ABSTRACT

Electricity is regarded as one of the indispensable means to growth of any countries economy. The main objective of any generation and distribution utility is to satisfy the demand of customers with a high quality product. To ensure this quality, the voltage and frequency should be constant during normal operation and uninterrupted service requirement should be satisfied. In power system, blackouts have been the most problem occur in the interconnected grid, which results in large loss. In recent years this phenomenon has considerably increased based on the frequency and the severity of this problem. Some kind of operation contributes to the recently occurred blackouts such as incorrect of protective systems, voltage instability, and lack of under frequency load shedding.

Under frequency load shedding (UFLS) scheme is proposed to enhance the reliability of power systems to against system failure and fault occur. Speed and accuracy of under frequency load shedding (UFLS) has a vital role in its effectiveness for preserving system stability and reducing energy loss. Initial rate of change of frequency is a fast and potentially useful signal to detect the overload when a disturbance happens. In order to improve the under-frequency load shedding performance, a global load shedding scheme with rate of frequency decline is proposed. This paper presents a new method for solving under frequency load shedding (UFLS) problem by using neural network and fuzzy logic controller. It also presents fast and accurate load shedding technique based on adaptive neuro-fuzzy controller for determining the amount of load shed to avoid a cascading outage. The development of new and accurate techniques for vulnerability control of power systems can provide tools for improving the reliability, continuity of power supply and reducing energy loss.

Keywords: Load shedding, Under Frequency, Rate of frequency decline, Adaptive Neuro-Fuzzy, fuzzy Controller, Nero-Fuzzy, Power system, Vulnerability control.

I.INTRODUCTION

The electric power system is a complex system, whose operating condition may not remain at a constant value. This necessitates the power system operator be alert to keep the system performance under normal condition. The various contingencies like, large load
variations, outage of components (transmission lines, transformers, generators, etc.) are more common. One of the major challenges of electric utilities in recent years is power system blackout. For instance the blackouts of Greece, Italy, North America, Sweden and Denmark, Iran and many others have been mentioned in the literature [1]-[5]. In fact, due to both economical and technological restrictions, it is not possible to completely prevent these blackouts. However, with the aid of some protection and control strategies, frequency and severity of these blackouts may be reduced [6]. One of the important protection strategies used for this purpose is a class of protection schemes known as ‘System Protection Schemes’ [7], [8].

System protection schemes are protection strategies designed to detect a particular system condition that is known to cause unusual stress to the power system, and to take some kind of predetermined action to counteract the observed condition in a controlled manner [9]. One of the most commonly used types of system protection schemes, generally accepted after the northeastern blackout of 1965, is Under Frequency Load Shedding (UFLS) scheme [10].

Conventional UFLS system is designed to recover the balance of generation and consumption following a generator outage or sudden load increase. The loads to be shed by this system are constant load feeders and are not selected adaptively. In other words always the same loads are dropped from the system, regardless of the location of disturbance. In this method loads are classified in three groups of non-vital, semi vital and vital loads [11]. The trend is to shed non-vital loads. However in severe conditions semi-vital loads may also be shed. Obviously this constant non-adaptive load shed scheme is not the most efficient one and may cause some problems in the system. As an example, outage of a major generating unit in the power system may cause transfer of high amount of power in long distances which can reduce voltage stability margin of the system. In this situation occurrence of another contingency may cause voltage instability, though the system is stable in terms of frequency. After occurrence of the system disturbance, frequency initially decreases and then it might return back to its near normal value, but system might become unstable due to voltage problem. The return of frequency is due to load dependency on voltage and frequency. Therefore, modeling the dependency of load upon voltage and frequency is of essential importance. In this research work this dependency is considered using appropriate load models.

Conventional UFLS schemes are generally implemented in a decentralized, i.e. distributed protection system. In this approach the decision to shed load is made using the local frequencies measured at the location of relays. However, in recent years, application of centralized load shedding algorithms to enhance adaptability of the schemes has been proposed in some publications [12].

This paper is organized as follows: Section-II gives the introduction to load shedding; conventional load shedding methods are discussed in section-III, proposed method is discussed in section-IV it also gives the mathematical analysis of shedding, Section-V gives the simulation results and comparison of different methods, finally we will conclude our work in Section-VI.

II. LOAD SHEDDING

As already mentioned, when a power system disruption creates a large generation load imbalance, resulting in a frequency decline, emergency action such as under frequency load shedding may be needed. If system frequency reaches a given threshold, even for a short amount of time, power stations may trip off resulting in further load imbalance which may lead to a global system collapse.
When there is a rapid decline in frequency, simple governor response may be neither sufficient nor quick enough to stop the frequency excursion before it reaches the protection threshold of frequency relays in other power plants. Thus, there is a need for a complementary emergency action in order to assure that the declining frequency is stopped before reaching this threshold.

III. CONVENTIONAL LOAD SHEDDING APPROACH

This section is a review of load shedding techniques that have been devised over a number of years each having its own set of applications and drawbacks.

A. Breaker Interlock Load Shedding

This is the simplest method of carrying out load shedding. For this scheme, the circuit breaker Interdependencies are arranged to operate based on hardwired trip signals from an intertie circuit breaker or a generator trip. This method is often used when the speed of the load shedding is critical. Even though, the execution of this scheme is fast, breaker interlock load shedding possesses a number of inherent drawbacks:

- Load shedding based on worst-case scenario
- Only one stage of load shedding
- Almost always, more loads is shed than required
- Modifications to the system are costly

B. Under-Frequency Relay (81) Load Shedding

Guidelines for setting up a frequency load shedding are common to both large and small systems. The design methodology considers fixed load reduction at fixed system frequency levels. Upon reaching the frequency set point and expiration of pre-specified time delay, the frequency relay trips one or more load breakers. This cycle is repeated until the system frequency is recovered, e.g., 10% load reduction for every 0.5% frequency reduction. Since this method of load shedding can be totally independent of the system dynamics, total loss of the system is an assumed possibility.

Additional drawbacks of this scheme are described below.

- Slow response time.
- Incorrect / excessive load shedding
- Analysis knowledge is always lost

C. Programmable Logic Controller-Based Load Shedding

With Programmable Logic Controller (PLC) scheme, load shedding is initiated based on the total load versus the number of generators online and/or detection of under-frequency conditions. Each substation PLC is programmed to initiate a trip signal to the appropriate feeder breakers to shed a preset sequence of loads. This static sequence is continued until the frequency returns to a normal, stable level.

A PLC-based load shedding scheme offers many advantages such as the use of a distributed network via the power management system, as well as an automated means of load relief. However, in such applications monitoring of the power system is limited to a portion of the network with the acquisition of scattered data. This drawback is further compounded by the
implementation of pre-defined load priority tables at the PLC level that are executed sequentially to curtail blocks of load regardless of the dynamic changes in the system loading, generation, or operating configuration. The system-wide operating condition is often missing from the decision-making process resulting in insufficient or excessive load shedding. In addition, response time (time between the detection of the need for load shedding and action by the circuit breakers) during transient disturbances is often too long requiring even more load to be dropped.

IV PROPOSED SYSTEM

A. Mathematical analysis of load shedding:

1) Active Power and Frequency

During normal operation of power system, the total mechanical power input to the system generators is equal to the sum of the connected loads plus all real power losses [13]. If for any reason, the balance of Generation and loads is disrupted, operating frequency of the system would change according to (1).

$$\frac{2H}{dt}f = P_m - P_e$$  \hspace{1cm} (1)

Where H is the inertia constant
f is the generator frequency in pu
P_m is the generator mechanical power in pu
P_e is the generator electrical power in pu

In general, power system loads are dependent on both voltage and frequency. To be able to compute exact amount of system load, this dependence should be considered. Power system voltage is a local parameter and its value is not usually known precisely for each remote system bus. As such, the effect of voltage in load modeling has been ignored in several researches.

Despite of voltage, system frequency is a general parameter and is almost similar at all points of a power system [14]. The frequency dependent characteristic of composite load may be expressed as (2):

$$P_e = P_L + d \Delta f$$  \hspace{1cm} (2)

Where d is load reduction factor
P_L is the load power in pu

2) Final Frequency

According to (1) and (2) if a power system encounters with an overload case, then frequency of the system begins to decline. At the same time, system load which is dependent on frequency by factor d is reduced as well. If no other action is performed, eventually system settles at a final frequency at which the amount of generation reduction would be equal to reduction of system loads [13].

$$\Delta P_m = d \Delta P_e$$  \hspace{1cm} (3)

The final frequency will be:

$$f_\infty = f_0 - \left(1 - \frac{lo}{(1+lo)d}\right)$$  \hspace{1cm} (4)

Where f is the initial frequency
f_\infty is the final frequency
lo is the amount of overload in pu

3) Minimum Allowable Frequency
All of the power system apparatus are made and designed for nominal frequency. Power plant auxiliary services are more demanding in terms of minimum allowable frequency. Steam turbine is the most sensitive equipment against frequency drops. Continues operation of steam turbines should be restricted to frequency above 47.5 Hz. Frequency falls below 47 Hz must be avoided. In fact, every commercial turbine can sustain up to 10 contingencies at 47 Hz just for one second without being jeopardize [4].

4) Load Amount to be shed

For a system overload the amount of load which must be shed is determined based on the minimum allowable frequency and the amount of overload. The minimum allowable frequency could be considered as 47 Hz instead of 47.5 Hz in load shedding schemes design, if the system dispatch center can increase the generation by governors quickly. Total amount of the load which must be shed to cover the maximum anticipated overload, is obtained from [5]

$$LD = \frac{L}{f_{HL} - d(1 - \frac{f}{50})}$$

(5)

Where LD is total load which must be shed
f is permissible settling frequency

B. Fuzzy Logic

The implemented expert system has the following components is shown in Figure 1.

- **Fuzzifier**
  The given Input values are converted to fuzzy valves for ease of access the input data. Here the input for the interference engine is Rate of change of frequency.

- **Inference Engine**
  Is that part of the expert system that is responsible for decision-making, using rules chaining. Chaining is either forward or backward. Forward chaining is used when there is no exact goal to search for, also if the initial states are less than the goal states. On the other hand, backward chaining is used when there is an exact solution to search for and it is required to find the path to this goal, also it is used when the number of final states is less than the initial states.

- **Decisions**
  Based on the obtained input from the controller the fuzzy controller decides the output based on the membership function we already given in its knowledge base.
Load Shedding Using Fuzzy Controller

In this paper the generation and load data are given as inputs to the simulation system shown in fig 3, it calculates the rate of change of frequency at that moment and sends that data to the fuzzy controller. The fuzzy controller decides the amount of load shed required to maintain the system to operate in stable manner.

C. Neuro-Fuzzy

Neuro-fuzzy system is a combination of neural network and fuzzy logic in which it combines the learning and adapting abilities of neural networks with the fuzzy interpretation of fuzzy logic system. An example of a neuro-fuzzy system is the adaptive neural network based fuzzy inference system (ANFIS) which combines the Takagi–Sugeno fuzzy inference system (FIS) with neural network. The ANFIS defines five layers which perform the function of fuzzification of the input values, aggregation of membership degree, evaluation of the bases, normalization of the aggregated membership degree and evaluation of function output values. A typical ANFIS structure with five layers and two inputs, each with two membership functions is shown in Fig 2. The five layers of the ANFIS are connected by weights. The first layer is the input layer which receives input data that are mapped into membership functions so as to determine the membership of a given input. The second layer of neurons represents association between input and output, by means of fuzzy rules. In the third layer, the output are normalized and then passed to the fourth layer. The output data are mapped in the fourth layer to give output membership function based on the pre-determined fuzzy rules. The outputs are summed in the fifth layer to give a single valued output. The ANFIS has the constraint that it only supports the Sugeno-type systems of first or 0th order. The system can only be designed as a single output system and the system must be of unity weights for each rule.

