UNDER FREQUENCY LOAD SHEDDING FOR ENERGY MANAGEMENT USING ANFIS/CASE STUDY

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ABSTRACT

Energy management is the major concern for both developing and developed countries. Energy sources are scarce and expensive to develop and exploit, hence we should confer a procedure to accumulate it by the use of load shedding. If the disturbance is large, like large load variations, outage of components (transmission lines, transformers, generators, etc.) causes power system blackouts. The conventional method is to solve an optimal power flow problem to find out the rescheduling for overload alleviation. But this will not give the desired speed of solution. 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 accrues. This paper presents a new method for solving UFLS problem by using 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 the energy loss. The applicability of ANFIS is tested on a case study at Renigunta 220/132/33 KV substation.

Keywords: Under Frequency Load shedding, Rate of frequency decline, Adaptive Neuro-Fuzzy, blackouts.

1. INTRODUCTION

When power system is in stable operation at normal frequency, the total mechanical power input from the prime movers to the generators is equal to the sum of all running loads, plus all real power losses in the system. The frequency conditions of the overall...
system will directly depend on the amount of active power that the generator prime movers could deliver to the system. With a small disturbance, the frequency decay rate will be low and the turbine governor will quickly raise the steam or water to the turbine to restore the frequency, provided the system has sufficient spinning reserve. However, if the disturbance is large, like large load variations, outage of components (transmission lines, transformers, generators, etc.) causes power system blackouts [5]. Recently there was a major disturbance in Northern Region at 02.33hrs on 30-07-2012. Subsequently, there was another disturbance at 13.00hrs on 31-07-2012 resulting in collapse of Northern, Eastern and North-Eastern regional grids [15]. Due to this the frequency may fall to a dangerous value before the turbine Governor fully operated. The decrease in system frequency, which occurs very rapidly and will lead to system collapse. The important protection strategy used for this purpose is a class of protection schemes known as system protection schemes (SPS). One of the most commonly used type of system protection scheme, generally accepted after the northeastern blackout of 1965, is Under Frequency Load Shedding (UFLS) scheme.

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]. However, in recent years, centralized load shedding algorithms to enhance adaptability of the schemes has been proposed in [4]. Adaptive under-frequency load shedding based on the magnitude of the disturbance estimation is considered in [9]. S. J. Huang and C. C. Huang presented Adaptive under-frequency load shedding based on the time based for remote and isolated power system networks [16]. Other adaptive load shedding methods based on df/dt are presented in [1], [6]-[8]. The work introduces the new intelligent UFLS using adaptive neuro-fuzzy controller to decide the amount of load to be shed.

2. 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.

2.1 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
- More loads are shed than required
- Modifications to the system is costly
2.2. Under-Frequency Relay Load Shedding

Guidelines for setting up a frequency load shedding are common to both large and small systems [12]. 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. Drawbacks of this scheme are

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

2.3. Programmable Logic Controller-Based Load Shedding

A PLC-based load shedding scheme offers many advantages such as the use of an existing distributed network via the power management system, as well as an automated means of load relief. However, in such applications monitoring 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

3. MATHEMATICAL ANALYSIS OF LOAD SHEDDING:

3.1 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 and all real power losses. If, for any reason, the balance of generation and loads is disrupted, operating frequency of the system would change according to equation (1).

\[ 2H \frac{df}{dt} = P_m - P_e \]  

(1)

Where H is the inertia constant, f is the generator frequency in pu, Pm is the generator mechanical power in pu and Pe is the generator electrical power in pu.

In general, power system loads are dependent on both voltage and frequency. 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 same at all points of a power system. The frequency dependent characteristic of composite load is
expressed in equation (2).

\[ P_e = P_L + d\Delta f \]  

Where, \( d \) is load reduction factor and \( P_L \) is the load power in Pu.

### 3.2 Final Frequency

According to equations (1) and (2) if, a power system encounters with an overload case, and 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. The final frequency is given by the equation (3).

\[ f_\infty = f_0 - \left(1 - \frac{l_0}{1 + l_0} d\right) \]  

Where, \( f_0 \) is the initial normal frequency, \( f_\infty \) is the final frequency and \( l_0 \) is the amount of overload in pu.

### 3.3 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. Continuous operation of steam turbines should be restricted to frequency above 47.5Hz. 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 [13].

