Adaptive Underfrequency Load Shedding design based on
generation losing estimation using Artificial Neural Network
method

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Abstract. Under Frequency Relay (UFR) is used to prevent the frequency instability of a
generation outage by balancing the load with the supply. The approach of this paper is to design
an Adaptive Under Frequency Load Shedding (AUFLS) model in power system simulation
software by estimating the magnitude of losing generation using artificial neural network (ANN)
based on the early response of frequency after the disturbance occurred then the shed loads will
be obtained based on this value estimation. The New England IEEE 39 bus system is used for
this dynamic simulation. There are three operation scenarios planned with different dispatches of
the generators, each generator is simulated by removing it from the system then the frequency
system response is used as training data for the ANN model. The analysis is performed by
comparing the frequency response of the system using Conventional 4 Steps Under Frequency
Relay Load Shedding (UFLS) and the Adaptive Under Frequency Load Shedding (AUFLS). The
results show that the frequency response after disturbance using the Adaptive Under Frequency
Load Shedding (AUFLS) revert to the initial frequency closer and faster than using Conventional
4 Steps Under Frequency Relay Load Shedding (UFLS).

1. Introduction
Frequency system becomes one of the electrical quality indicators that must be maintained at nominal
frequency 50 Hz. Frequency shows the balance between load and supply, if the supply greater than load,
the frequency will be increased over the nominal frequency, otherwise if the load greater than the supply,
the frequency will be decreased under the nominal frequency. The power imbalance between load and
supply could be occurred because the loss of the generator the load. One of the efforts that conducted in
solving under frequency phenomena is Under Frequency Relay Load Shedding, where several loads will
be removed from the system based on the initial calculation to balance with the supply [1-4].

Figure 1. The power imbalance between supply and load that illustrate the under frequency phenomena.
This study will be focused on the under frequency phenomena (Figure 1), where there is an improvement in determining the power imbalance or the magnitude of the loss of generation using Artificial Neural Network (ANN) that process the training data from the response frequency that known before. The 3 operating scenarios with 30 different generator dispatches, where each generator outage is prepared as the training data to construct the ANN model then the testing is conducted by simulating the generator outage in the power system simulation software, its frequency response system is tested to the ANN model using the numerical calculation software, the output will be used by the load shedding algorithm in the power system simulation software to balance the frequency [5-8].

2. Problem formulation

The power imbalance $\Delta$ or the magnitude of the loss generator estimated by the generator swing equation:

$$\frac{2H_i}{f_n} \frac{df_i}{dt} = P_{mi} - P_{ei} = \Delta P_i$$

By avoiding the inertia $H_i$, where $P_{ei}$ is the electric power, $P_{mi}$ is the mechanical turbine power, with the assumption the electrical power is load while the mechanical turbine power is supply, it can be known that frequency rate change or frequency decline $\frac{df_i}{dt}$ is power imbalance $\Delta P$, so the idea of this study is to balance the frequency by removing the loads as much as the loss of generation.

Next step is to design the AUFLS, it involves The Power System Simulation Software to conduct the dynamic simulation and The Numerical Calculation Software to conduct the ANN process, there is a data exchange between that software, The Numerical Calculation Software needs the frequency response to be processed in ANN model construction, while The Power System Simulation Software needs the output of the ANN model as the input for the Load Shedding.

![Figure 2. The adaptive under frequency load shedding (AUFLS) algorithm.](image)

The AUFLS algorithm (Figure 2) can be explained as following steps below:

- Step 1: Prepare the training data, collect the frequency response of each generator outage from the 30 different dispatch generator of The New England IEEE 39 Bus System using Power System Simulation Software (Table I)
- Step 2: Construct the ANN model from the training data in the Numerical Calculation Software (Figure 4)
- Step 3: Conduct the generator outage simulation in the Power System Simulation Software
- Step 4: Plot and observe the frequency response.
- Step 5: The Numerical Calculation Software will read the frequency response continuously to detect when the outage occurred then grab the frequency a few seconds later. This sample will be tested with the ANN model (Figure 5)
• Step 6: The output of the ANN model which is the estimation of the loss of generator will be read by the Load Shedding Algorithm in the Power System Simulation Software.
• Step 7: The AUFLS will release the loads appropriate with the output of the ANN model.
• Step 8: Plot and observe the frequency response after AUFLS

![Figure 3](image)

**Figure 3.** The training methods of ANN Model construction.

Artificial Neural Network (ANN) is used for estimating the magnitude of the loss of generator. The ANN Toolbox is used to generate the model. The data training is obtained from the frequency response of 30 dispatch generators (**Figure 7**). The training method used the Bayesian Regularization (**Figure 3**), while the hidden layer used 10 layers.

![Figure 4](image)

**Figure 4.** The ANN model construction process.

![Figure 5](image)

**Figure 5.** The exchange data between power system simulation software and numerical calculation software during the AUFLS process.

