system is mentioned in next Section 4.2.

4.2 FUZZY LOGIC SYSTEM (FLS):

A Fuzzy logic system (FLS) system defines the controlling action of a process by the use of simple If-Then rules. It describes the algorithm for controlling the process as fuzzy relation between information to be controlled which is on the process condition and the controlled action. Therefore it provides a linguistic expression or fuzzy model, developed based on human interpretation, human logic and understanding. Instead of providing a mathematical model it provides linguistic expressions for human experience and understandings. The control action of Fuzzy Logic system (FIS) is determined by evaluating linguistic rules with simple set of rules. it does not require mathematical expression or model to define the linguistic rules, but it only depends on complete and systematic understanding of process which needs proper controlling technique. The model used in Fuzzy Logic system (FIS) can be of single input and single output or multi-input and multi-output type. With the use of membership functions and linguistic inputs, fuzzy IF-THEN rules can understand the human's reasoning. This is done by the use of fuzzy inference systems.

4.3 FUZZY INFERENCE SYSTEM:

These systems are knowledge based systems which utilizes the following concepts; Fuzzy logic, membership functions and Fuzzy IF-THEN rules. The main component of Fuzzy Inference systems is shown below:

Fig4.1 Fuzzy inference system (FIS):

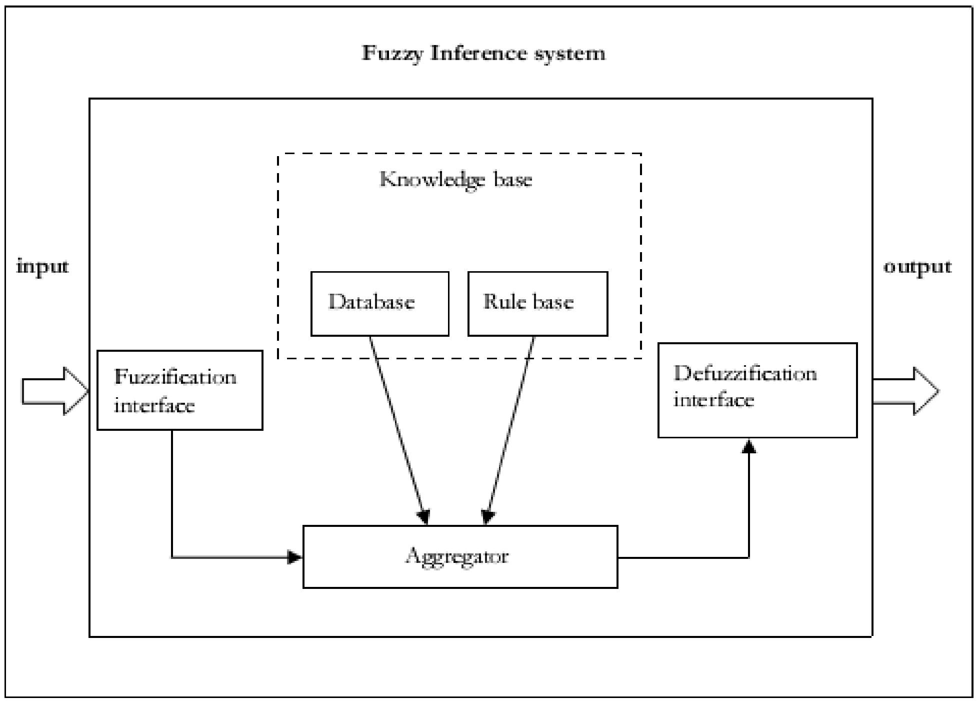


Figure 4. 1: Fuzzy Inference system.

The internal structure of a Fuzzy Logic system (FIS) system is in Figure 4.2

The main components of fuzzy inference systems are :

- Rule Base: contains all the fuzzy rules (if-then) rules.
- Data Base: is used for defining the membership functions.
- Aggregator: performs the operation based on fuzzy if –then rules.
- Fuzzification interface: here in this process converts crisp inputs values to linguistic values.
- Defuzzification interface: here in this converts the fuzzy results into crisp output values.

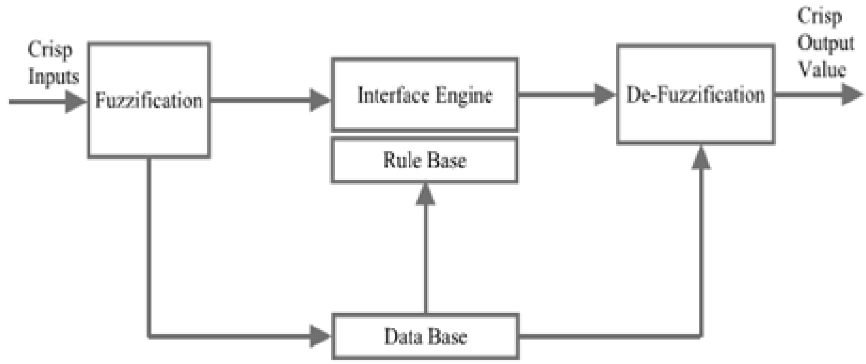


Figure 4. 2: Internal Structure of FLS

Below are the following procedures performed by FIS while processing the inputs.The main components of the FL system are:

1. **Fuzzification:** The Fuzzy logic uses the linguistic terms and expressions instead of using numerical variables. The measured quantities are in real numbers values (crisp values).The conversion process of a input numerical variable into a linguistic variable output is known as fuzzification. It is the classification of input data variables into suitable linguistic expressions or sets.

2. **Rule Base or Decision Making**: This involves the control action which processes the knowledge of the control rules and the linguistic variable to obtain the fuzzified output. It has three different sub-components which are described below:

- IF part of rule (predecessor or antecedent) – fuzzy operators are used in it.
- THEN part of rule – implication from antecedent part to the subsequent part.
- Aggregation means accumulation of the subsequent of all rules. The output from each rule is aggregated to obtain the final output of the process. Some of the commonly used aggregation methods are Mamdani method type implication (Min-Max implication method), Lusing Larson method type implication and Sugeno method type implication. The Mamdani method implication is the most commonly used for processing of mapping specific input variable to specific output variable.

3. **Defuzzification:** It is here in this process that conversion of input variable i.e., conditional fuzzy control actions to a crisp values or to the non-fuzzy control action is done. The choice of defuzzification strategy is a comparison between intensity of computation and accuracy. Some of the commonly used methods used for defuzzification are Centre of Area method,

Height method, Centre of gravity of largest area method and Mean of Maxima method. In this work Centre of Area defuzzification method is used for obtaining the results.

4.4 FUZZY LOGIC APPROACH FOR POWER SYSTEM CONTINGENCY RANKING:

The results of post contingent state of line power flows and voltage indices are obtained using Newton Raphson load flow method .The membership functions for these post contingent quantities are first recognized and defined and with these formed membership functions, the computation of overall severity index is done to obtain the contingency ranking The method is as described. For each post contingent quantities which is obtained by the conventional load flow method is known by different linguistic variable and with the membership function associated with it. The inputs to the fuzzy inference system are line loadings, and voltage profiles indices and the outputs to the same FIS are the severity indices, which are computed using the simple set of rules of Fuzzy.

The post contingent quantities of line flows and bus voltage must be expressed in fuzzy set rules notation first, and then only it can be further processed for reasoning rules of fuzzy logic.

I.For Line Loadings*:*

Each post-contingent quantity of line loadings in percentage is obtained and with Fuzzy set notation isdivided into four categories. They are:

Lightly loaded with, 0-50% of load is regarded as (LL), Normally loaded, 50-80% of load is regarded as (NL), Fully loaded 85-100% of load is regarded as (FL), Overloaded, above 100% of load is regarded as(OL).

Similarly the membership functions for the output of these quantities have also been described using Fuzzy set notation and is divided into four categories for the evaluation of the severity of a post-contingent quantity. They are:

(i)Less severe (LS),

(ii)Below severe (BS),

(iii)Above severe (AS) and

(iv) More severe (MS)

And the Fuzzy rules, meant for defining severity indices of post-contingent quantities of line loadings for evaluation are:

Input variable	Output variable
Active Power	OSILL
LL,NL,FL,OL	LS,BS,AS,MS

After getting severity indices for all lines loadings, the overall severity index (OSILL) of the line loading for a particular line outage is obtained using the following expression:

OSILL=$\sum$ w SI,

Where w= is defined as Weighting coefficient of the severity index.

SI= Severity Index for a post-contingent quantity.

The weighting coefficient used for different severity indices used are :

w= 0.25 for severity index which is Less Severe (LS).

= 0.50 for severity index which is Below Severe (BS).

= 0.75 for severity index which is Above Severe (AS).

= 1.00 for severity index which is Most Severe (MS).

The effect of these weighting coefficients which are multiplied means that overall severity indexes (OSILL) is first dominated by fourth category of severity index (MS) next by third, second and first category of severity index respectively. The severity of a system with contingency occurring in it is indicated by overall severity index.

II.For Bus voltage profiles*:*

In this, each post-contingent quantity of bus voltage profiles are classified into three categories as described using Fuzzy set notations. They are:

(i)Low voltage, below 0.9pu of the voltage (LV),

(ii) Normal voltage, 0.9-1.02pu of the voltage (NV) and

(iii) over voltage, above 1.02pu of the voltage (OV).

The severity of a post-contingent quantity is also divided into three categories using Fuzzy set notations. The evaluation is done by using output membership functions:

(i) Below severe (BS),

(ii) Above severe (AS) and

(iii) More severe (MS)

Fuzzy rules, which are used for evaluating of severity indices of post-contingent quantities of voltage profiles, are

Input Variable	**Output Variable**
Voltage	OSIVP
LV,NV,OV	BS,AS,MS

After getting the severity indices of all the voltage profiles, the overall severity index (OSIVP) of the bus voltage profile for a particular line outage is computed using the following expressions.

OSIVP $=\sum$ w SI,

The weighting coefficient used for indicating the severity indices are

w = 0.30 for BS (Below Severe)

= 0.60 for MS (Most Severe)

= 1.00 for AS (Above Severe)

After obtaining the severity indices and overall severity index for the line loadings and bus voltages profile indices are computed by using the respective fuzzy rules. The overall composite overall severity index (OCOSI) is obtained by adding the three overall severity indices.

After figuring out the overall severity index for each contingency, the contingency list is obtained .From the list it can be inferred that the overall severity indices for those contingency cases with a severity index which exceeds a pre-specified value are listed out and the ranking is done according to the network composite overall severity index.

OCOSI=OSILL + OSIVP.

4.5 METHODOLOGY FOR FUZZY LOGIC APPROACH:

The important steps involved in this approach for contingency ranking is as follows:

a) For the given system, consider a single line outage at a time, load flow study is performed to determine bus voltage profiles and line loadings.

b) Using trapezoidal membership function, the bus voltage profiles and Line loadings are represented in fuzzy set notation.

c) Severity index of Line loadings and bus voltage profiles are also represented in fuzzy set notation.

d) Then using Fuzzy-If-Then rules overall severity index for bus voltage profiles and Line loadings is obtained.

e) The overall severity index is computed using the formula:

OCOSI=OSILL + OSIVP.

f) For all the line outage contingency the above procedure is repeated outages and the contingencies are ranked in the decreasing order of overall severity index and thus it helps in measuring of actual severity of contingency.

4.6 TEST RESULTS USING FUZZY LOGIC:

The fuzzy approach is applied and is tested on IEEE 5 bus system, 14 bus systems. The post contingent quantities are first obtained using Newton Raphson load flow method, and then these quantities are fuzzified using fuzzy set notation. With the use of simple IF-THEN rules, rule base form has been made and overall severity index has been obtained. This logic has been carried out using in Matlab environment and the outputs have been obtained. After obtaining the overall severity index ,which is combination of overall severity index of line loadings and overall severity index for voltage profile, is arranged in decreasing manner indicating the severity of contingencies.

Table 4. 1: For IEEE 5 bus system

Outage line	OSIP	OSIVP	Overall	Ranking
1	258	37.549	295.549	7
2	301.75	36.987	338.737	4
3	300	37.036	337.036	5
4	216.78	127.72	344.5	6
5	328.78	36.810	365.59	2
6	324.342	36.84	361.182	3
7	146.19	398.44	544.63	1

Table 4. 2: For IEEE 14 bus system

Outage	OSIP	OSIVP	(OSI)	Ranking
1	96.2019	151.1413	247.3432	16
2	96.6866	132.7781	229.4647	19
3	97.6086	158.7695	256.3781	11
4	115.6861	122.2550	237.9411	18
5	96.4969	147.5746	244.0715	17
6	101.6117	157.3918	259.0035	9
7	97.7995	157.6713	255.4708	12
8	137.3049	149.3197	286.624	2
9	96.4989	155.5821	252.081	14
10	99.8579	160.1452	260.003	7
11	114.2900	135.6979	249.9879	15
12	139.5220	133.5081	273.0301	4
13	96.5310	165.1978	261.7288	6
14	97.3242	125.9913	223.315	20
15	96.2613	163.2490	259.5103	8
16	121.2223	156.1825	277.4048	3
17	188.2364	130.0279	318.2643	1
18	96.3205	155.8524	252.1729	13
19	112.1647	150.6582	262.8505	5
20	101.2017	157.5832	258.7849	10

4.7 SUMMARY:

In this chapter, fuzzy logic has been used for the contingency ranking of line outages of power system. The proposed method assures the ranking to be more realistic. The results or the outputs obtained from the previous chapter, i.e., post contingent quantities of line flows and bus voltage profiles has been used for this approach. This method provides very useful and important information about the effects of contingency on system and thus helps the operational engineers in taking prior and necessary actions and steps to avoid any unavoidable situations occurring in a power system.

Chapter 5

Contingency ranking using Artificial Neural Networks

5.1 Introduction:

The contingency analysis method by the conventional method or basic load flow method using Newton Raphson method gives the analysis or contingency solution by considering one line outage at a time. This method is unable to satisfy the real time requirement as the analysis on power system consists of large number of contingencies is time consuming. In a power system, load pattern, bus voltages are crucial factor for deciding the stability of the system. Any increase of these factors affects the limit of stability drastically. Therefore there is need of a method which is fast, accurate, and flexible and can operate for voluminous results. Artificial Neural Networks (ANN) has found various applications in the area of power system contingency analysis because of its ability of synthesizing complex mappings quickly and accurately. It also provides its application in the field of pattern recognition, speech etc. Because of its advantage in learning and storing of past data and information, it has found its application in the field of power system also. This technique reduces the online computational requirement and is quick in response time. This technique can be easily adapted and has the potential for reducing the response time in online applications. This computational speed for online application and generalization capability of Artificial Neural Network makes this technique as suitable for power system analysis and monitoring of the security.

This chapter consists of brief overview of Artificial Neural Network, its security monitoring method of power system and its potential to solve the contingency analysis. Here by this technique, two IEEE bus systems have been used to demonstrate the effectiveness of this technique, and comparisons are made with the results obtained using conventional method.

5.2 Brief description of Artificial Neural Network (ANN):

Artificial Neural Network (ANN) is reliable and fast for modelling of any nonlinear complex problem. The advantage of artificial Neural Network (ANN) is that in which any hidden network can be adapted to the degree of accuracy with the help of efficient training. McCulloch & Pitt were the first to propose the model of Artificial Neural Network (ANN).

Thereafter various researchers proposed networks like Hebbs model, Hopfield neural networks topology, Radial Basis Function neural networks (RBFNN) and the Vector support machine network model is one of the latest model in the neural net topology [20].

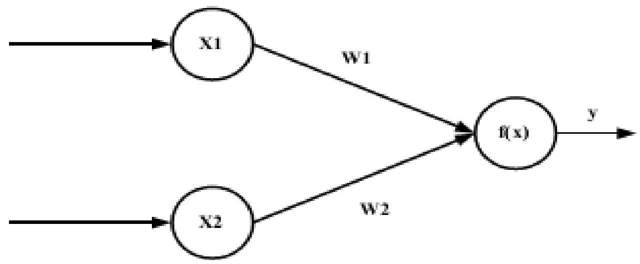


Figure 5. 1: Structure of Artificial Neural Network (ANN)

The basic structure of Artificial Neural Network (ANN) is shown in fig 5.1 which is similar to neural network of brain. The neurons acts as node and receives signal which are transmitted from one another with help of connecting links, these connecting links are in association of weights and these weights are multiplied with incoming input signals and thus the output is obtained using activation of the net input. Based on architecture, activation functions and learning process and training process, there are various neural network topologies.

Based on architecture of neural networks, various types of networks are:

1) Feed Forward Network Topology.
2) Feedback Network topology.
3) Recurrent network topology.
4) Competitive network topology.

The process of using proper value of weights between network layers in order to obtain the desired output is called training of network. The internal process which takes place during the training of network is known as learning.

The common training methods are described below:

Supervised training:

In this kind of training new set of inputs are given into the network to obtain the output. And the output so generated from the network is compared with previously obtained target data. The difference between the actual obtained output and the previously obtained data is called error is calculated and this learning rule is used to modify the associated synaptic weights associated within the layers. This training method is mostly used for pattern association, error back propagation technique and etc.

Unsupervised training:

This training process is adaptive one and the target data are unknown. Here in this, network modifies the weights which are associated with input vectors to obtain the output data. This learning process is difficult and complex as it consists of loop inside the network and iteration process continues inside the network till stable output has not been achieved. This is referred to as self organizing network as it has the ability to self train and learn the network.

To calculate the output response activation functions are used, the activation functions can be linear and non linear. Non linear activation functions are used for multilayer networks. There are various activation functions, some of them have been discussed below.

The binary step activation function is defined by the formulae eq.5.1

$$f(x)=1;\ \text{if } f(x) \geq \Theta$$
$$=0;\ \text{if } f(x) \leq \Theta \quad (5.1)$$

where Ө is threshold of activation function.

Gaussian activation function(GAF) is defined by the formulae eq4.2

$$h\left\| X_i - t_j \right\| = \exp\left(-\frac{\left\| X_i - t_j \right\|^2}{2\sigma^2} \right) \quad (5.2)$$

Where, X_i= it is the input pattern till ith term.

tj= it is the bias centre at jth term.

σ = it is the width of spread.

This activation function is used for activation of hidden layer of the radial basis function network.

Binary sigmoidal function are also known as hyperbolic functions and are used for multilayer networks especially in back propagation. It is given by the formulae eq 5.3

$$f(x) = \frac{1}{1+\exp(-\sigma x)} \tag{5.3}$$

It lies in the range of 0 to 1.

Binary sigmoidal function which lies in the range of -1 to 1 are used as hyperbolic tangent and is given by the formulae eq4.4

$$f(x) = \frac{1-\exp(-\sigma x)}{1+\exp(-\sigma x)} \tag{5.4}$$

5.3ARTIFICIAL NEURAL NETWORK MODEL:

The two models used for prediction purpose are multi layer feed forward network (MLFNN) and Radial basis function neural network (RBFNN).

5.4 MFNN model:

The MLFNN model used here comprises of three layers, the input layer which is the first layer, the hidden layer which is the middle layer and the third layer is the output layer. The input layer comprises of two neurons corresponding to the two inputs. The number of output neurons depends on the no. of estimated parameters taken, therefore two in the present model, corresponds to the performance index (PIp and PIv). The back propagation algorithm (BPA) is used for the purpose of training of the network. The activation function used is sigmoidal function represented by eqn. 5.5 and is used for all the neurons used in network except for those present in the input layer.

$$s(x)=1/(1+e^{-x}) \tag{5.5}$$

The choice of optimized number of hidden neurons, N_h is the most interesting and challenging aspect in designing the MFNN.

