A New Approach Applied to Adaptive Centralized Load Shedding Scheme

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Abstract: - One of major contingencies of an electric power system is due to imbalance between loads and generated power. This leads to instability in the power system and hence to a blackout. A load shedding scheme may be used to avoid such problem by reducing the total load. The aim of this work is to develop a new approach applied to an adaptive load shedding scheme using recent development technology such as wide area synchrocphasor measurement. All generator frequencies that may be measured by phasor measurement units are sent to center where a magnitude of disturbance will be calculated. These measured frequencies also will be used to determine the amount of load to be shed as well as the number of shedding steps.

Key-Words: - Power system, Adaptive load shedding scheme, Threshold power and critical power.

1 Introduction
An electric power system is a large interconnected system that produces, transmits and distributes an electric energy to different consumers. Stability of the power system is of a great concern, since it is subjected to different disturbances that may cause a local or complete system collapse if no adequate action is taken to prevent it. Therefore, many techniques have been developed to make the power system survives during disturbances and continue to operate. One common disturbance is the imbalance between generation and load due to an overload situation caused by generator outage or loss of transmission lines. Generally, this situation has an effect on frequency behavior of the system and hence the frequency decreases below the rated operating value. The system spinning reserve can compensate small overload, whereas large one requires rapid emergency control actions to be taken by under frequency load shedding schemes that trip temporary certain loads in order to balance the system and consequently recover the nominal operating frequency.

2 Load Shedding Scheme
Under frequency load shedding scheme is the most commonly used control system to balance the generation and load (power demand) and it is the last control step for preventing electric power system from blackouts. It deals with shedding the appropriate amount of load for removing the overload situation. This may be performed in many steps with each step having its own setting frequency and percent of load to be shed. The most important requirements taken into account when dealing with load shedding are:

- the minimum allowable frequency for secure system operation (generator and steam turbine can properly operate above 47.5 Hz),
- the amount of load to be shed (small amount can be compensate by spinning reserve and no load shedding is required),
- the frequency settings (from 49.5 to 47.5 Hz),
- the number and size of steps (from 3 to 5 steps).

In order to satisfy these above mentioned requirements many algorithms have been developed such as our proposed one.

2.1 Load Shedding Scheme Types
Three main types of load shedding schemes may be distinguished: traditional (conventional), semi-adaptive and adaptive load shedding scheme [1]. Traditional load shedding scheme that is simple deals with shedding a given percent of load whenever frequency falls below a frequency setting value. The
values of the frequency setting and the amount of load to be shed for each step are determined off line, which are based on the experiences and the simulations.

Semi-adaptive load shedding scheme is almost similar to the traditional one, but the main difference is that a rate of frequency change \( \frac{df}{dt} \) is measured when a frequency setting is reached and accordingly the amount of load to be shed is determined. The amount to be shed depends on the rate of frequency decline, the higher rate needs the larger the amount of load is shed. Usually, the measure of the rate of frequency change is performed at first frequency setting.

In adaptive load shedding scheme, the amount of load as well as the percent of load to be shed in each step are selected adaptively according to the magnitude of the disturbance. The latter is determined using the initial rate of frequency decline and is based on the System Frequency Model (SFR) [2]. From the reduced SFR model, the relation between the frequency decline and the size of the disturbance \( P_d \) is obtained as follows:

\[
\frac{df}{dt} = \frac{P_d}{2H_{sys}} , \text{ (Hz/s)}
\]

(1)

where \( P_d \) is the disturbance magnitude in per unit, and \( H_{sys} \) is the inertia constant of the system, in seconds.

### 2.2 Load Shedding Scheme Architecture

Load is typically shed by opening the circuit breakers that installed at the terminals of the feeders in the distribution substations. The architecture of load shedding schemes can be: local, distributed or centralized [3].

A) Local Load Shedding

All decisions of load shedding are made locally in each associated distribution substation, where one or more under frequency relays are installed. The feeder breakers are tripped based on the logic incorporated in the circuitry of the substation.

B) Distributed Load Shedding

Distributed load shedding is like the local load shedding, the decisions of the breakers tripping are made locally in the individual distribution substations. However, in the distributed load shedding scheme, each feeder is equipped with its own under frequency relays.

C) Centralized load shedding

It is similar to the local load shedding, one or more under frequency relays are connected to busses in the distribution substations. But, in centralized load shedding, each under frequency relay output information is sent back to a central location where processed by a computer program, which is used to perform the overall load shedding. Decision is then sent from the central station to the distribution substation to trip breakers as selected by the computer control program.

### 3 A Proposed Algorithm

In this paper, a new approach which is applied to the adaptive centralized under-frequency load shedding scheme is described. The frequencies measured by Phasor Measurement Unit (PMU) [4] are used for calculating the rate of change of frequency as well as the magnitude of the disturbance in the power system.

The advantage of this approach, as compared to the conventional under-frequency load shedding scheme, is to estimate the magnitude of overload occurring from different disturbances and accordingly to determine the necessary amount of load to be shed as well as the size and frequency setting of each shedding step. Therefore, it avoids unnecessary shedding actions.

#### 3.1 Determination of the disturbance magnitude

After measuring the frequency by PMU at each generator in the power system, the rate of frequency decline of each generator is determined in the center, and then the system mean frequency decline of the system is calculated according to the following formula [5]:

\[
\frac{df_c}{dt} = \frac{\sum_{i=1}^{n} f_i H_{c_i}}{\sum_{i=1}^{n} H_i} , \text{ (Hz/s)}
\]

(2)

Where: \( df_c/dt \) is the rate of mean frequency decline, and \( df_i/dt \) is the rate of generator \((i)\) frequency decline, and \( H_i \) is the inertia constant of generator \((i)\).

Then, once the mean rate of frequency decline \( \frac{df_c}{dt} \) is known, the size of the disturbance in the system may be determined using the following formula [6]:

\[
P_d = 2H_{sys} \frac{df_c}{f_n} , \text{ (pu)}
\]

(3)

Where \( f_n \) is the nominal frequency of the system in hertz (50Hz), and \( H_{sys} \) is the equivalent inertia constant (in second) of the system given by the following formula[2]:

\[
H_{sys} = \sum_{i=1}^{n} \frac{S_i H_i}{\sum_{i=1}^{n} S_i} , \text{ (MVA)}
\]

(4)

Where: \( S_i \) is the rated apparent power of generator \((i)\), and \( n \) is the total number of generators.

#### 3.1 Determination of the disturbance condition and the load shedding parameters:

After the disturbance is estimated using (3), its condition is determined by comparing it to two specific values which are threshold power \((Pth)\) and critical power \((Per)\), where:

The threshold power \((Pth)\) is the amount of overload at which the minimum curve of the frequency response of the weakest generator in the power system reaches the critical value of frequency 47.5 Hz. [1],[7],[8]. This value is determined using the SFR (Slow Frequency Response) of the system.
(synchronized interconnected generator system) following the same procedure explained previously for the threshold power determination. Therefore, the estimated disturbance $P_d$ is compared to both the critical and threshold powers and the condition of the power system as illustrated in Fig. 1 is determined as follows:

1. If $P_d \leq P_{th}$: “No load shedding is required”
   - The disturbance is not dangerous for the power system, and the frequency decline can be recovered by the system spinning reserve. Thus, no load shedding is required in this case.

2. If $P_{th} \leq P_d \leq P_{cr}$: “small disturbance range”
   - The disturbance is small
   - Determine the frequency setting and the size of the two steps of load shedding
   - Shed load in two steps
   - 1

3. If $P_{crit} \leq P_d \leq P_{th}$: “The disturbance is large”
   - Determine the frequency of shedding
   - Shed Load in one Step
   - $P_{step} = P_{Shed}$

4. If $P_{d} > P_{th}$: “The disturbance is very small, no load shedding is applied”

Figure 1. The flowchart of the proposed algorithm
The disturbance is ranged as small disturbances, and under this condition the shedding is performed in two steps. The size of load to be shed is determined using this formula [2]:

\[ P_{sh} = 1.05(P_d - P_h), \quad \text{(pu)} \]  \hspace{2cm} (5)

The term \((P_d - P_h)\) is multiplied by the correction factor 1.05 in order to take into account the delay in initiating the various steps of load shedding [9].

The size and frequency setting of each step are determined as follows:

Step 1: The size of load shedding in this step is

\[ P_{sh1} = \frac{1}{3}P_{sh}, \quad \text{(pu)} \]  \hspace{2cm} (6)

Where \(P_{sh1}\) is the size of load shed in the first step.

Step 2: The remaining load \(P_{sh2}\) to be shed which is tripped in this step, is:

\[ P_{sh2} = \frac{2}{3}P_{sh}, \quad \text{(pu)} \]  \hspace{2cm} (7)

The setting frequency of both steps can be determined using the following expression [10]:

\[ f(t) = f_c \left(1 + \frac{P_d}{D} \left(1 - \exp \left(\frac{-D}{2H_{sys}} t\right)\right)\right), \quad \text{(Hz)} \]  \hspace{2cm} (8)

Where \(D\) is the load damping factor.

