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# Adaptive under frequency load shedding using synchrophasor measurement

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***Abstract -***
*The imbalance between the generation and the demand is the major factor that causes frequency instability in a power system. Conventional Under frequency Load Shedding (UFLS) is used to balance between generation and load when under frequency conditions occur. It sheds a fixed, predetermined amount of load irrespective of disturbance location. However, in the adaptive UFLS can be implemented by using synchrophasor measurements.*

*In this paper, measurement is taken from detailed time domain simulation using PSAT, by assuming that PMUs are located in all buses to implement adaptive UFLS. This paper presents adaptive UFLS based on real time domain simulation of IEEE39-bus system.*

*The results obtained shows that the adaptive UFLS scheme curtails the load based on voltage dip and restored the frequency.*

***Keywords –*** WAMS; adaptive UFLS

## I. INTRODUCTION

Power systems have evolved through continuing growth in interconnections, use of new technologies and controls, and the increased operation in highly stressed conditions, different forms of system instability have emerged. For example, voltage stability, frequency stability and inter area oscillations have become greater concerns than in the past [1].

Synchronized phasor measurements have become an important component of wide area measurements in power systems. Since phasor measurement units (PMUs) provide voltage and current phasors synchronized with high precision to a common reference of the global positioning system (GPS), they facilitate a number of wide-area applications including measurement-assisted state estimation, adaptive protection, remedial action schemes (RAS), improved system analysis and control, and many others. [4]

Load shedding is used to stabilize the frequency as well as voltage of the system. Load shedding requirement in the system has been calculated based on computed disturbance power as well as the voltage stability condition of the system,with the aid of real-time data, assumed to be available from the synchrophasor based wide area monitoring and control system (WAMCS) .

## II. FREQUENCY STABILITY

Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. It depends on the ability to maintain/restore equilibrium between system generation and load, with minimum unintentional loss of load. Instability that may result occurs in the form of sustained frequency swings leading to tripping of generating units and/or loads. Severe system upsets generally result in large excursions of frequency [3]. Various schemes are used to recover the system frequency. Load shedding is one of the method used for frequency stability. Typical under frequency threshold value settings are 57-58.5 for a 60Hz system.[2]

## III. LOAD SHEDDING

Load shedding is an emergency control action to ensure system stability, by curtailing system load. The emergency Load shedding would only be used if the frequency/voltage falls below a specified frequency/voltage threshold. Typically, the Load shedding protects against excessive frequency or voltage decline by attempting to balance between real and reactive power supply and demand in the system. Most common Load shedding schemes are the UFLS schemes, which involve shedding predetermined amounts of load if the frequency drops below specified frequency thresholds [5].

There are three load shedding schemes are explained here

1. Traditional
2. Semi adaptive
3. Adaptive

The traditional scheme sheds a certain amount of the load under relief when the system frequency falls below a certain threshold. In this scheme, large amount of load has been shed. The values of the thresholds and the relative amounts of load to be shed are decided off-line, on the base of experience and simulations.

The semi-adaptive scheme measures $df/dt$ when a certain frequency threshold reached. According to that value, a different amount of load is to shed. In other words, this scheme checks also the speed at which the threshold exceeded: the higher this speed is, the more load is shed. Usually, the measure of the ROCOF is evaluated only at the first frequency threshold, the following ones being traditional.

Adaptive UFLS schemes, which uses the frequency derivative .The initial value of the ROCOF is proportional to the ratio of the size of the disturbance $P_{step}$ to inertia constant multiplied by two. The measure of the initial ROCOF is through H - a backward estimate of the disturbance and consequently an adequate countermeasure in terms of load shedding can be operated.

$$\left.\frac{df}{dt}\right|_{t=0} = \frac{P_{step}}{2H}$$

Where $f$ is expressed in per unit on the base of nominal frequency (50 or 60 Hz) and $P_{step}$ is in per unit on the total MVA of the whole system.

In case of a sudden under frequency conditions appearance in the power system only a centralized gathering of measurements and global actions (e.g. use of so-called WAMC technology – Wide Area Measurement and Control) can represent an appropriate approach to a global problem. In such circumstances, under frequency load shedding is often the last resort tool for avoiding a total power system blackout.

## IV. PSAT(POWER SYSTEM ANALYSIS TOOLBOX )

PSAT is a MATLAB toolbox for static and dynamic analysis and control of electric power systems. PSAT includes power flow, continuation power flow, optimal power flow, and small signal stability analysis and time domain simulation. All operations can be assessed by means of graphical user interfaces (GUIs) and a Simulink-based library provides an user-friendly tool for network design.

PSAT core is the power flow routine, which also takes care of state variable initialization. Once the power flow has been solved, further static and/or dynamic analysis can be performed. These routines are:

1. Continuation power flow
2. Optimal power flow
3. Small signal stability analysis;
4. Time domain simulations;
5. Phasor measurement unit (PMU) placement

## V. PROPOSED ADAPTIVE UNDER FREQUENCY LOAD SHEDDING SCHEME

Adaptive under frequency load shedding scheme is used to restore frequency stability and prevent the probable consequent voltage instability that can occur after a major disturbance caused by a generator outage. This algorithm is implemented by using frequency and voltage variables gathered from different locations of the power system to decide the optimum amounts and locations of load to be shed in order to restore system stability. The proposed load-shedding algorithm monitors the system frequency and voltages at load buses continuously. When it senses any generation load unbalance that may lead to frequency instability, it performs the following steps:

### 1. Estimation of the Total Load to be Shed [6]

The magnitude of the disturbance power is the amount of unbalance between the generated and demanded active power. The measured frequency of local generator bus cannot provide enough information all the system. The concept of COI (centre of inertia) has been widely used in electric power systems .The disturbance power or power mismatch for each generator in the system is calculated using the generator swing equation

$$\Delta P_i = P_{mi} - P_{ei} = \frac{2H_i}{f_n}\frac{df_i}{dt} \qquad (1)$$

Where

$\Delta P_i$ Power mismatch of generator in per unit;

$P_{mi}$ Mechanical turbine power of generator in per unit;

$P_{ei}$ Electrical power of generator in per unit;

$H_i$ Inertia constant of generator in seconds;

$f_n$ System-rated frequency in hertz;

$f_i$ Generator frequency in hertz.

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The total disturbance power in the system that has N generators is equal to the addition of all online generators' disturbance power and is represented by

$$\Delta P = \sum_{n=1}^{N} \Delta P_i = 2\sum_{i=1}^{N} H_i \times \frac{\frac{df_c}{dt}}{f_n} \qquad (2)$$

$\Delta P$ Total disturbance power in the system (in per unit);
$f_c$ Center of Inertia (COI) frequency in hertz.

$$f_c = \frac{\sum_i^N H_{i\_sys} f_i}{\sum_i^N H_{i\_sys}} \qquad (3)$$

$H_{i\_sys}$ Inertia constant of generator in seconds based on a common system base.

$$H_{i\_sys} = \frac{H_{i\_sys} \times S_i}{S_{base\_sys}} \qquad (4)$$

$S_i$ Apparent power of generator in megavolt-amperes;
$S_{base\_sys}$ System base in megavolt-amperes.

### 2. Calculation of the Amount of Load to be Shed at Each Candidate Load Bus

The total amount of overload is distributed among the load buses. The load buses should be ranked according to their voltage dip; higher ranked buses are selected to share the amount of load shed. When frequency reaches below to its set value i.e. 59.5Hz

The amount of load to be shed at each candidate bus is calculated using (5) and is proportional to the voltage dip of that bus due to the disturbance (the greater the voltage drop at bus, the more load will be shed at that bus) .Voltage dip has been calculated by taking 1 second before and 1 second after the disturbances.

$$P_{shed\_i} = \left(\frac{\Delta V_i}{\sum_{i\in N_L} \Delta V_i}\right) \times \Delta P \qquad (5)$$

$P_{shed\_i}$ Power to be shed from the load bus;
$\Delta P$ Total amount of power to be shed from the system;
$N_L$ Number of load buses;
$\Delta V_i$ Voltages dip at the load bus

## VI. SIMULATION RESULT AND DISCUSSION

Effectiveness of the proposed load-shedding scheme has been tested on 39-bus New England system [7], a simplified representation of 345 kV transmission system having 10 generators and 29 load buses. Fig. 1 shows the single line diagram of the system. The threshold value of frequency has been chosen for load shedding 59.5Hz. At this frequency, load shedding has been started.