Value of N_h is deciding factor of MLFNN model, as large value can reduce the training error associated with this MLFNN model. If we gets a tolerable training error (less value) with some large value of N_h , then there is problem with complexity of time and computational problem. Then there is of no requirement of increasing the value of N_h as to enhance the performance of model. Normalization of input and output values are done before they those values can be used and processed further in the network. During normalization the maximum values of input and output vector components are determined and can be expressed as follows:

$$n_{i,nor}(p) = \frac{n_i(p)}{n_{i,\max}} \qquad (5.6)$$

$$o_{k,nor}(p) = \frac{o_k(p)}{o_{k,\max}} \qquad (5.7)$$

ANN parameters:

The ANN parameters used are the learning rate η_1, and the momentum factor α,plays an important role and have a very considerable effect on the learning speed of the BPA. The BPA provides estimation to calculate the weight space which are computed by the steepest descent method. For small value of η_1 there is slow rate of learning, while if the value of η_1 is too large for speeding up the learning rate, the MFNN becomes unstable or (oscillatory). The MLFNN can be made stable with increasing the rate of learning but this condition can be achieved by increasing the value of momentum factor α. Preferably the values of η_1 and α should lie between 0 and 1 for achieving the desired output of MLFNN model.

Weight update equations: The weights between the hidden layer and the output layer are updated based on as follows

$$w_b(j,k,m+1) = w_b(j,k,m) + \eta_1 * \delta_k(m) * S_b(j) + \alpha * (w_b(j,k,m) - w_b(j,k,m-1) \qquad (5.8)$$

Where m is the number of iterations, jvaries from 1 to N_h and k is the number of estimated output parameters. The value of k is 1 as only PI_p and PIv is to be estimated. $\delta_k(m)$ is the error for the kth output at the mth iteration. $S_b(j)$ is the output from the hidden layer.

Similarly, the weights between the hidden layer and the input layer are updated as follows

$$w_a(i,j,m+1) = w_a(i,j,m) + \eta_1 * \delta_j(m) * S_a(i) + \alpha * (w_a(j,k,m) - w_a(i,j,m-1) \qquad (5.9)$$

Mean absolute error:

The mean absolute error (E_{ts}) measures the accuracy of the ANN system. The E_{tr} tells how well the network adopts to fit into the training data only, even if the data are contaminated.

On the other hand, the E_{ts} indicates the behaviour of trained network with a new set of data which is different and is not included in the training set. The E_{ts} for the test data expressed in percentage is given by

$$E_{ts} = (1/S)*\left(\sum^{S}\left|(PIp_4 - PIp_3)\right| / PIp_3\right)*100 \qquad (5.10)$$

5.5 RADIAL BASIS FUNCTION NEURAL NETWORK:

It is very important to decide which neural network can solve contingency analysis of power system accurately, quickly and reliably. Multilayer perceptron neural network along with back propagation algorithm is mostly used in analysis of complex problem, but it has the disadvantage that: rate of convergence is slow and the problem of local minima. The problem of local minima can be tackled with the combination of supervised and unsupervised learning. In unsupervised learning data's are screened and processed before they are processed in supervised learning.

Out of all neural network RBFNN is such a neural network which provides powerful technique for interpolation in multidimensional space. It also provides no local minima problem with faster rate of convergence on multi dimensional network. It can augment a data without any retention of previous data. It has more advantages like it is simple in structure, efficient in training, mapping capability for non linear network, self and progressive learning.

5.6 DESCRIPTION OF RADIAL BASIS FUNCTION NN (RBFNN):

Radial basis function is a feed forward neural and consists of three layers. First layer is the input layer, middle layer is the hidden layer and the third layer is the output layer. It has the capability of non linear mapping of input to output.

The hidden layer has neurons which are activated with Gaussian activation functions, and the output layer neurons activated with linear activation function. The input variables with unity weights are fed into the neurons of the hidden layer directly through interconnections during the training time. the weights which are associated with hidden layer and output layers are to be trained. The Gaussian activation function is the exponential of the distance measured, called as Euclidean distance.

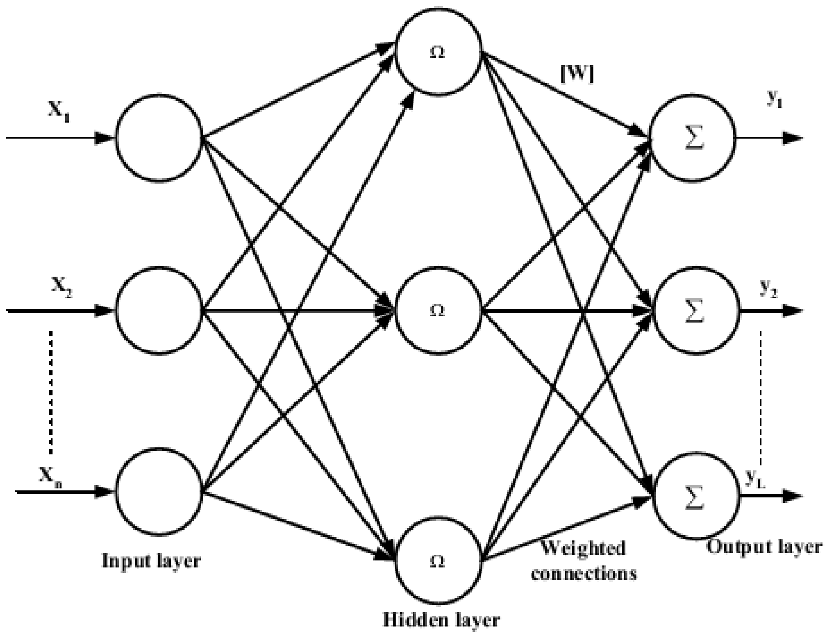


Figure 5. 2: Basic structure of MFNN and RBF neural network.

5.7 Contingency ranking using radial basis function neural network:

With the use of RBFNN, the contingency ranking is done by evaluating the performance indices; active power performance index (PIp) and voltage performance index (PIv). After obtaining the two performance indices by RBFNN, overall severity index is obtained which is the summation of these two parameters, and the contingency ranking is done by arranging the severity in the descending manner. It is understandable that a neural network when applied to any practical problem operates with the help of two modes of procedure known as training and testing modes.