![ANFIS Structure with 1 input, 1 Output, and 1 Membership Function for each input](image)

Load Shedding Using Neuro-Fuzzy Controller

Fuzzy logic system needs rules to be defined first, but one may have no knowledge about a power system for the formation of rules. Therefore, automated parameters tuned by a neural network embedded inside a fuzzy system can replace the need for prior knowledge about a power system. To implement the proposed load shedding scheme for vulnerability control of power systems, firstly, base case simulation is carried out on a power system so as to analyze the system behavior at the base case condition. The next step is to analyze the system behavior when subjected to credible system contingencies such as line outage (LO), generator outage (GO), load increase (LI) and disconnection of loads (DL). The selection of inputs to the controller is an
important design consideration and therefore for power system vulnerability control, the Rate of change of frequency is selected as input variables for the load shedding controllers. The overall output of the ANFIS is the estimated amount of load shed.

In this paper Rate of change of frequency is given as input for the Neuro-Fuzzy controller and the output obtained is the amount of load is required to shed in order to maintain the system in a stable manner. Here the training data is given which was collected from the Electricity Board and error is observed.

V. SIMULATION RESULTS

Figure 3: simulation diagram of Fuzzy Controlled Load Shedding

<table>
<thead>
<tr>
<th>df/dt</th>
<th>Actual output value</th>
<th>Fuzzy output value</th>
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<tr>
<td>-0.4</td>
<td>160</td>
<td>152</td>
</tr>
<tr>
<td>-1.3</td>
<td>520</td>
<td>503</td>
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<tr>
<td>-1.9</td>
<td>760</td>
<td>728</td>
</tr>
<tr>
<td>-2.5</td>
<td>1000</td>
<td>960</td>
</tr>
</tbody>
</table>

Table 1: comparison of actual output value with Fuzzy output value
Figure 4: variation of Frequency when load is more than generation and restoration

<table>
<thead>
<tr>
<th>Generation</th>
<th>Load</th>
<th>df/dt</th>
<th>Actual difference</th>
<th>Fuzzy output value</th>
</tr>
</thead>
<tbody>
<tr>
<td>10000</td>
<td>9500</td>
<td>0.8355</td>
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</tbody>
</table>

Table 2: Output Values of Fuzzy controller

Figure 5: Results of the fuzzy controller
VI. CONCLUSIONS

In power system, blackouts have been the most problem occur in the interconnected grid which results in large loss. In recent years this phenomenon has considerably increased based on the frequency and the severity of this problem. Under frequency load shedding (UFLS) scheme is proposed to enhance the reliability of power systems against system failure and fault occur.

A new load shedding scheme is developed by means of using neuro-fuzzy controller to determine the optimal amount of load to be shed so that a power system can remain in a secure condition. The neuro-fuzzy load shedding technique combines the use of fuzzy logic and neural network techniques. The performance of the proposed neuro-fuzzy load shedding is validated. The proposed neuro-fuzzy technique has proven to be a more effective method in determining the optimal value of load shed in which the average absolute error for the neuro fuzzy technique within tolerable limits. It is also demonstrated to be a useful load shedding tool for providing fast vulnerability control. By this method we can avoid the unnecessary load shedding and reduce the energy loss.
REFERENCES

AUTHORS BIBILOGRAPHY:

M.S. Sujatha is currently pursuing her PhD degree in Electrical and Electronics Engineering department at university of JNTUCA, Anantapur, A.P, India. She received her B.E degree from Mysore University and M.Tech degree from JNTUCA, Anantapur. Her research interest includes wireless technologies for power system applications; protection, monitoring and control and reduction in Energy Losses.

Manoj Kumar .N is currently pursuing his M.Tech at Sree Vidyanikethan Engineering college, Tirupati, affiliated to JNTUCA. He completed his B.Tech at N.B.K.R. Institute of Science and Technology, Vidyaganagar, A.P, India in the year 2010.

Dr. M. Vijay Kumar Graduated from NBKR Institute of Science and Technology, Vidyaganagar, A.P, India in 1988.He obtained M.Tech degree from Regional Engineering College, Warangal, India in 1990. He received Doctoral degree from JNT University, Hyderabad, India in 2000. He has guided 10 PhD’s. Currently, he is Professor in Electrical and Electronics Engineering Department at JNTUA, Anantapur A.P, India. His areas of research interest are power system protection, monitoring, control, power electronic and drives and power quality issues. He is the recipient of The Pandit Madan Mohan Malaviya Memorial Prize.