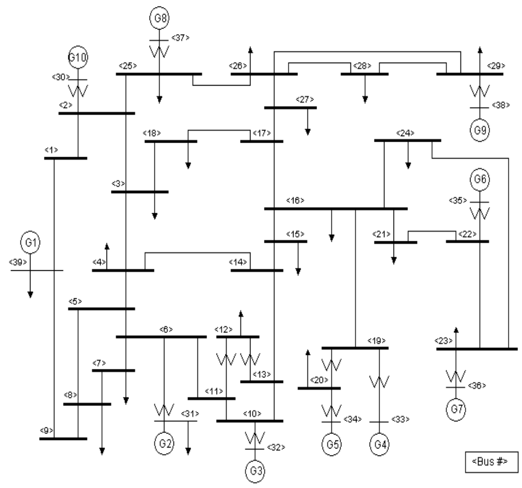

Figure:1-IEEE 39 bus system

Two generators were selected to be taken out. Therefore two test cases were performed. In each case, a generator outage is performed in real time. The disturbance power is calculated by swing equation written in MATLAB. Fault or disturbance created using Fault.con and breakers are connected using Breaker.con. Initialized the PSAT using MATLAB, then run power flow and time domain simulation. Shed the load by using perturbation file in PSAT.

**1. Test Case: Outage on Generator-3(bus 32)**

Generator G3 Generates 650 MW during normal operating conditions before the disturbance. When Generator G3 was tripped off in real time, by opening its circuit breaker, the power generated from G3 dropped to zero, and its speed increased beyond 60 Hz. As the frequency of system goes below 59.5 Hz. Some controlling action has to taken. Figure-2 shows the frequency response of disturbed system. To restore the system frequency load to be shed, for this perturbation file in PSAT is used .The amount of the load to be shed has been calculated by equation (2) in MATLAB was 432.48 MW. The location of load shedding is decided according to their voltage dip calculated by using equation (5). Table -1 shows the amount of load shed among the busses. After load shedding, frequency response is as shown in figure-3.

**TABLE: 1-TEST CASE -1**

| Bus No. | Voltage dip | Amount of load shed(MW) |
|---|---|---|
| 15 | 0.0269 | 158.7137 |
| 7 | 0.0164 | 96.7622 |
| 8 | 0.0154 | 90.8621 |
| 12 | 0.0146 | 86.1420 |

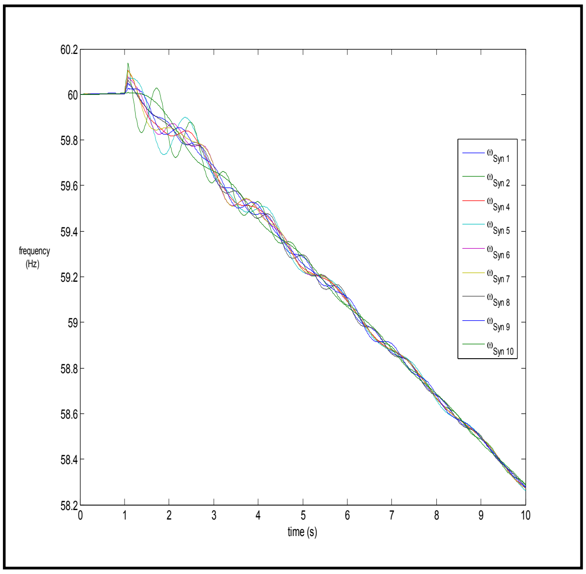


Figure: 2- Frequency of disturbed system Test case 1

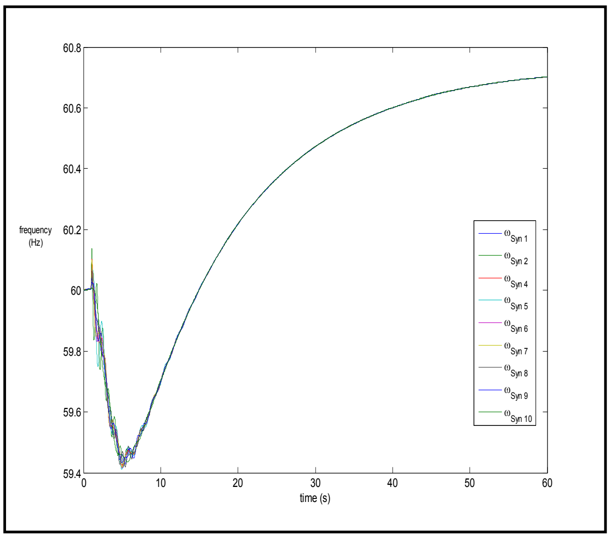


Figure :3- Frequency of recovered system Test case 1

## 2. Test Case: Outage of Generator-4(bus 33)

Generator G4 generates 632 MW during normal operating conditions before the disturbance. When Generator G4 was tripped off in real time, by opening its circuit breaker, the power generated from G4 dropped to zero, and its speed increased beyond 60 Hz. As the frequency of system goes below 59.5 Hz. Some controlling action has to taken. Figure-4 shows the frequency response of disturbed system. To restore the system frequency load to be shed, for this perturbation file in PSAT is used .The amount of the load to be shed has been calculated by equation (2) in MATLAB was 432.48 MW. The location of load shedding is decided according to their voltage dip calculated by using equation (5). Table -2 shows the amount of load shed among the busses. After load shedding, frequency response is as shown in figure-5

**TABLE-2: TEST CASE -2**

| Bus No. | Voltage dip | Amount of load shed(MW) |
|---|---|---|
| 10 | 0.0406 | 167.6292 |
| 8 | 0.0145 | 59.8676 |
| 13 | 0.0138 | 56.9774 |
| 11 | 0.0122 | 50.3713 |

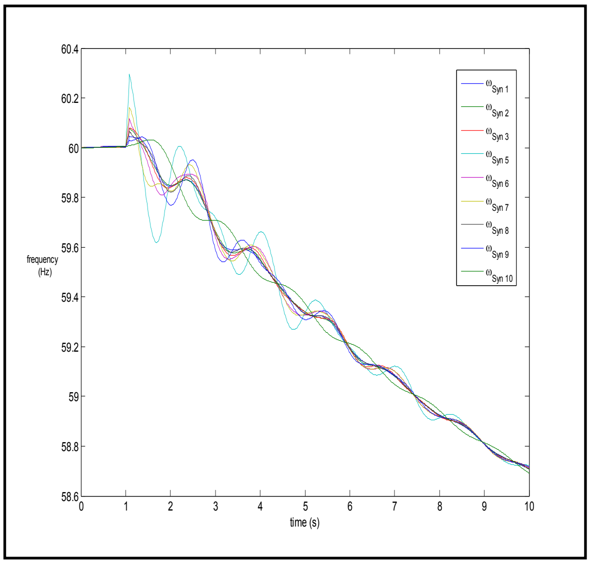


Figure: 4- Frequency of disturbed system Test case 2

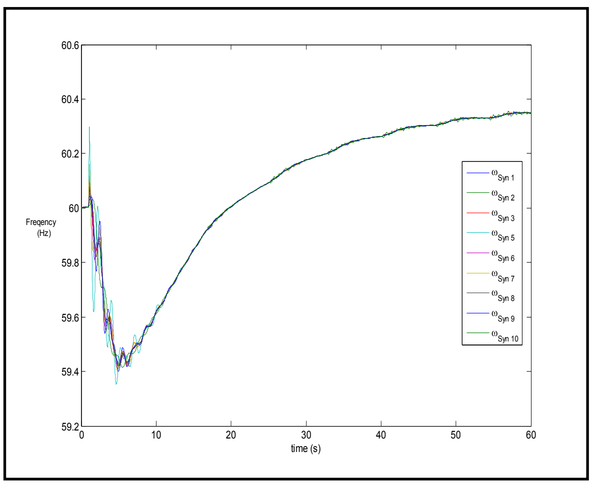


Figure:5- Frequency of recovered system Test case 2

## VII CONCLUSION

In this paper, an adaptive UFLS scheme has been proposed. This proposed scheme ensures frequency stability utilizing real-time measurements, assumed available through synchrophasor based Wide Area Measurement System (WAMS). This scheme initiates control actions for frequency instability by estimating the magnitude of disturbance in real-time and chooses control locations based on a voltage dip calculated at each load bus when frequency goes below a specified value. This scheme has been test on 10-machineNew England 39-bus system

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