A Fast Method for Frequency Response Calculation in Under Frequency Load Shedding Scheme

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Abstract: - A simple and efficient method for load shedding based on frequency response calculation in power systems is presented in this paper. The frequency response is computed by an efficient and accurate method. This method gives an analytical expression for calculation of frequency response using parameters of power system, which is suitable for frequency response calculation. In order to test and verify the proposed method, simulations were carried out on system dynamic model. Simulation of frequency response can be done by change of load. In the simulation, a step load is used which represents changes of load in the system.

Key-Words: - Isolated power system, Load shedding, frequency response, Under frequency relay

1 Introduction
The maintenance of maximum service reliability has always been the primary concern of the electric utility industry. To attain this end, power systems are designed and operated so that for any predicted system condition, there will always be adequate generating and transmission capacities to meet load requirements in any system area. It is essential that the generation deficiency be quickly recognized and the necessary steps taken to prevent the disturbance from cascading into a major system outage.

When an isolated power system encounters a serious disturbance or a large generator trip, the system frequency may drop once the total generating power could not supply the load demand sufficiently. It is known that an isolated power system should be self-sufficient to provide security, reliability and economy of electricity. In such a system, the speed of frequency decay due to loss of generation is particularly significant. Therefore, more attention should be paid to the load shedding scheme design [1–3].

Load shedding resulting from a system under frequency event should be controlled so as to balance generation and load, permit rapid restoration of electric service to customer demand that has been interrupted, and when necessary re-establish transmission interconnection ties.

The main objective of an under frequency load shedding scheme is to quickly recognize generation deficiency within any system and automatically load shed, such that the generation-load balance is achieved and nominal system frequency is restored. To accomplish this under frequency relays are used throughout the system to drop increments of load at specific frequencies. A properly designed scheme will prevent a major system outage under various abnormal operating conditions [4].

The traditional load-shedding scheme consists of under frequency relays located at critical feeder locations. When the frequency drops below a preset value, the critical feeders are disconnected from the system. If the frequency continues to drop, other load shedding stages are activated. Some under frequency load-shedding schemes have as many as five under frequency stages set [5].

The main frequency is an important parameter of an electrical power system. The frequency can change over a small range due to generation-load mismatches. Load shedding takes place as an emergency measure in case of falling frequency conditions or loss of power generation. It is therefore important that response to emergency situations is as quickly as possible in order to achieve fast system recovery with minimum system disturbance.

In our approach, a typical load shedding scheme in five steps was applied. A special procedure is carried out in case of critical situations, where emergency control actions are defined. The method can be a helpful tool for operation planning studies, security analysis, and reliability evaluation of power systems. Simulations have been carried out in order to show the effectiveness of the proposed method.
One of the aims of this paper is to investigate load shedding problem based on frequency response calculation of the power system. This work proposes a fast and effective frequency response calculation.

2 Frequency Response Analysis

It has been shown that the frequency performance of an islanded power system can be represented by linear system frequency response model [6, 7]. The basic objective of this section is to present the development of simple methods for the rapid and sufficiently accurate assessment of dynamic power system frequency changes resulting from significant power imbalances. The main characteristic of these methods are analytical expressions for calculation of frequency response.

2.1 Proposed method

Figure 1 shows a simple block diagram for the prime mover under consideration. Based on this diagram, the transfer function \( \Delta \omega(s) \) can be determined and then transformed back into the time domain. This function can be used for dynamic studies of frequency response calculation. The model inputs consists of change in speed changer setting (\( \Delta P_{ref} \)) and change in load demand (\( \Delta P_L \)).

Model’s parameters include the gain (\( K_m \)), damping factor (\( D \)), inertia constant of the island (\( H \)), high pressure turbine power fraction (\( F_{HP} \)) and reheat time constant (\( T_{RH} \)).

\[
\begin{align*}
\Delta \omega(s) &= k \frac{N(s)}{D(s)} \\
N(s) &= \frac{1}{T_{RH} + s} \\
D(s) &= \left( \frac{D}{2HT_{RH}} + \frac{K_m}{2HRT_{RH}} \right)s + \left( \frac{K_mF_{HP}}{2HR} + \frac{D}{2H} + \frac{2}{T_{RH}} \right)s^2 + s^3
\end{align*}
\]

Once the roots are available, \( D(s) \) can be formulated in a factored form as:

\[
D(s) = \prod_{j=1}^{4} (s - z_j)
\]

where \( z_j \) : the roots of \( D(s) \).

Equation (1) can then be expanded in partial fractions to obtain:

\[
\Delta \omega(s) = k \sum_{j=1}^{4} \frac{R_j}{s - z_j}
\]

where

\[
R_j = \left. \Delta \omega(s)(s - z_j) \right|_{s = z_j}
\]

Frequency in time domain is shown as (8):

\[
f(t) = \left[ 1 - \sum_{j=1}^{4} \left( R_j \exp(z_j t) \right) \right] f_n
\]

This expression can be used to calculate the system frequency very fast and accurately.