### 3.4. Conventional under frequency load shedding scheme

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 47.5Hz 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 equation (4) is employed in [10].

\[ LD = \frac{L}{1 + L} - d \left(1 - \frac{f}{50}\right) \]  

Where, \( LD \) is the total load which must be shed, \( L \) is the rate of overload per unit produced in the system, \( f \) is permissible settling frequency and the \( d \) coefficient is the load reduction coefficient which is related to the type of disturbance.
4. PROPOSED SYSTEM

Proposed system discusses the neural network, fuzzy logic and adaptive neuro fuzzy methods of load shedding.

4.1. Neural network

Fast and optimal adaptive load shedding method for power system is using, Artificial Neural Networks [2], [14]. The first step in the design of a NN is to determine an architecture that will yield good results. The idea is to use the simplest architecture while maximizing performance. Usually, NN architecture is determined based on subjective assessment on the part of the engineer. In order to achieve appropriate neural network training lots of neural networks have been trained and concluded that the architecture of 2 hidden layers, the first with 14 nodes and the second with 10 nodes, was best suited for this application.

Levenberg Marquardt Back Propagation technique [3] is used to train the NN. This consists of the same routine as typical back propagation with the exception that instead of one learning rate for all the NN nodes, a learning rate was assigned to each of the nodes in order to speed up convergence. The activation function used within this work is a hyperbolic tangent function and the inputs were normalized to have a mean of zero and a variance of one.

4.2 Fuzzy Logic

The generation and load data are given as inputs to the simulation system shown in Figure 1, 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 as shown in Table.3 [17].

4.3. 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.

A typical ANFIS structure with five layers and two inputs, each with two membership functions and Rule viewer in ANFIS approach is shown in Figures 2 and 3 respectively. The ANFIS has the constraint that it only supports the Sugeno-type systems of 1st 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.

Fig.1: Simulation diagram of Fuzzy Controlled Load Shedding
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 variable for the load shedding controller. The overall output of the ANFIS is the estimated amount of load shed. Here the training data is given which was collected from the Electricity Board and error is observed.

5. SIMULATION RESULTS

Figure 4 shows the training error of neuro fuzzy controller. Figures 5a, 5b and 5c show the variation of frequency during normal condition, load is greater than generation and after restoration using proposed technique respectively. Table 1 shows the inputs of the fuzzy controller (Generation and Load) by that it calculates the rate of change of frequency.
(df/dt) and the output obtained is the amount of load shed required to maintain the system to operate in a stable manner. Table 2 shows comparison of actual load shed using conventional approach with fuzzy and neuro-fuzzy.

**Fig. 4**: Training Error of Neuro-fuzzy controller

**Fig. 5a**: Variation of frequency under different operating conditions

**Fig. 5b**: Variation of frequency under different operating conditions

**Fig. 5c**: Variation of frequency under different operating conditions

**Table 2**: Comparison of load shed values of AP grid with neural, Fuzzy and Neuro fuzzy systems.

<table>
<thead>
<tr>
<th>df/dt</th>
<th>Actual value shed by AP grid</th>
<th>Neural shed value</th>
<th>Fuzzy shed value</th>
<th>Neuro fuzzy shed value</th>
</tr>
</thead>
<tbody>
<tr>
<td>-.3</td>
<td>120</td>
<td>123</td>
<td>119</td>
<td>119</td>
</tr>
<tr>
<td>-.9</td>
<td>360</td>
<td>357</td>
<td>344</td>
<td>358</td>
</tr>
<tr>
<td>-1.4</td>
<td>560</td>
<td>554</td>
<td>536</td>
<td>557</td>
</tr>
<tr>
<td>-1.8</td>
<td>720</td>
<td>717</td>
<td>695</td>
<td>717</td>
</tr>
<tr>
<td>-2.6</td>
<td>1040</td>
<td>1042</td>
<td>1000</td>
<td>1039</td>
</tr>
</tbody>
</table>
6. CASE STUDY

In the case study 220/132/33KV substation, Renigunta, AP is considered. It consists of 13 numbers of 132 KV, 6 numbers of 20KV and 7 numbers of 3KV feeders.

Table 3 & Table 4 shows the import and export details of Renigunta 220/132/33 KV substation respectively. By observing here, it is clear that the generation is lower than load, so load shedding must require to protect the grid from collapse and reduce the drastically decrease in frequency. By using these Import and Export details, neural network is trained and the amount of load shed required for maintaining the grid in stable was observed. In this work the generation and load data are given as inputs to the simulation system, 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. Table 5 shows that, the amount of load to be shed by fuzzy and neuro – fuzzy using rate of change of frequency as the input to the controller.

From the Table 6, it is observed that the required amount of load to be shed is less than the existing method of load shedding value. The amount of load shed by neural, fuzzy and neuro – fuzzy approach is very low when compared to existing method of load shed value. By this it is clear that, using proposed method energy is saved, frequency is restored and power can be supplied for more number of consumers.

Table 3: Import details of Renigunta 220/132/33 KV sub-station

<table>
<thead>
<tr>
<th>Feeder name</th>
<th>Input power</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manubolu-1</td>
<td>55MW</td>
</tr>
<tr>
<td>Manubolu-2</td>
<td>55MW</td>
</tr>
<tr>
<td>CK Palli</td>
<td>135MW</td>
</tr>
<tr>
<td>Kodur</td>
<td>70MW</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>315MW</strong></td>
</tr>
</tbody>
</table>
Table 4: Export details of Renigunta 220/132/33 KV sub-station

<table>
<thead>
<tr>
<th>Feeder name</th>
<th>Output value</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.Mngalam-1</td>
<td>72 MW</td>
</tr>
<tr>
<td>M.Mngalam-2</td>
<td>72 MW</td>
</tr>
<tr>
<td>Railway-1</td>
<td>0 MW</td>
</tr>
<tr>
<td>Railway-1</td>
<td>6 MW</td>
</tr>
<tr>
<td>Grindwel</td>
<td>10 MW</td>
</tr>
<tr>
<td>Amaraja</td>
<td>16MW</td>
</tr>
<tr>
<td>Puttur-1</td>
<td>12MW</td>
</tr>
<tr>
<td>Puttur-2</td>
<td>12MW</td>
</tr>
<tr>
<td>Tirupathi</td>
<td>50MW</td>
</tr>
<tr>
<td>Chandragiri</td>
<td>17MW</td>
</tr>
<tr>
<td><strong>Lv-1</strong></td>
<td><strong>17.6MW</strong></td>
</tr>
<tr>
<td><strong>Lv-2</strong></td>
<td><strong>12.4MW</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>324MW</strong></td>
</tr>
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</table>

Table 5: Comparisons of Actual, Neural, Fuzzy, and Neuro – Fuzzy output values

<table>
<thead>
<tr>
<th>df/dt</th>
<th>Actual difference</th>
<th>Fuzzy output</th>
<th>Neuro-fuzzy output</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.2</td>
<td>8</td>
<td>7</td>
<td>7.8</td>
</tr>
<tr>
<td>-0.4</td>
<td>16</td>
<td>14</td>
<td>15.6</td>
</tr>
<tr>
<td>-0.5</td>
<td>20</td>
<td>17</td>
<td>19.5</td>
</tr>
<tr>
<td>-0.7</td>
<td>28</td>
<td>24</td>
<td>27.5</td>
</tr>
</tbody>
</table>
Table 6: Comparing real time and project values

<table>
<thead>
<tr>
<th>Required amount of Load shed(MW)</th>
<th>Actual Load shed value(MW)</th>
<th>Neural output (MW)</th>
<th>Fuzzy output (MW)</th>
<th>Neuro-fuzzy output (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>28</td>
<td>12</td>
<td>10</td>
<td>11</td>
</tr>
<tr>
<td>20</td>
<td>28</td>
<td>19</td>
<td>17</td>
<td>19</td>
</tr>
<tr>
<td>27</td>
<td>36</td>
<td>26</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>35</td>
<td>40</td>
<td>33</td>
<td>30</td>
<td>33</td>
</tr>
</tbody>
</table>

7. CONCLUSIONS

Due to the shortage of electricity, load shedding is extremely common in India. To overcome drastically decreasing frequency of the system, usually, load shedding is performed. Automatic load shedding is required to anticipate and relieve the overloaded equipment before there is loss of generation, line tripping, equipment damage, or a chaotic random shutdown of the system.

The present work deals with under frequency load shedding. It shows greater importance in maintaining the frequency in a stable and constant manner. Stability is mainly based on recovering, rate of change of frequency to normal value. To avoid this drastically decrease of rate of change of frequency an ANFIS controller is designed to find the amount of load to be shed at demand side in order to bring back the frequency to a normal value.

The existing methods such as Breaker inter locking system, Under Frequency Relay Load Shedding, PLC based controllers are used for the load shedding. These methods are time consuming and also shed excess amount of load. Compared to other under frequency load shedding control methods, the ANFIS method/approach shows the advantages like lower value of load shedding, shorter response of time, saving more amounts of energy and benefiting more consumers. The applicability of ANFIS is tested on a case study at Renigunta 220/132/33 KV sub-station.

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AUTHORS BIBLIOGRAPHY

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