The weights of the network are adjusted with the use of training data's sets in training mode. While in testing mode, the response of the network is seen for the data which is new and had never been used in training mode. The input for the training data for contingency analysis is obtained from the conventional load flow method, N R Load flow method for different line loadings of the power system . And the training mode or process is continued till the error is small, which is the difference between desired and actual output. While, in testing mode the data which has not been used in training process is used. The RBFNN has three layers, first-input layer, middle-hidden layer and third- output layer. It is in the middle/hidden layer computation of output is done by the exponential measure involving input data and the sample one (data). A general model adopted for the contingency analysis comprising of input layer, hidden layer and output layer is shown with the help of diagram below:

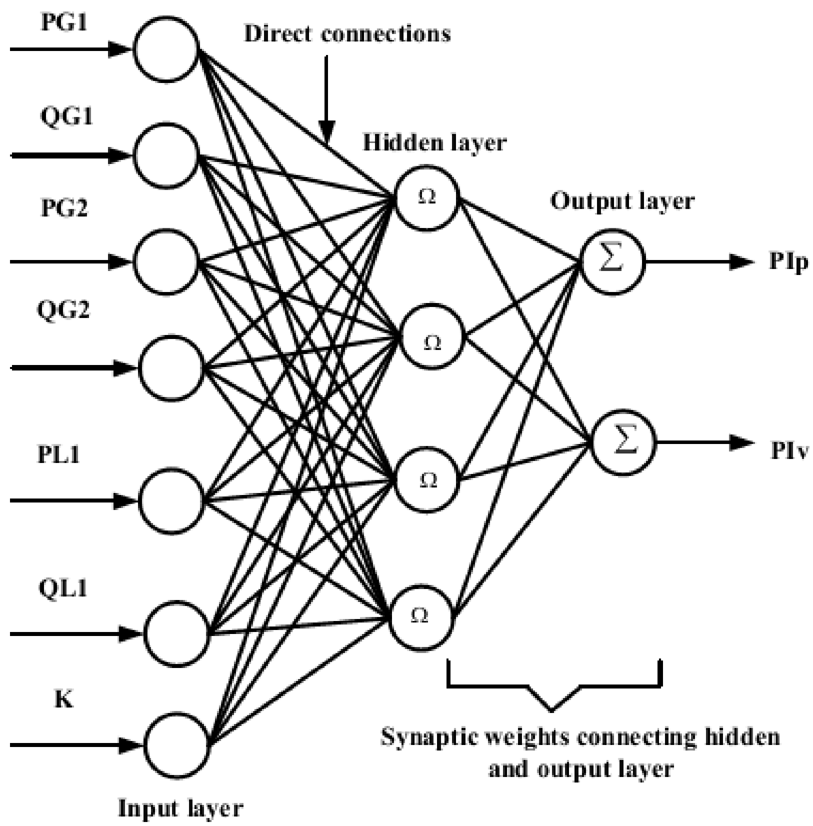


Figure 5. 3: RBFNN model for contingency analysis.

The most important features of this model are:

- Input Layer: This is the first layer and it involves as many neurons as necessary to obtain the desired input data. Generally, the condition of power system is characterized by bus voltage, line flows and bus injections. As the power flows and bus voltage cannot be obtained directly therefore here in this work, power injections to load buses and generator buses is taken as the raw input to ANN.

The input layer [x] ,which is the raw input consists of power flows injected at the load buses and generator buses, real power P and reactive power Q at the generator and load buses, and the value K_i represents the line outage at i-th term.

The raw input of the input layer can be represented by the following expression:

$[x] = [P_{G1}, Q_{G1}, \ldots\ldots\ldots P_{Gg}, Q_{Gg},$

$P_{L1}, Q_{L1}, \ldots\ldots\ldots P_{Ln}, Q_{Ln}, K_i]$ (5.11)

Where G = represents generator bus.

g = represents the no. of generators in a power system.

L = represents the load bus.

n = represents the no. of load buses in power system.

K_i = represents the line outage at i-th term.

- The Hidden layer: Hidden layer is the middle layer and it does not have any specific selection criteria for deciding the number of neurons in the hidden layer. and the selection of the no. of neurons in this hidden layer is based on experimental and simulated results, but the number of neurons must not be in large number as network will not fit to the target and over fitting may occur.
- The output layer: Output layer is the third layer which comprises of two elements particularly active power performance index and reactive power performance index.

[O] = [PIp, PIv] (5.12)

Number of Centres:

According to this approach model the location , from the input training patterns the centres are chosen randomly. The activation function used for RBFNN is Gaussian activation function whose deviation is standard and is at kept fixed with respect width of spread.

Radial basis functions: The functions used in RBFs are as follows

$$G\left(\|x_1 - x_2\|^2\right) = \exp(-(m_1 / d_{\max}^2) * \|x_1 - x_2\|^2) \quad (5.13)$$

The RBFs are multiplied with each of their respective weights and is summed at the end. The trained output obtained at the mth iteration is expressed as:

$$PIp(m)=\sum_{j=1}^{m1}G\left(\|x_1-x_2\|^2\right)*w_{aj}(m) \qquad (5.14)$$

Weight update equation: The weights wa(j) are updated by a linear optimization strategy. LMS algorithm is used as the linear optimization strategy. The weight update equation according to LMS algorithm is as in (5.15)

$$w_{aj}(m+1)=w_{aj}(m)+\eta_2*G\left(\|x_1-x_2\|^2\right)*e_{1p}(m) \qquad (5.15)$$

5.8 RESULTS AND DISCUSSIONS:

The results obtained by using the prediction technique MFNN and RBFNN is shown here in this section. By varying the values of learning rate η_1 and momentum factor α, optimization of the network has been done. Starting with values 0.1 for both η_1 and α, N_h has been set. After getting the N_h value, learning rate and momentum factor has been varied to obtain the E_{tr}. The combination of hidden layer N_h, learning rate η_1 and momentum factor α which gives the least value of E_{tr} is considered to be the best combination for getting an optimum value.

Similarly in case of RBFNN, learning rate and number of centre m_1 have been varied to obtain the least value of mean square error E_{tr} .the combination which gives the least value of E_{tr} is considered to be the best one for getting the optimal value.The algorithm is applied on two bus system, IEEE 5 bus and 14 bus systems and the whole work was carried out in MATLAB environment. The main objective was to predict the performance indices. The predictions techniques have been applied on two bus systems which are referred as case –I and case-II.

5.8.1 Case-I: 5 bus system:

The bus data and the line data sheet of 5 bus system is given in appendix A. The results obtained by using the prediction technique MFNN and RBFNN are given in the table. From table 5.1 it shows the variation of E_{tr} with α=0.1and η=0.1 and iter=400 and it is quite obvious that with N_h =5 and combination of α=0.1and η=0.1 and iter=400, gives the least training data that is 8.0289*10^-4.

Table 5. 1:Variation with (α=0.1and η=0.1 and iter=400) for PIp

N_h	E_{tr}
2	2.3988e-04
3	1.3986e-04
4	1.0200e-04
5	**8.0289e-04**
6	6.6970e-04
7	5.5476e-04

From table 5.2 this table gives the variation of E_{tr} with N_h =5,α=0.1 and iter=400 and with η value changing and the least value is obtained at η=0.6.

Table 5. 2: Variation of with η (=5 and α=0.1 and iter=400)

η	E_{tr}
0.2	1.2251e-05
0.3	2.3197e -06
0.4	2.1146e-06
0.5	1.2289e-06
0.6	**7.9391e-07**
0.7	5.5098e-06

From this table5.3 it can be found out that N_h =5 ,η=0.6 and iter=400 and α=0.7 least value training data is obtained.

Table 5. 3: Variation of with α (=5 ,η=0.6 and iter=400)

α	E_{tr}
0.3	5.1942e-07
0.4	4.1361e-07
0.5	3.0821e-07
0.6	1.9943e-07
0.7	**7.5100e-08**
0.8	4.3998e-08

Similarly for 5 bus system, the same procedure was continued and the following results were obtained.

5 bus system for optimizing PIv value:

Table 5. 4: Variation with (α=0.1and η=0.1 and iter=400)

N_h	E_{tr}
2	2.3970e-04
3	1.3974e-04
4	1.0190e-04
5	**8.0289e-05**
6	6.6886e-05
7	5.5399 -05

Table 5. 5: Variation of   with η (=5 and α=0.1 and iter=400)

η	E_{tr}
0.2	1.2187e-05
0.3	4.3059e -06
0.4	2.1061e-06
0.5	1.2232e-06
0.6	**7.8969e-07**
0.7	5.4772e-06

Table 5. 6 :Variation of   with α(=5 ,η=0.6 and iter=400)

α	E_{tr}
0.3	5.1624e-07
0.4	4.1087e-07
0.5	3.0594e-07
0.6	1.9769e-07
0.7	**7.4182e-08**
0.8	4.2142e-08

5.8.2 Case-II : For 14 bus system

Table 5.7: It shows the variation of E_{tr} with α=0.1and η=0.1 and iter=400 and it is quite obvious that with N_h =5 and combination of α=0.1and η=0.1 and iter=400, gives the least training data that is 9.3971e-04.

PI_p value:

Table 5. 7: Variation with (α=0.1and η=0.1 and iter=400) for PIp:

N_h	E_{tr}
2	0.0028
3	0.0017
4	0.0012
5	**9.3971e-04**
6	7.5962e-04
7	6.0974e-04

From table 5.8 this table gives the variation of E_{tr} with N_h =5,α=0.1 and iter=400 and with η value changing and the least value is obtained at η=0.6.

Table 5. 8: Variation of with η (=5 and α=0.1 and iter=400)

η	E_{tr}
0.2	1.4531e-04
0.3	5.1196e-05
0.4	2.4919e-05
0.5	1.4403e-05
0.6	**9.2595e-06**
0.7	6.3981e-06

From this table5.9 it can be found out that N_h =5 ,η=0.6 and iter=400 and α=0.6 least value training data is obtained.

Table 5. 9: Variation of with α(=5 ,η=0.6 and iter=400)

α	E_{tr}
0.3	5.5968e-06
0.4	4.1949e-06
0.5	7.2598e-06
0.6	**7.6675e-08**
0.7	7.2598e-07
0.8	7.6675e-07

14 bus system for optimizing PIv value:

Table 5. 10: Variation with (α=0.1and η=0.1 and iter=400)

N_h	E_{tr}
2	0.0028
3	0.0017
4	0.00012
5	**9.3952e-04**
6	7.5944e-04
7	6.0958e-04

Table 5. 11: Variation of with η (=5 and α=0.1 and iter=400)

η	E_{tr}
0.2	1.4525e-04
0.3	5.1167e -05
0.4	2.4902e-05
0.5	1.4391e-06
0.6	**9.2506e-06**
0.7	6.3913e-06

Table 5. 12: Variation of with α(=5 ,η=0.6 and iter=400)

α	E_{tr}
0.3	5.5904e-06
0.4	4.187e-06
0.5	2.9271e-06
0.6	1.7837e-06
0.7	**7.8426e-08**
0.8	7.6361e-07
0.9	7.1245e-08

RBFNN MODELING:

RBFNN(5 bus) for PIp

Table 5. 13: Variation of with number of centres m1(η_2=0.5 and iter=400)

.m1	E_{tr}
2	4.5316e-06
3	2.3761e-05
4	1.7722e-05
5	8.4060e-06
6	**9.5783e-06**
7	3.4606e-05
8	4.6057e-06

From table5.13 It can be inferred that by varying E_{tr} with number of centre's m_1 , the least value is obtained at m_1 =7

Table 5. 14: Variation of with η_2(m1=6 and iter=400)

η_2	E_{tr}
0.2	6.7702e-05
0.3	3.4873e-05
0.4	1.7949e-05
0.5	**9.5783e-06**
0.6	8.6212e-06
0.7	8.1337e-06
0.8	7.3303e-06

FOR PIv (5 BUS SYSTEM)

Table 5. 15: Variation of   with number of centres m1(η_2=0.5 and iter=400)

.m1	E_{tr}
2	4.5482e-06
3	2.3535e-05
4	1.7703e-05
5	8.4060e-06
6	**9.5783e-05**
7	3.4606e05
8	4.6057e-06

Table 5. 16: Variation of   with η_2(m1=6and iter=400)

η_2	E_{tr}
0.2	9.5783e-06
0.3	8.6212e-06
0.4	8.1333e-06
0.5	7.8143e-06
0.6	7.5589e-06
0.7	7.3303e-06
0.8	7.1155e-06

RBFNN(14 bus) for PIp

Table 5. 17: Variation of with number of centres m1(η_2=0.2 and iter=400)

.m1	E_{tr}
2	0.0140
3	0.0141
4	0.0142
5	0.0143
6	0.0139
7	**7.974e-04**
8	0.011

From table5.17 It can be inferred that by varying E_{tr} with number of centre's m_1 , the least value is obtained at m_1=7

Table 5. 18: Variation of with η_2(m1=7 and iter=400)

η_2	E_{tr}
0.2	7.9749e-04
0.3	4.6571e-04
0.4	3.2984e-04
0.5	2.2568e-04
0.6	2.0299e-04
0.7	1.6589e-04
0.8	1.4368e-04
0.9	1.7500e-04
1.0	1.1051e-04
1.1	8.9949e-05
1.2	**8.1495e-05**
1.3	7.4716e-05

PIv(14 BUS SYSTEM):

Table 5. 19: Variation of   with number of centres m1(η_2=0.2 and iter=400)

.m1	E_{tr}
2	0.0140
3	0.0141
4	0.0142
5	0.0143
6	0.0139
7	**7.974e-04**
8	0.011

Table 5. 20: Variation of   with η_2(m1=7 and iter=400)

η_2	E_{tr}
0.2	7.978e-04
0.3	4.6456e-04
0.4	3.2098e-04
0.5	2.2134e-04
0.6	2.090e-04
0.7	1.6576e-04
0.8	1.4908e-04
0.9	1.2492e-04
1.0	1.1044e-04
1.1	**8.9375e-05**
1.2	8.1430e-05

5.9 Comparisons between MFL, MFNN and RBFNN for MSE (E_{tr}):

(i)For 14 bus system:

Table 5. 21: comparisons between MFL, MFNN and RBFNN for MSE:

	PI_p	PI_V
MFNN	0.2376	0.1989
RBFNN	0.9987	0.9890
MFL	5.8960	5.8320

(ii)For 5 bus system:

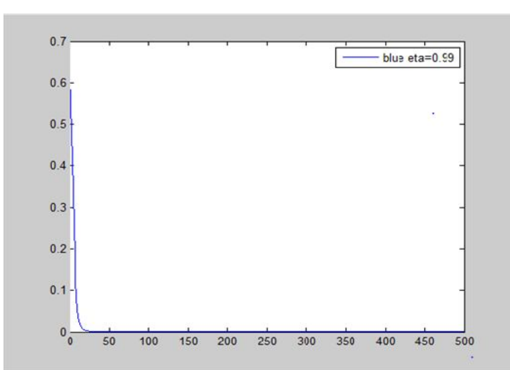
Table 5. 22: Comparisons between MFL,MFNN and RBFNN for MSE

	PI_p	PI_V
MFNN	0.2188	0.2274
RBFNN	0.8204	0.8234
MFL	4.306	5.042

5.10: Graph plots obtained for MSE for PI_p and PI_V .

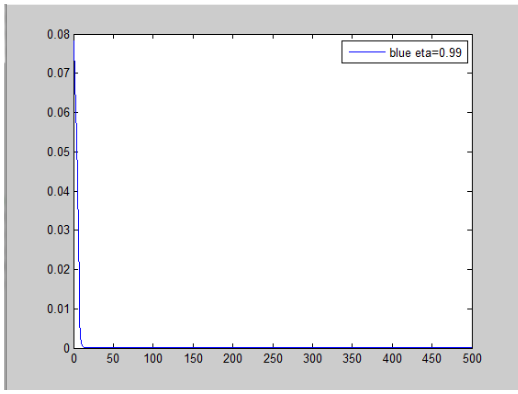
(i)For 5 bus using MFNN forPIp*:*

Variation of E_{tr} with α (N_h =5 ,η=0.6 and iter=400 and α=0.7) least value training data is obtained at E_{tr} =7.51008e-08. The MSE obtained does not change after attaining its minimum value.



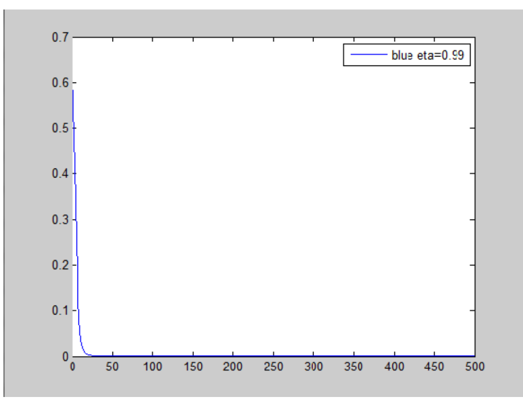
For PI_V:

Variation of E_{tr} with α (N_h =5 ,η=0.6 and iter=400) gives MSE of 7.418e-08.

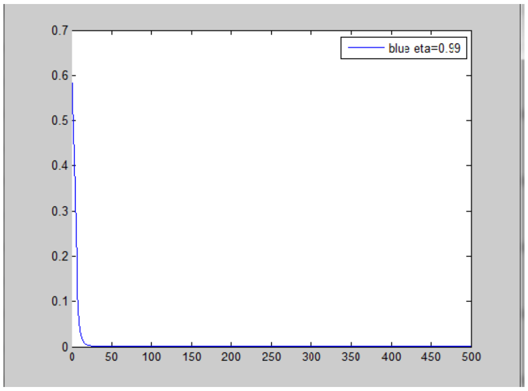


(ii)Using RBFNN for 5 bus system*:*

For PI_p :Variation of E_{tr} with η_2(m1=6 and iter=400)



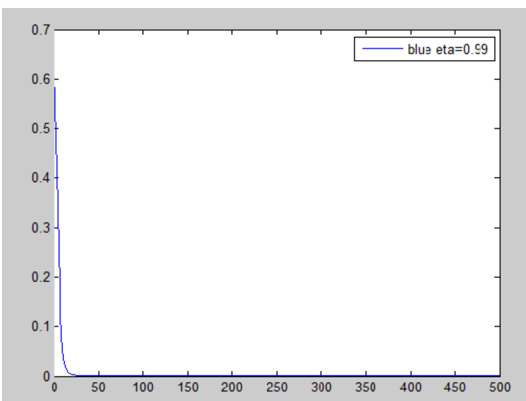
For PI_V :Variation of E_{tr} with η_2(m1=6and iter=400)



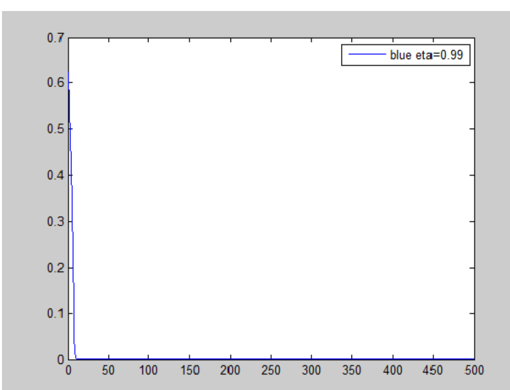
Using MFNN the graphs of MSE for PI_p and PI_V :

(iii)For 14 bus system using MFNN *:*

Variation of E_{tr} **with α(** N_h **=5 ,η=0.6 and iter=400)**

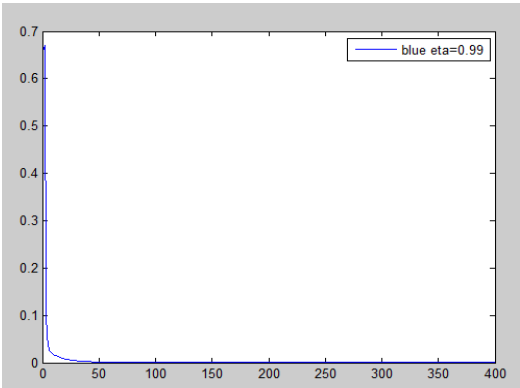


Variation of E_{tr} **with α(** N_h **=5 ,η=0.6 and iter=400)**

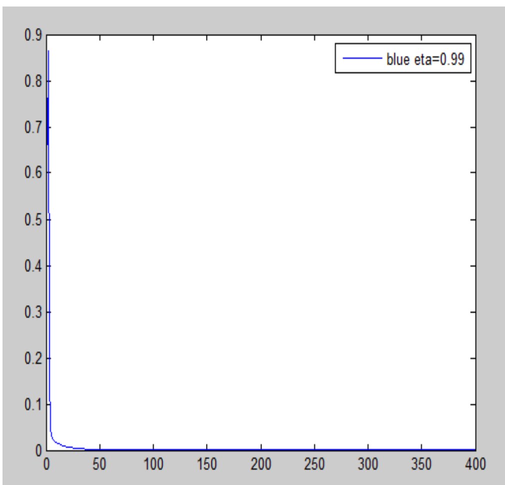


(iv)Using RBFNN FOR 14 BUS SYSTEM:

Variation of E_{tr} with (N_h =7,iter=400)



Variation of E_{tr} with (N_h =7,iter=400):



From the above graphs it can be shown that the MSE decreases with increase in number of iterations and remains constant at certain value and doesnot change after attaining a least value. This graphs also indicates that least MSE is obtained quickly in case of MFNN rather than in RBFNN.

5.11 CONCLUSION:

Both the models used MFNN and RBFNN gave very minimum results MSE(E_{tr}).Less than 0.28%, for PIp and PIv of 14 bus system, and gave less than 0.21 % for 5 bus system in case of MFNN and in case of RBFNN it gave less than0.98% for 14 bus and less than 0.83% in case of 5 bus system . Thus it can be concluded that the simulations results obtained shows the superiority of MFNN model over the RBFN model used in terms of accuracy in .predicting the performance indices.

Chapter 6
Conclusion and Scope for Future work

6.1 CONCLUSIONS:

In this work, the contingency selection and ranking which are important for contingency analysis have been done by evaluating two important performance indices namely; active and reactive power performance index (PIP& PIV). These indices were calculated for various test bus systems using the NR method, since the for the contingency ranking, Overall Performance Index (OPI) is calculated which is the summation of two severity indices namely Active power performance index and Voltage performance index using Newton-Raphson load flow method. But the system parameters are dynamic in nature, which initiates for the application of Artificial Neural Networks. In order to predict the Overall Performance Index, two Neural Network architectures namely Multi-layer Feed forward Neural Network (MFNN) and the Radial Basis Function Network (RBFN) and Fuzzy logic have been considered. The simulation result shows the superiority of the MFNN over RBFN and Fuzzy logic in terms of accuracy in predicting OPI. The proposed techniques have been tested on standard 5 bus system and IEEE-14 bus system in MATLAB 2010a environment .

6.2 SCOPE FOR FUTURE WORK:

The followings can be taken up for further study and analysis:

This prediction technique can be further implemented for higher bus systems and the prediction technique can be further extended to other soft computing techniques and further comparisions can be made.

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APPENDIX-A

The bus data and line for the 5 bus test system has been given in Table A.1 and A.2 respectively. The following conventions were used for all the test bus systems; Base MVA = 100; Coding used for buses: 0-Load Bus, 1-Slack Bus, 2-PV Bus.

Table A.1:Bus Data of 5-BUS SYSTM:

Table A.1

Bus Data of 5-Bus System

Bus No.	Bus code	Voltage Mag.	Angle Degree	Load MW (pu)	Load MVAR (pu)	Gen. MW (pu)	Gen. MVAR (pu)	Gen. Qmin	Gen. Qmax	Injec. MVAR
1	1	1.06	0.0	0.00	0.00	0.0	0.0	0.0	0.0	0.0
2	0	1.0	0.0	0.20	0.10	0.4	0.3	0.0	0.0	0.0
3	0	1.0	0.0	0.45	0.15	0.0	0.0	0.0	0.0	0.0
4	0	1.0	0.0	0.40	0.05	0.0	0.0	0.0	0.0	0.0
5	0	1.0	0.0	0.60	0.15	0.0	0.0	0.0	0.0	0.0

LINE DATA OF 5 BUS SYSTEM:

Table A.2

Line Data of 5-Bus System

Start Bus	End Bus	R (pu)	X (pu)	½ B (pu)	Tap Set value
1	2	0.0200	0.0600	0.0300	1
1	3	0.0800	0.2400	0.0250	1
2	3	0.0600	0.1800	0.0200	1
2	4	0.0600	0.1800	0.0200	1
2	5	0.0400	0.1200	0.0150	1
3	4	0.0100	0.0300	0.0100	1
4	5	0.0800	0.2400	0.0250	1

APPENDIX-B

The bus data and line data are given in table B.1 and B.2

BUS DATA FOR IEEE-14 BUS SYSTEM:

Bus No.	Bus Code	Voltage Magnitude	Angle Degrees	Load		Generator				Injected MVAR
				MW	MVAR	MW	MVAR	Qmin	Qmax	
1	1	1.06	0	30.38	17.78	40	-40	0	0	0
2	2	1.045	0	0	0	232	0	-40	50	0
3	2	1.01	0	131.88	26.6	0	0	0	40	0
4	0	1	0	66.92	10	0	0	0	0	0
5	0	1	0	10.64	2.24	0	0	0	0	0
6	2	1.07	0	15.68	10.5	0	0	-6	24	0
7	0	1	0	0	0	0	0	0	0	0
8	2	1.09	0	0	0	0	0	-6	24	0
9	0	1	0	41.3	23.24	0	0	0	0	0
10	0	1	0	12.6	8.12	0	0	0	0	0
11	0	1	0	4.9	2.52	0	0	0	0	0
12	0	1	0	8.54	2.24	0	0	0	0	0
13	0	1	0	18.9	8.12	0	0	0	0	0
14	0	1	0	20.86	7	0	0	0	0	0

TableB.2:LINE DATA for 14 BUS SYSTEM:

Sending end Bus	Receiving end bus	Resistance p.u.	Reactance p.u.	Half Susceptance p.u.	Transformer tap
1	2	0.01938	0.05917	0.0264	1
2	3	0.04699	0.19797	0.0219	1
2	4	0.05811	0.17632	0.0187	1
1	5	0.05403	0.22304	0.0246	1
2	5	0.05695	0.17388	0.017	1
3	4	0.06701	0.17103	0.0173	1
4	5	0.01335	0.04211	0.0064	1
5	6	0	0.25202	0	0.932
4	7	0	0.20912	0	0.978
7	8	0	0.17615	0	1
4	9	0	0.55618	0	0.969
7	9	0	0.11001	0	1
9	10	0.03181	0.0845	0	1
6	11	0.09498	0.1989	0	1
6	12	0.12291	0.25581	0	1
6	13	0.06615	0.13027	0	1
9	14	0.12711	0.27038	0	1
10	11	0.08205	0.19207	0	1
12	13	0.22092	0.19988	0	1
13	14	0.17093	0.34802	0	1