3 Under Frequency Load Shedding

The objective of the Under Frequency Load Shedding (UFLS) program is to provide security and protection to the interconnected bulk power network by arresting frequency decay during periods of insufficient resources.

Any part of a power system will begin to deteriorate if there is an excess of load over available generation. The prime movers and their associated generators begin to decelerate as they attempt to carry the excess of the load. Tie lines to other parts of the system, or to other power systems, attempt to supply the deficiency of generation. This combination of events could provoke that the tie lines open due to overload, or the separation of various parts of the systems due to power swings, which results in an instability condition. To prevent the complete collapse of the system, under frequency relays are used to automatically drop...
loads, by following a predetermined scheme, to reduce the imbalance between the available generation and the remnant load in the affected area. To avoid damages in parts of the power system due to abnormal frequency conditions, such actions must be taken promptly and must be of sufficient magnitude to preserve critical loads, while enabling the remainder of the system to recover from the under frequency condition. The main objective of an under frequency load shedding scheme is to quickly recognize generation deficiency within any system and automatically load shed, such that the generation-load balance is achieved and nominal system frequency is restored. To accomplish this under frequency relays are used throughout the system to drop increments of load at specific frequencies. A properly designed scheme will prevent a major system outage under various abnormal operating conditions.

In our approach, a typical load shedding scheme in five steps was applied, as shown in Table 1. This scheme provides the capability to drop up to 50% of the load. In this case, large amounts of load are shed in the first three stages to restore the system frequency rapidly.

Table 1: Under frequency load shedding scheme proposed

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Time delay (Cycles)</th>
<th>Tripping delay (Cycles)</th>
<th>Load shed %</th>
</tr>
</thead>
<tbody>
<tr>
<td>59.5</td>
<td>3</td>
<td>2</td>
<td>15</td>
</tr>
<tr>
<td>59.3</td>
<td>3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>58.8</td>
<td>3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>58.6</td>
<td>3</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>58.5</td>
<td>3</td>
<td>2</td>
<td>7</td>
</tr>
</tbody>
</table>

4 Simulation Results

In order to test and verify the proposed method, simulations were carried out on system dynamic model. Simulation of frequency response can be done by change of load. In the simulation, a step load is used which represents changes of load in the system. Response of islanded configuration to change of load is shown in Figure 2.

Figure 3 shows the corresponding time with minimum frequency as a function of the amount of load being shedding. The time where the minimum occurs is not function of load.

This simulation approves that the time where the minimum frequency occurs does not depend on load. Figure 4 shows the minimum frequency as a function of the amount of load being shedding and shows the minimum frequency is a linear function of the amount of load. Therefore calculation of maximum load shedding for a given frequency decline can be carried out based on proposed frequency response calculation methods.
These results can be used in order to determine the maximum amount of load that can be safely shedding at once, when an allowable frequency is known. Therefore, the minimum frequencies $f_{1l}$ and $f_{2l}$ for two different arbitrary loads $P_1$ and $P_2$ are calculated. The maximum load that can be shedding safely is calculated by:

$$P_{\text{limit}} = P_1 + \frac{(P_1 - P_2)}{(f_{1l} - f_{2l})} (f_{\text{limit}} - f_{1l}) \quad (9)$$

where $f_{\text{limit}}$ stands for the minimum allowable frequency. This expression can be used to calculate the amount of load shedding fast and accurate. Therefore calculation of maximum load shedding for a given frequency decline can be carried out based on frequency response calculation methods. This method can select load steps fast and flexible.

In addition of table 1, the amount of load shedding usually is determined according to rate of change of frequency and maximum overload which is allowable and doesn’t need load shedding. Total amount of load shedding can be calculated by equation (10):

$$P_{\text{LS}} = \Delta P_L - \Delta P_{\text{LNS}} \quad (10)$$

$$\Delta P_L = 2H \frac{d\Delta \omega(t)}{dt} \mid_{t=0} \quad (11)$$

where

$P_{\text{LS}}$: Total amount of load shedding

$\Delta P_{\text{LNS}}$: Maximum allowable overload

$\Delta P_L$: Disturbance in generation-load

Maximum allowable overload can be calculated according to minimum frequency and it is the overload of the system that cause the minimum of system frequency reach to allowable operating frequency. This amount can be considered as initial load shedding conservatively.

4 Conclusion

Load shedding serves as the ultimate guard that protects the power system from a disturbance-induced collapse. Normally, this critical load preservation is done with the use of under-frequency relaying schemes. This paper has introduced a fast load shedding method. This method combines frequency response calculation, equipment ratings, defined model, and a knowledgebase of load shed table, to continually perform dynamic load shedding. Time domain based frequency response calculation for islands can be used in load shedding schemes.

References:


