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# An Artificial Neural Network Based Approach for Forecasting the Frequency of Power Grid to Achieve Optimal Frequency Stabilization

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**ABSTRACT:** Significant involvement of soft computing techniques like neural network and neuro-fuzzy system, leads to the computation of different parameter in advance for the purposes like safety, operation, expansion, risk management, market analysis, etc. A large variety of approaches have been developed in load and electricity price forecasting using the neural network techniques with appreciable accuracy. Still, the frequency is the parameter of the power grid which is not forecast. It is also believed that the frequency is somewhat the constant parameter and need not be forecast which never attracted the attention of research analysts. Random and fast switching of load faced by the grid in a typical practice causes the frequency disturbance and this disturbance is quite dangerous even in small amount with respect to grid operation and safety. A small percentage change in frequency may lead to even grid failure. In this paper, Artificial Neural Network is used to make frequency forecast.

**KEYWORDS:** Frequency Forecasting, Frequency Response, Grid Model, Neural Networks

### I. INTRODUCTION

The frequency forecasting will surely be a key issue for power system operation and grid security. Significant involvement of soft computing techniques like neural network and neuro-fuzzy system, lead the computation of different parameter in advance for the purposes like safety, operation, expansion, risk management, market analysis etc. [1]. It is also very much important for those grids which adopted deviation settlement mechanism or unscheduled interchange mechanism for frequency stabilization. Frequency forecasting will certainly be a helping tool for this type of grids and its entities in economic point of view also.

In this paper, grid with regional entities, regional interconnected grids and industrial interconnected grids are considered. The grid, whose frequency is to be forecast, is termed here as central grid and its regional interconnected grid systems are termed as regional grid. The entities of the grid are considered in a number of small grids with their own generation and demand, thus developing the model of central grid and reducing it to a more practical and compact model, the parameters of artificial neural network are examined.

## II. GRID FREQUENCY RESPONSES

In this section, we examine the frequency responses for alternator in different systems and frequency responses for grid system.

### A. ALTERNATOR FREQUENCY RESPONSE & GRID FREQUENCY RESPONSE

In a single alternator system, the frequency response

can be obtained from its prime-mover characteristics as shown in Fig. 1, which shows that as the load (MW) increases,

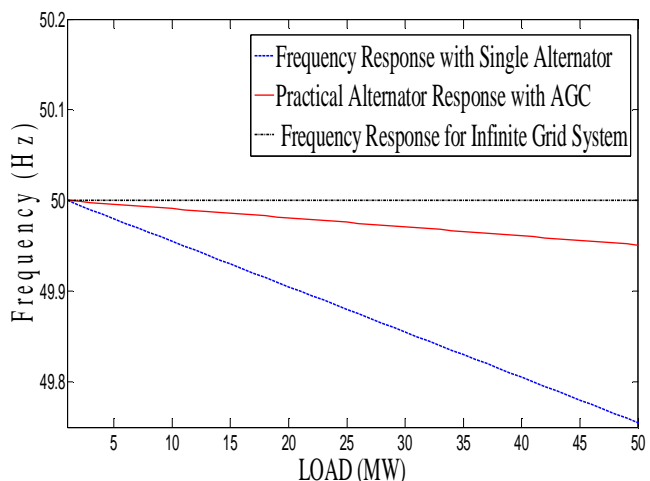


Figure 1 Frequency response for single generator system

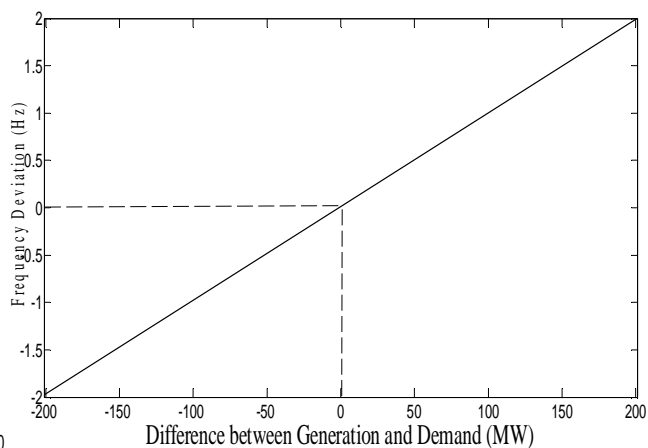


Figure 2(Frequency response of alternator in different systems)

of alternator decreases. Similarly, for ideal infinite bus systems, the frequency is strictly constant and independent of the load as shown in Fig.1. But the practical power system is neither belongs to first case nor to second case, but belongs in between the two. Although by using the automatic gain control at boiler-turbine arrangement this characteristic can be improved to get characteristics closer to the ideal one that is the infinite grid frequency response which is also shown in Fig. 1 [2][3]. Clearly, the slopes of practical cases, one with AGC and other without AGC are different. Hence, down-fall in frequency by increasing the load in practical case is much less than single generator case. On extending the concept to grid level, this statement can be mathematically described as:

$$\Delta f \propto \Delta P \quad (1)$$

Hence, the characteristics drawn from the equation (1) & considering negligible transmission loss is shown in Fig. 2 [3]. Where  $\Delta f$  is the frequency deviation and  $\Delta P$  is the difference between generation and load. In this paper, grid with  $n$  number of generating plants and  $m$  number of load centres is assumed & this can be shown in Fig. 3. Where;

$P_{Gi}$  = Generation in MW by  $i^{\text{th}}$  unit or station

$P_{Lj}$  = Load drawn in MW by  $j^{\text{th}}$  load centre or load bus

Hence, to make frequency forecast, each grid should be generalized in the form as shown in Fig. 3.

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### B. CAUSES OF FREQUENCY DEVIATION OR DISTURBANCE

As seen from equation (1), if value of  $\Delta P$  is zero, the deviation in frequency is also zero, hence, the frequency will be constant and effect of disturbance will be zero. Following are the causes of frequency disturbance in the grid:

- Fast and random switching of load [4]
- Transients in steam inlet and prime-mover rotational transients. [5]
- Contingencies (loss of load block or generating block) [5]
- Power harmonics in grid due to various types of load(mainly non-linear loads)

This paper deals with the main and continuously observed reason of frequency disturbance i.e. fast and random switching of load and steam inlet transient that causes transient in prime mover rotational speed.

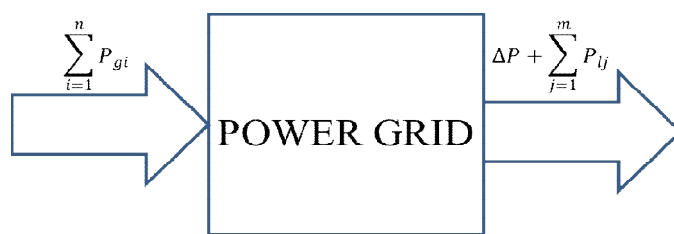


Figure 3 (Power grid model after considering the random and fast switching)

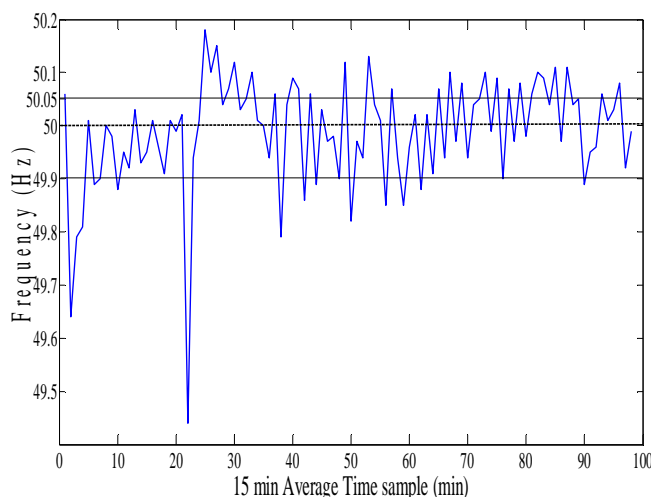


Figure 4 Typical frequency response

From Fig. 3, if;

$$\sum_{i=1}^n P_{gi} = \sum_{j=1}^m P_{lj} \quad (3)$$

Then, value of  $\Delta P$  would be zero. Hence, the frequency will be constant. If the random and fast switching results in unbalance in total generation and total demand as shown in Fig. 3, Where;

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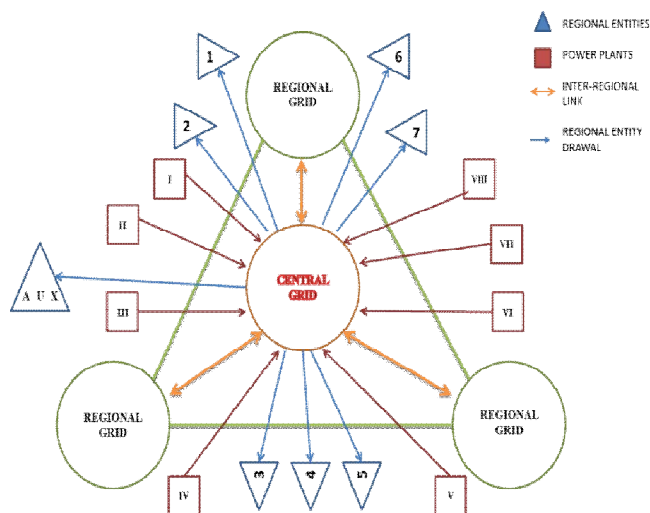


Figure 5(Generalized grid model)

$\Delta P < 0$ ; is termed as power chock ( $P_c$ );  
 $\Delta P > 0$ ; is termed as power lapse ( $P_L$ );

Excess generation then demand leads to chock of power within the grid. The energy corresponding to this chock power results in two major scenario;

- Increases in grid frequency
- Transmission losses increases

Similarly, for power lapse, the energy corresponding to the power lapse results in frequency also. Similar cases can be judged, if prime-mover rotation transients are considered which also leads to the problem of power chock or power lapse [6][7]. Power chock will be having random value depending upon the switching instants.

### C. DIFFICULTIES IN FREQUENCY FORECASTING

A typical frequency profile of an Indian utility system is shown in Fig. 4. This grid has an allowable frequency deviation band of 0.15 Hz and since the bandwidth of the frequency is very low and deviation from its fixed value is (in this case it is 50Hz) of order 1-2% are very critical and may lead to grid failure. So, the first difficulty in forecasting the grid frequency is its accuracy, as the bandwidth itself is very small, so the forecasting accuracy must be very high (more than 94%).

In this paper, the suggested accuracy of forecasting frequency will be in terms of the absolute error & is 33% of its maximum bandwidth. If the bandwidth is 0.15 Hz, the absolute error should range about 0.05 Hz for appreciable forecasting.

The second difficulty encountered in frequency forecasting is its very random characteristics and time independence. In this paper, the mutual disturbance is considered as zero which is caused by grid connected by inter-regional linkages of central grid [8].

So, due to this fast and random switching, the frequency will not be a linear function of load for alternator. Switching and prime-mover transients make the frequency characteristics to be non-linear. As we know the powerful tool to analyse any non-linear function is an Artificial Neural Network, so in this paper, this technique is discussed to make frequency forecasting.



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## III. GRID MODEL & FREQUENCY FORECASTING PARAMETERS

In this section, the power grid is generalized to find out the parameters to decide the grid frequency and then the model is reduced to make frequency forecast.

### A. MODELLING GRID

To make frequency forecasting, entire grid needs to be converted into a form as shown in Fig.3. In this paper, a generalized grid is considered which is named as central grid whose frequency is to be forecast. Let  $n$  number of regional grids which makes a complete network with the central grid.  $m$  number of regional entities are considered with their own generating stations. Central grid is connected to the regional grid via inter-regional corridor in which power exchange is termed here as inter-regional exchange (IRE),  $x$  number of generating stations (which are actively working) dump their power into central grid. These power stations may be inter-state generating station, captive power plant or independent power plant. An auxiliary power drawal is also considered. The complete structure of grid system is shown in Fig.5.

### B. MODEL REDUCTION

The grid model is shown in Fig. 5 is to be reduced to calculate the check power ( $P_c$ ) or lapse power ( $P_l$ ). The reduced grid model is shown in Fig. 6 with its entire considered component network; The central grid can further be divided into two similar smaller blocks in which net power input to the grid would be;

$$P_{rg} = \sum_{i=1}^x P_{cgi} \quad (4)$$

And net demand of central grid;

$$P_{rd} = \sum_{i=1}^m P_{drwli} + P_{aux} \quad (5)$$

In the perspective of frequency forecasting, the impact on frequency due to power chock caused by the regional entities would be different from the power chock caused by inter-regional exchange, because IRE is power exchange within the same network and  $P_{drwl}$  is power exchange to another network. Hence, the reduced grid model for frequency forecasting is shown in Fig. 6. The  $P_{rg}$  is total regional generation,  $P_{rd}$  is total regional demand, and IRE is total power exchange within the same network. The  $P_{drwl}$  is power drawal by the regional entities from the central power grid.  $P_{rg}$ ,  $P_{rd}$  and IRE will decide the chock or lapse in a grid with their own effect on frequency as a different non-linear function and are input vector to the ANN.

If IRE is considered as export;

$$P_c = P_{rg} - P_{rd} - IRE \quad (6)$$

So,

$$\text{Grid frequency} = \text{non-linear function} (P_{rg}, P_{rd}, IRE) \quad (7)$$

### C. PARAMETER GENERALIZATION

Input vector to the ANN would now be;

$$[V] = [P_{rg} \ P_{rd} \ IRE] \quad (8)$$

The generalization is done by taking the percentage of load to generation. Thus, the first element after generalization of input vector will be 1 and can be neglected as we already consider bias in ANN structure.

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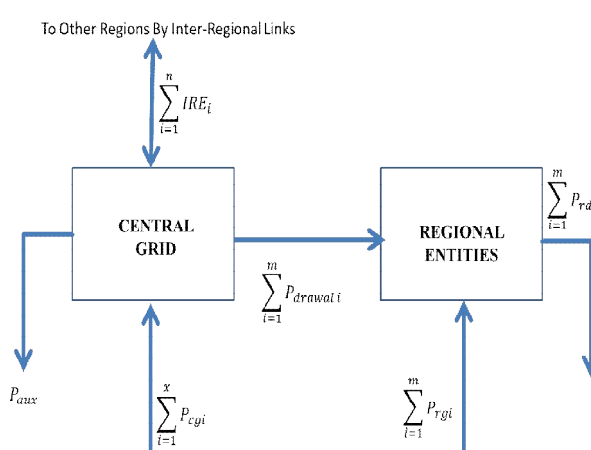


Figure 6(Reduced model of central grid)

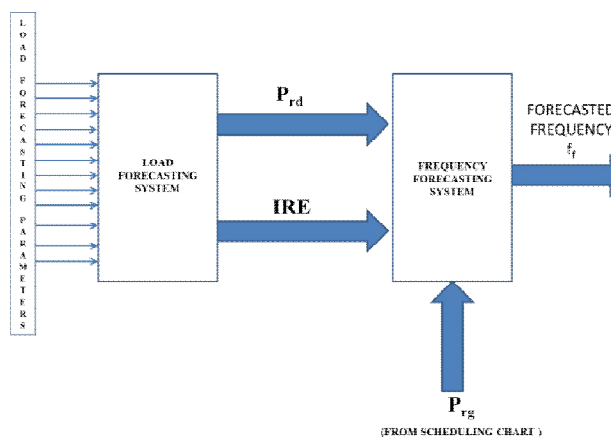


Figure 7(Frequency forecasting system complete structure)

$$\text{Generalized } [V] = [P_{rd} / P_{rg} \text{ IRE} / P_{rg}] \times 100 \quad (9)$$

$$\text{Generalized target } [T] = [f]/f_0 \quad (10)$$

Where  $f_0$  is rated operating frequency of system.

## IV. FREQUENCY FORECASTING

In this section, the complete structure of the frequency forecasting system is discussed along with its advantages and limitations.

### A. FORECASTING SYSTEM

The value of the input vector  $[V]$  can be easily forecast using load forecasting techniques and  $P_{rg}$  can be taken from scheduling chart of generators. Since, forecasting of frequency requires forecasting of load first so, forecasting the frequency will be independent of the type of model designed for a specific period of forecast [9]. For example, if load forecasting is done for the entire 24-hours, frequency profile can be forecast and if load forecasting system is designed to forecast next minute load, next minute frequency can be estimated. Hence, using this forecasting system, any type of forecast can be attempted, that is from next minute frequency to 24-hour profile. Since, various methods and techniques are already available to make load forecast it would be very easy to use load forecasting system and already power industries use them for scheduling their generators [10].

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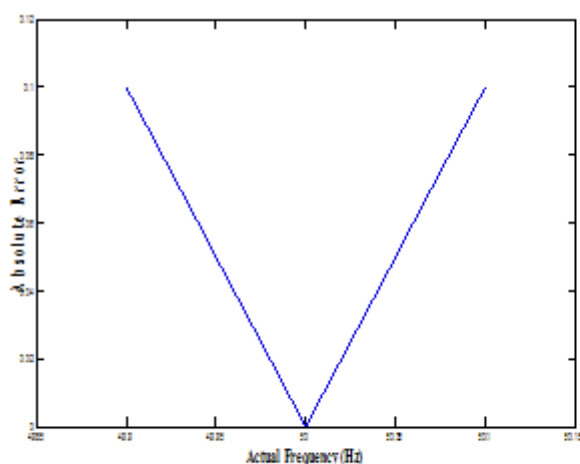


Figure 8 Error pattern in result

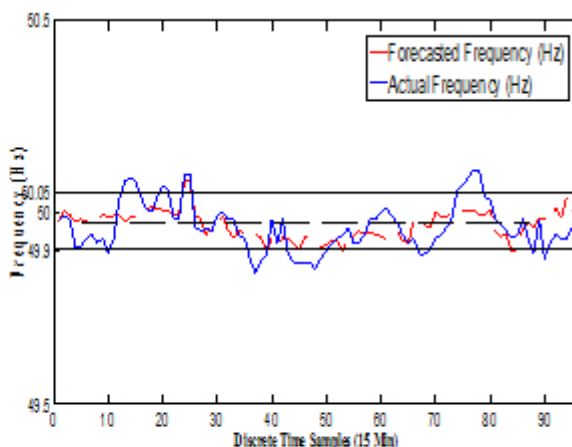


Figure 9 Frequency Forecast

## B. LIMITATIONS OF FREQUENCY FORECASTING SYSTEM

The grid frequency forecasting system has few limitations as given below;

- The system should be harmonic free or effect of harmonics on grid frequency is neglected.
- Power trading is not considered in this paper
- Effect of load type on grid frequency is negligible
- Frequency forecasting system's accuracy depends on the accuracy of load forecasting system.
- System inertia is considered to be same for industrial and commercial loads.

## V. CASE STUDY & NUMERICAL RESULTS

The forecast is performed on the western regional grid of PGCIL, India considering it to be central grid. Data are recorded from 1<sup>st</sup> SEP 2016 in every minute to record about 5000 training sets for ANN, which is further divided into *training*, *validation* and *testing sets* to avoid overfitting[11][12]. Central grid considered for forecast is one of the 5 regional grids of India with all regions connected via inter-regional corridor.

This grid has 7 regional entities (Gujrat, Madhya-Pradesh, Chhattisgarh, Maharashtra, Goa, Daman-Diu, and Dadra Nagar Haveli). The recorded data set is used to train Backpropagation feed-forward network using MATLAB NEURAL NETWORK TOOLBOX. The training rule used is Levenberg-Marquat. The forecasting performance is evaluated by using the mean absolute percentage error (MAPE) and mean absolute error (MAE).  $f_f$  is the frequency forecast,  $f_a$  is the actual frequency and T is sampling time and n is the number of samples.

Then;

$$MAPE = \frac{1}{nT} \sum_{n=1}^{nT} \frac{f_f - f_a}{f_a} \times 100 \% \quad (11)$$

And;

$$MAE = \frac{1}{nT} \sum_{n=1}^{nT} (|f_f - f_a|) \quad (12)$$



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The net regression line obtained after training the ANN is close to 0.6 which is appreciable result. The frequency forecasting system is tested on selected day of SEP 2016 to get 24-hour profile with an input vector taken from real time readings uploaded by WRLDC, Mumbai on the web with an average 10% error in input vector to acknowledge load forecasting system. The forecast frequency profile is shown in Fig. 9 along with actual profile. Error encountered in this forecasting system considering instantaneous forecast is also shown in Fig. 8 [12]. The reason behind this type of error plot is mainly due to the fact that the data sets used for the training consist of maximum number of sets belonging to that category or range of frequency which is close to rated frequency.

In other words, ANN is best trained to forecast the grid frequency when the actual frequency of the grid is its rated frequency.

Table 1 (Performance parameters of ANN based grid frequency forecasting)

Performance Parameter	Numeric Value(%)
MAE	4.39
MAPE	0.0878
MSE	0.28

## VI. CONCLUSION

This paper represents the importance of frequency forecasting for the power grid and bring the frequency response of grid system in practical scenario. The grid is generalized to make a model that was reduced to get a frequency forecasting input vector of ANN. This approach is an elementary and effective way to forecast frequency at grid level. Although, system has few limitations and initial consideration over which further research is expected.

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