The New England IEEE 39 Bus System is tested for this study; it consists of 39 buses with 10 generators.
Table 1: The 30 different dispatch generator of training data.

|      | Op.Scenario 1 | Op.Scenario 2 | Op.Scenario 3 |
|------|---------------|---------------|---------------|
| G 01 | 1000 (Disp.1) | 700 (Disp.11) | 2000 (Disp.21) |
| G 02 | 521.2 (Disp.2) | 571.8 (Disp.12) | 495.7 (Disp.22) |
| G 03 | 650 (Disp.3) | 650 (Disp.13) | 598 (Disp.23) |
| G 04 | 632 (Disp.4) | 670 (Disp.14) | 600 (Disp.24) |
| G 05 | 508 (Disp.5) | 500 (Disp.15) | 300 (Disp.25) |
| G 06 | 650 (Disp.6) | 600 (Disp.16) | 650 (Disp.26) |
| G 07 | 560 (Disp.7) | 450 (Disp.17) | 550 (Disp.27) |
| G 08 | 540 (Disp.8) | 500 (Disp.18) | 550 (Disp.28) |
| G 09 | 830 (Disp.9) | 800 (Disp.19) | 300 (Disp.29) |
| G 10 | 250 (Disp.10) | 700 (Disp.20) | 100 (Disp.30) |

Table 1 shows 30 dispatch generators that will be simulated to be removed from the system, while each system frequency response will be made as training data to construct the ANN model is showed in Figure 6. There are three time-sampling of data training to grab the frequency response after the outage occurred, 9s, 3s, and 2s. The comparison of those time sampling is shown in Table 3. From the result, it can be known that 3s time sampling is the best that delivers the smallest error value. So, the training data will use 3s after the outage to construct the ANN model.

Figure 6. The frequency response of 30 Dispatch generator as ANN model training, (a) 9s data training after the outage, (b) 3s data training after the outage, (c) 2s data training after the outage.

3. Step Under Frequency Load Shedding (UFLS)

The 4 Step Under Frequency Load Shedding (UFLS) is the conventional UFLS protection method that most used to prevent power system collapse due to the imbalance of frequency. The load is adjusted to match the generation supply. This method is set the static amount of shedding load due to the frequency setting step that defined before. When the system frequency falls below the frequency step setting, the UFLS is performed to do the load shedding. The illustration of 4 Step Under Frequency is shown in Figure 7. There are four step frequency settings and its amount of shedding load (Table 2) is equal in every step, which consideration is the frequency could be balanced as fast as possible.
Figure 7. Four step UFLS illustration.

Table 2. Four steps UFLS frequency setting.

|       | Frequency (Hz) | Load Trip (%) | Delay (s) |
|-------|----------------|---------------|-----------|
| Step 1 | 49.2           | 10            | 0.1       |
| Step 2 | 49.0           | 10            | 0.1       |
| Step 3 | 48.8           | 10            | 0.1       |
| Step 4 | 48.6           | 10            | 0.1       |

4. Adaptive Under Frequency Load Shedding (AUFLS)

The idea of the Adaptive Under Frequency Load Shedding (AUFLS) is to determine accurately the power imbalance or the amount of the loss of generator that becomes the input value for the load shedding algorithm to release the load as much supply that lost.

Table 3. Simulation result with several time-sampling training.

|       | Out (MW) | 9s Training | 3s Training | 2s Training |
|-------|----------|-------------|-------------|-------------|
|       | Est. (MW) | Error (%)   | Est. (MW)   | Error (%)   | Est. (MW) | Error (%) |
| G 02  | 538      | 545         | -1.20       | 536         | 0.41      | 547       | -1.58     |
| G 03  | 500      | 509         | -1.81       | 502         | -0.40     | 510       | -2.10     |
| G 04  | 550      | 545         | 0.75        | 541         | 1.63      | 540       | 1.81      |
| G 05  | 370      | 357         | 3.35        | 369         | 0.06      | 373       | -0.81     |
| G 06  | 500      | 486         | 2.64        | 505         | -1.05     | 509       | -1.90     |
| G 07  | 300      | 311         | -3.87       | 310         | -3.65     | 322       | -7.42     |
| G 08  | 425      | 447         | -5.34       | 438         | -3.19     | 443       | -4.40     |
| G 09  | 600      | 606         | -1.00       | 609         | -1.6      | 601       | -0.18     |
| G 10  | 850      | 855         | -0.69       | 891         | -4.84     | 908       | -6.91     |

5. Simulation result

The simulation result is showed in Figure 8 and Figure 9. The dotted line shows the result of Adaptive Under Frequency Load Shedding (AUFLS) while the solid line shows the result of 4 Step Under Frequency Relay Load Shedding. Figure 9 shows the frequency response when generator G 02 is
removed from the system, figure 10 shows the frequency response when generator G 08 is removed from the system, and Figure 11 shows the frequency response when generator G 09 is removed from the system.

From those figures, it can be seen that the frequency response after the outage of a generator when using AUFLS is faster and closer to the steady-state of initial frequency 50 Hz than 4 Step UFR. Figure 8 shows AUFLS revert to the steady in 20 s, which frequency is 50.053 Hz, while 4 Step UFR revert to the steady in 30 s which frequency is 49.743 Hz. Figure 9 shows AUFLS revert to the steady in 20 s which frequency is 50.009 Hz, while 4 Step UFR revert to the steady in 30 s which frequency is 49.815 Hz.

**Figure 8.** Frequency response during the outage of G 02.

**Figure 9.** Frequency response during the outage of G 08.
6. Conclusion
In this paper, the improvement of the magnitude of generation losing estimation used in an AUFLS plan is presented. Through the frequency response data, we can predict earlier in 3s after the outage how much the loss of generation that occurred, so that the load shedding algorithm could remove the accurate number of load, so that the supply and the load will be balance and the frequency can revert faster and closer to the initial frequency 50 Hz after the outage occurred.

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