After performing these two steps of load shedding, the disturbance is brought back to the range of “very small disturbances” where no more shedding is required. If \(P_d \geq P_{cr}\) : “Large disturbance range”

In this case, the amount of disturbance is in the range of large disturbances, the algorithm starts by shedding the overload in three steps:

Step 1: The size of disturbance is reduced first to a value less than to the critical power and hence bring the disturbance to the range of small disturbances \((P_h \leq P_d \leq P_{cr})\), and the frequency is brought to a value above the critical frequency (47.5Hz).

The amount of load to be shed in this step is:

\[ P_{sh3} = 1.05(P_d - P_{cr}), \quad \text{(pu)} \]  \hspace{2cm} (9)

The term \((P_d - P_{cr})\) is multiplied by the correction factor 1.05 for the same reason explained before. This value of \(P_{sh3}\) is shed in one step.

The setting frequency of this step is set at 49.5 Hz, and the setting frequencies of the second and third steps may be determined by the same procedure previously described.

After performing the first step of load shedding, the disturbance is brought back to the small disturbance range and the size of this new disturbance \((P_d')\) is:
Now, the steps of the small disturbance case stated above are performed, and the necessary amount of load to shed is obtained as follows:

\[ P_{\text{sh}} = 1.05(P_{\text{th}} - P_{\text{th}}) \]  \hspace{1cm} (pu)  \hspace{1cm} (11)

The sizes of step2 and step3 are \( \frac{1}{3}P_{\text{th}} \) and \( \frac{2}{3}P_{\text{th}} \) respectively.

4 Simulation Results and Discussion

To test and evaluate the proposed algorithm, a model of IEEE-9 bus power system shown in Fig.2 is used, where the power flow from one bus to another is indicated as well as the size of each load and the generating capacity. The table I gives the different parameters of the three generators that are used for plotting the system frequency response using the SFR model.

At the beginning, the threshold power (Pth) and the critical power (Pcr) are determined using SFR model. These values are 171.9525 MW and 244.0250 MW respectively. Generator 3 has the smallest inertia constant and rated generating power capacity, and hence it is very sensitive to frequency decline (caused by considerable disturbances) as compared to the two other generators. Therefore, the threshold power Pth is obtained using the parameters of this weakest generator.

<table>
<thead>
<tr>
<th>Generator</th>
<th>Gen. 1</th>
<th>Gen. 2</th>
<th>Gen. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volt Ampere (MVA)</td>
<td>247.5</td>
<td>192.0</td>
<td>128.0</td>
</tr>
<tr>
<td>Power factor (PF)</td>
<td>0.9</td>
<td>0.85</td>
<td>0.85</td>
</tr>
<tr>
<td>Inertia constant (H)</td>
<td>9.55</td>
<td>3.33</td>
<td>2.35</td>
</tr>
<tr>
<td>Droop factor (R)</td>
<td>0.06</td>
<td>0.05</td>
<td>0.08</td>
</tr>
<tr>
<td>High Pressure Power</td>
<td>0.2</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Reheat Time Constant</td>
<td>8</td>
<td>7</td>
<td>5</td>
</tr>
<tr>
<td>Damping Factor (D)</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Mechanical Power Gain</td>
<td>0.95</td>
<td>0.9</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table I: The generation unit parameters of the system model.

It can be noticed that the system model behaved in an adaptive manner to the different disturbance sizes, and the system frequency drop was stopped before reaching the critical frequency value 47.5 Hz as shown in Figs.5-7. However, the main task of this scheme is to stop the frequency decline rapidly and let the time to the spinning reserve to act in order to recover the frequency to the nominal value. At the end of the load shedding action,

\[ P_d = P_{\text{th}} \]  \hspace{1cm} (pu)  \hspace{1cm} (10)

constant and rated generating power capacity, and hence it is very sensitive to frequency decline (caused by considerable disturbances) as compared to the two other generators. Therefore, the threshold power Pth is obtained using the parameters of this weakest generator.
the system frequency is brought to a safe margin (around 49.2 Hz) and the size of the disturbance is reduced to a value less than the threshold power, and hence the disturbance is reduced from the small or large disturbance range to the very small disturbances range which can be removed by the spinning reserve without any further load shedding action.

5 Conclusion

In this work, one application of PMU in power system has been described which is the implementation of an adaptive load shedding scheme. Because in this type of load shedding the amount of load to be shed is determined adaptively according to the size of the disturbance and hence avoids excess load to be shed. The obtained simulation results are satisfactory. The first frequency setting of the proposed adaptive centralized load shedding scheme is set to 49.5 Hz in order to allow the frequency decline to be arrested far before reaching the critical frequency. The other frequency settings are determined automatically according to the last value of shedding frequency.

The advantage of this method is that the amount of load to be shed is not large for all the disturbances unlike the conventional one. Therefore, unnecessary shedding is avoided which allows both a better service to different consumers and the system collapse prevention.

References: