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# A Control Strategy for Load Frequency Control Coordinating Economic Load Dispatch & Load Forecasting Via Kalman Filter

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**Abstract:** This paper presents a control mechanism for Automatic Generation Control of multi generating interconnected power system. This control technique organise the excellent relationship between the electric load forecasting & Economic Load Dispatch for interconnected power system. The main component of LFC is to monitor the frequency nearly at constant standard value (50 Hz in India) & to regulate the net balance interchanged tie-line power flow between the different control areas within the prescribed limit. Since, electrical load is always fluctuating in nature & due to slow response of Area Control Error (ACE), needs some other means to overcome this limits& this leading to the forecasting technique to be incorporated with the Economic Load Dispatch for improved dynamic response of the power system. Load prediction technique is incorporated by Kalman filter recursive algorithm & then this bank of load is interpolated at a regular interval of 5 – minutes & these conceptscalled as “a very short-term load forecasting”. Total forecasted demanded electric load is distributed among the different generating unit via participation factors in context with the concepts of Economic Load Dispatch & Generation allocation. Results & Discussion section of this paper support this control technique wisely for the given simulated interconnected power system.

**Keywords**: Load Frequency control (LFC), Kalman Filter, Economic Load Dispatch, Genetic Algorithm (GA)**,** Generation allocation, Load Forecasting.

## 1. Introduction

Load frequency control (LFC) is a very important for power system, operation & control for sufficient & good quality of reliable power supply. In the present scenario planning resources are important to forecast the future load demand for efficient running &operation of the power system. The main components of load frequency control includes, keeping the frequency nearly at a constant value ( 50 Hz in India ), keeping the net interchanged tie-line power flow within prescribed limit and considering the concepts of economic load dispatch. A more accurate LFC mechanism can be obtained by incorporating the load prediction technique and economic load dispatch mechanism to the power system. LFC acts as a balance between generated power & the power demanded while keeping the net interchanged tie-line power within the standard acceptable limit. For more reliable & uninterrupted power supply, it is necessary to have a mechanism which includes concepts of the load forecasting & economic load dispatch. Earlier in some literatures studies on AGC for interconnected power system have been investigated [4, 14, 29, 30]. So here onlyemphasisewill be given on Load Forecasting technique along with Economic Load Dispatch& generation allocation for multi power generating units (thermal unit, hydro unit, gas unit & nuclear unit). Also, some short-term load forecasting has been investigated via [9, 17, 18, 25, 26, 31]. Load forecasting methods are classified into two categories according to investigated literature survey.

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a) Parametric based method –It includes load model ARs, MAs, ARMAs, ARIMAs etc. [32, 33, 34, 35, 36, 37, 38]
b) Artificial based intelligent technique –It includes Neural Network for load forecasting [16, 21, 22, 23, 28].

The above all methods use the following general concepts for load forecasting technique as
a) Analysis past load data
b) To identify system model
c) Parameter estimation
d) Load prediction algorithm and finally
e) Forecasted load.

After Successful modelling and simulation of generating units. Load prediction is accomplished byKalman filter approach [9, 15, 24] due to having excellent estimation recursive nature & properties. This data is interpolated for 5 minutes of regular intervals, after which the required forecasting data is successfully obtained. This forecasted electric load is distributed according to economic load dispatch as well as generation allocation concepts; to insure proper load sharing among the different generatingunits. Using the concepts of Genetic Algorithm and optimization technique, the optimal gain of the integral controller for each control area is optimized. Hence, whole research paper can be summed as
a) Analytical study of load frequency control, economic load dispatch and load prediction technique.
b) Modelling of power system i.e. hydro, thermal, gas & nuclear.
c) Kalman filter algorithm for load forecasting as well as a very short-term load prediction.
d) Generation allocation of generating units via units' participation factors.
e) Optimization for optimal integral gain of secondary controller through GA optimization technique.

## 2. Modelling of the Interconnected Power System

The power generating units of the simulated power system in this paper consists firstly of control area containing the combination of hydro, thermal, gas & secondly the combination of thermal, hydro & nuclear generating units [3, 39]. For net interchanged tie-line power flow both control area are connected through tie-line, for which block diagram is shown below.

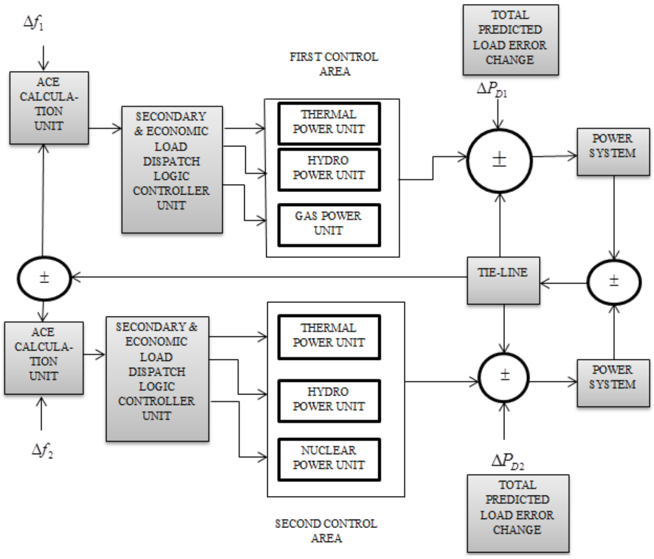

Figure 1. Complete Block Diagram of Multi Generating Interconnected Power System.

## 3. Short term load forecasting using Kalman filter algorithm

In this section of work, load forecasting technique has been implemented with the help of Kalman Filter recursive model. Time series, ARMA etc approaches has been widely used for load forecasting for relatively simplicity of the system model. But these methods may be leadingtheignorance of the statistical information about the historical load data &that may not give the improved load forecasting. These drawbacks may be avoided by using the Kalman Filter recursive approach & hence, may be able to obtain the improved load forecasting model as well as improved performance of the power system. Kalman Filter model is mainly based on state space equations as well as optimal estimation of the given system. It uses the past historical load data as the observation model & performing the basic Kalman recursive state estimation to the available load data, hence forecast the future predicted load data. It may be noted that Kalman filter technique may be affected by non-availability of the required state variable model of the concern load data. So, for proper system model identification, Gauss-Markov model [41, 42] may be helpful for achieving this purpose. The system matrix equation should be smart choice to get more accurate estimated load model. The detailed derivation & application of the Kalman filter may be referred to the deferent literatures and basic books [38]. The only necessary equation is given below & the information used at time $x(k-1)$ to obtain the estimation at time of $x(k)$ and in discrete-time format the signal model is represented in state-space form is given as.

$$x(k+1) = A(k).x(k) + w(k) \tag{1}$$

$$z(k) = c(k).x(k) + v(k) \tag{2}$$

Equation (1) representing the (possibly unobserved) state model & equation (2) shows the observation model or estimate model of the simulated system. Since Kalman filter prediction is mainly based on recursive equation iterated successively to find out the optimal estimation of the given equation. The Kalman gain is obtained through the standard equation as,

$$K(k) = A(k)P\left(\frac{k}{k-1}\right)c^T(k).\left(c(k)P\left(\frac{k}{k-1}\right)c^T(k) + R(k)\right)^{-1} \tag{3}$$

The new state estimate of the system is given below

$$\hat{x}\left(\frac{k}{k-1}\right) = A(k)\hat{x}\left(\frac{k}{k-1}\right) + K(k)\left(y(k) - c(k)\hat{x}\left(\frac{k}{k-1}\right)\right) \tag{4}$$

Error covariance update is estimated as

$$P\left(\frac{k+1}{k}\right) = A(k)P\left(\frac{k}{k-1}\right)A^T(k) - K(k)C(k)P\left(\frac{k}{k-1}\right)A^T(k) + Q_2(k) \tag{5}$$

Where, $x(k) = n\times 1$ system states, $A(k) = n\times n$ time varying state transition matrix, $c(k) = m\times n$ time varying output matrix, $z(k) = m\times 1$ measurement vector, $w(k) = n\times 1$ uncorrelated white noise, $R(k) =$ Covariance matrix, $v(k) = m\times 1$ uncorrelated white noise & having zero mean, $Q_1$ & $Q_2$ Positive semi definite and positive definite matrix respectively.

Zero means, equation hold the relation,

$$E[w(k)] = E[v(k) = 0 \tag{6}$$

And no time correlation & having covariance matrix i.e,

$$E[w(i)W^T(j)] = E[V(i)V(i)] = 0 \text{ for } i = j \tag{7}$$

And known covariance matrix (noise levels) is

$$E[W(k)W^T(k) = Q_1 \tag{8}$$

$$E[V(k)V^T(k)] = Q_2 \tag{9}$$

Here to enhancement of convergence characteristics of the Kalman filter then must be smart choice of the priori estimated state $\hat{x}_0$ and its covariance error $P_0$. Equation (1) and (2) may be contained the following assumptions:

a) State transition matrix A(k) is a constant identity matrix.
b) The error covariance matrix Q1 and Q2 are constant matrix and its value is depends upon the actual characteristics of the past information available of process error and measurement noise respectively. They must be chosen as identity matrix.
c) Vector x (k) consist of n-parameter likes load data, weather data, humidity data etc.
d) C (k) is N-variable time varying row vector which relates the relationship of the load data.
e) Z (k) represents the optimal estimated load at the instant of time k.

Steps should be followed for prediction algorithm based on Kalman filter is,

a) The load data is selected as the input to be predicted via Kalman filter algorithm approach, the initial condition of the parameter vector is fixed arbitrarily.
b) Covariance matrix Q1 and Q2 of the equation (7) and (8) are set to unity matrix with appropriate dimension.
c) We go through recursive Kalman approach for the first hour of the day and use this result coefficient to be used later for prediction.
d) By using the estimated parameter of the various hours as initial condition for estimating the next hour coefficient by Kalman filter.
e) Repeat the above steps for all 24 hours of the day.
f) The observation vector z(k), for this application is scaler representing the load at time of instant k referring equation (10)

Again, forecasted load is obtained by using this equation,

$$z(k+1) = c(k).x\left(\frac{k}{k-1}\right) \tag{10}$$

It may be noted that the filtering approach implies the removal of the disturbance or term with zero mean. So, complete recursive estimation model of Kalman filter is given below.

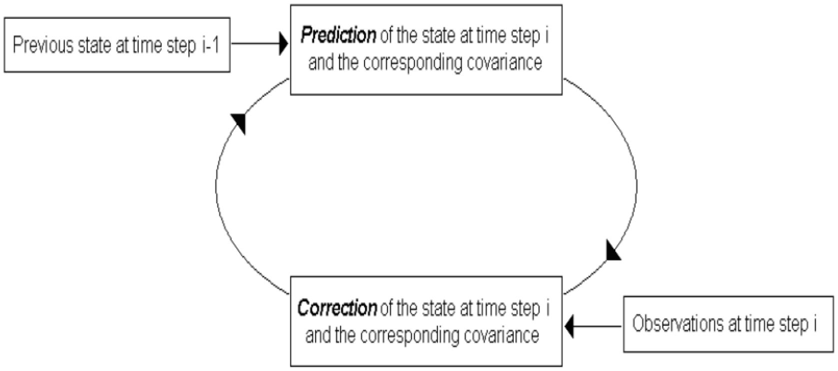

Figure 2. Complete Block Diagram of Kalmanfilter for prediction algorithm.

## 4. Five minute ahead load forecasting technique

For good & improved performance of Kalman filter forecasted 24 hour load data is interpolated at a regular interval of 5 minutes. As the load changes, the load error will directly fed to the given power system model. Now let us consider $y(t)$ be the forecasted load at the instant of the time $t$, then $y(t+5)$ is forecasted load change will be

$$y_d(t) = y(t+5) - y(t) \tag{11}$$

hence, this total changed load will be consider at the instant of the time t & five minute look-ahead control algorithm is designed. According to the unit's participation factors, this 5 minutes load is divide to all generated unit and highlighted as " a very short – term load prediction technique".

## 5. Generation Allocation of the Generating Units

Toensure demanded electric load distribution between different generating units in a proper way, the concepts of economic load dispatch is taken into account. This logic decides how many generating units will participate in load sharing as per units' participation factors. Participation factor is defined as the rate of change of each unit's output with respect to a change in total generation of that control area. The summation of participation factors of each control area is unity. If the present unit generation is equal to the total generation, then economic load dispatch is assigned as the base point generation which is the most economic output for any unit. The generation allocation of multiple generating unit w.r.t generation output can be related to LFC & concepts of economic load dispatch.

$$P_{ides} = P_{ibase} + pf_i \times \Delta P_{total} \tag{12}$$

Where, $P_{ides} =$ desired output from i$^{th}$ unit, $\Delta P_{total} =$ change in total generation, $P_{ibase} =$ base-point generation for i$^{th}$ unit, $pf_i =$ participation factors for i$^{th}$unit

$$\sum Pf_i = 1 \tag{13}$$

To find out the participation factors of each unit, we use the concepts of economic load dispatch calculation and the following equations accomplish the execution task. The quadratic cost function of the power system is given as

$$F_i(P_{Gi}) = \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 \quad (14)$$

$\alpha_i$, $\beta_i$ and $\gamma_i$ are the coefficient of the cost function and $P_{Gi}$ is power generation of the i$^{\text{th}}$ unit.

$$\min.F(T) = \sum F_i(P_{Gi}) \quad (15)$$

Power balance constraint is given as

$$\sum P_{Gi} = P_D + P_L \quad (16)$$

Where, $P_D$=load demand & $P_L$ =Transmission losses & enequality is given as

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad (17)$$

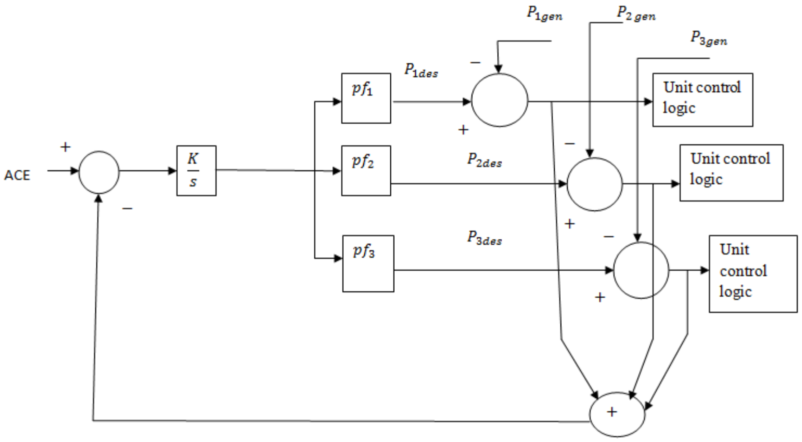

Figure 3. Complete Block Diagram of Generation Allocation of Multi Generating Units.

## 6. Optimization technique through Genetic Algorithm (GA)

The objective function (Integral Square Error) using as error of the given simulated system to optimized the gain of the integral controller by GA, which is based on search through natural selection & genetics of the system [6, 7, 13]. This technique searches the best point from the randomly generated population of point, which is transitory in nature. Since, after successful short term load forecasting using Kalman filter estimation approach, this forecasted load is distributed among the generating units of each control area properly according to Economic Load Dispatch mechanism. So, at each instant of load distribution, gain of the integral controller of both control area should be optimized to obtain the improved performance of the simulated interconnected power system. Hence, GA is using for this purpose &its different specifications; information as well as GA operators are given below.

### *A. Objective function*

The objective function is consider for minimization of  the system error, so performance index of the system is ISE (Integral Square Error) is using here as the objective function to minimizing the error, for getting the optimized gain value of the secondary controller. So fitness function of this paper is given as,

$$J = \int_0^t (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie12}^2) dt \qquad (18)$$

Where, $\Delta f_1$ = Frequency deviation of first control area, $\Delta f_2$ = Frequency deviation of second control area & $\Delta P_{tie12}$ = Net tie-line power flow deviation of interconnected power system.

*B. Reproduction*

Selection is the process of selecting the population from the current population which will survive for the next generation population for next process of the Genetic Algorithms. In this paper we select the Roullete Wheel selection process for the selection or reproduction of the next generation population. The brief study has been performed in past some decade.

*C. Crossover*

Crossover is also known as recombination of the population or reshuffled the selected population. Here, we select two random selected populations & then we choose random site & interchanged the individual Chromosomes with each other and finally produced the new off spring, and we proceed for next process. The performed analysis is studied [13].

*D. Mutation*

In this process, we select the individual bit randomly and interchanged with '0' or '1'and it gives some variations in information of the population, although its probability rate is quite small as compare to crossover probability rate. The mutation and its application have been analyzed [6].

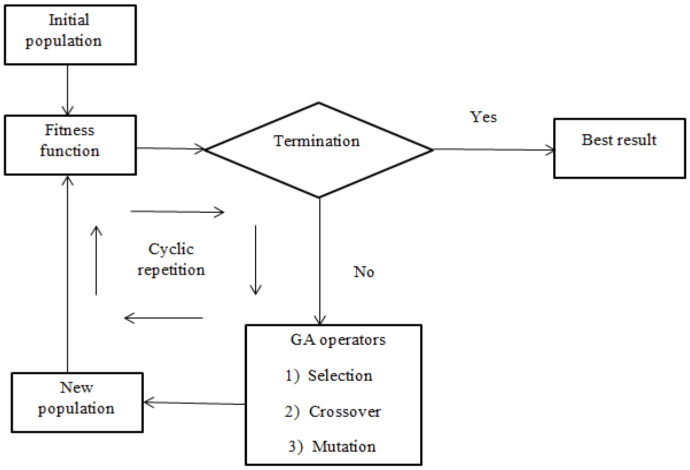

Figure 4. Complete Block Diagram of genetic algorithm.

## 7. Result and Discussion

The control designed (for Integral controller or secondary controller) described in the paper deals exclusively for the interconnected multi generating units power system. The proposed multi generating units is simulated in MATLAB & SIMULATION toolbox. The complete transfer function block diagram of the simulated multi generating power system is given in figure (5). This control concept revels that the predicted load data from Kalman forecasting algorithm, is then interpolated at 5 minutes of regular intervals. This concepts arises a very short-term forecasted load to ahead of the real time. This forecasted load data, is then fed to the first control area of the power system& the corresponding system performance of the simulated system is obtained. The comparison between the actual load data and forecasted load data is shown in figure (6). After this, the gain of the secondary controller is optimized by minimising the system error (ISE) through genetic algorithm optimization method. The performance of the proposed control technique for the simulated multi generating units (thermal power unit, hydro power unit, gas power unit & nuclear power unit) of the power system is given in belowsimulation figures. The frequency response of the simulated multi generating powersystem is given in the figure (7) & figure (8). Kalman filter prediction technology & its performance of the forecasted load data and actual load data graphare demonstrated in the figure (6) which forms the whole basis of the implemented control mechanism. The deviation of the Area Control Error (ACE) againstthe time, which is the control input to the integral

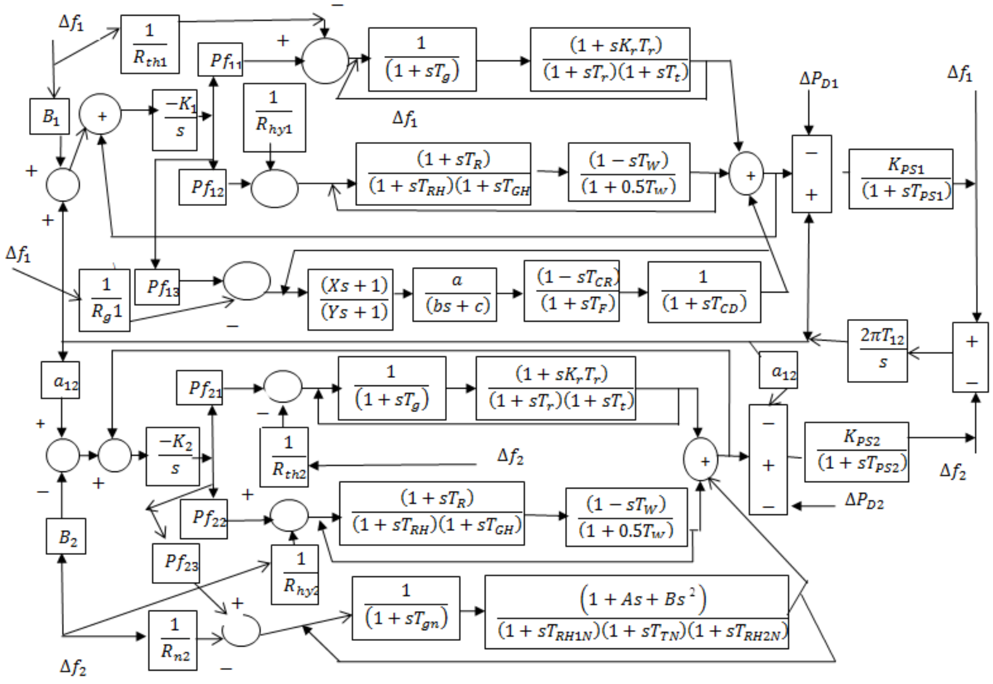

Figure 5. Complete Transfer function Block Diagram of Multi Generating Interconnected Power System.

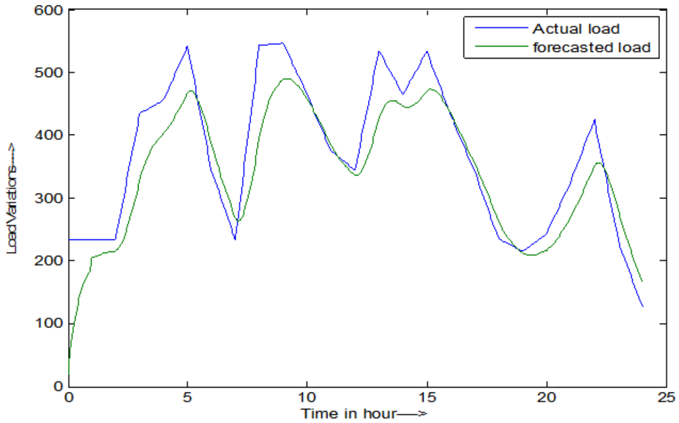

Figure 6. Comparison between Actual load and Predicted load.

controller (secondary controller) of the system, is demonstrated in the figure (8) &figure (9) of the respective control area. Hence this control technique, which incorporates the logic of the load forecasting & economic load dispatch for load frequency controlgives better dynamic & stable frequency response to the power system of the respective control area, which is essential for successful & efficient operation of the power system.

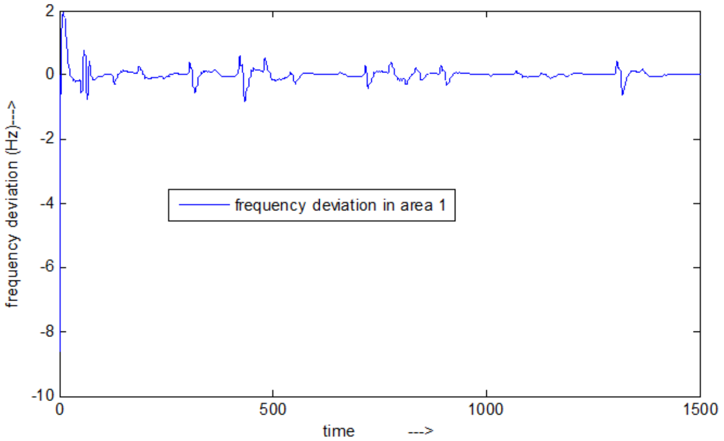

Figure 7. Frequency deviation graph in area one with time (in minutes)

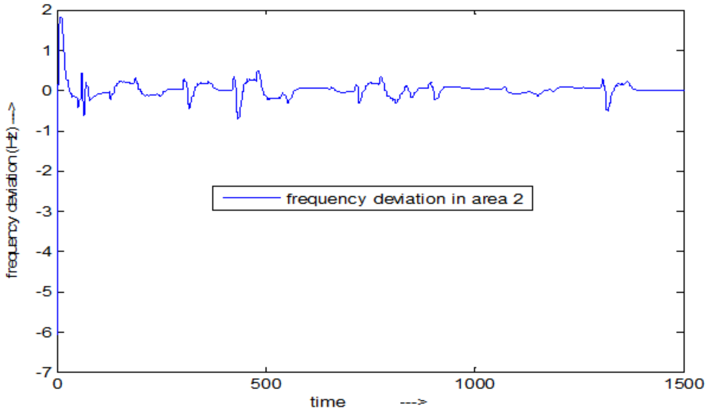

Figure 8. Frequency deviation graph in area two with time (in minutes)

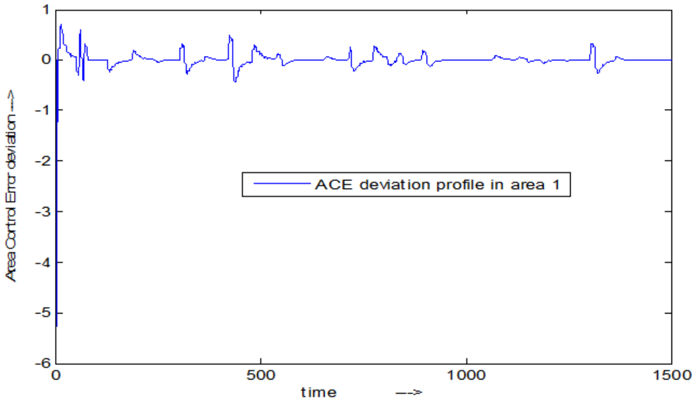

Figure 9. Area Control Error (ACE) graph with time (in minutes) of area 1.

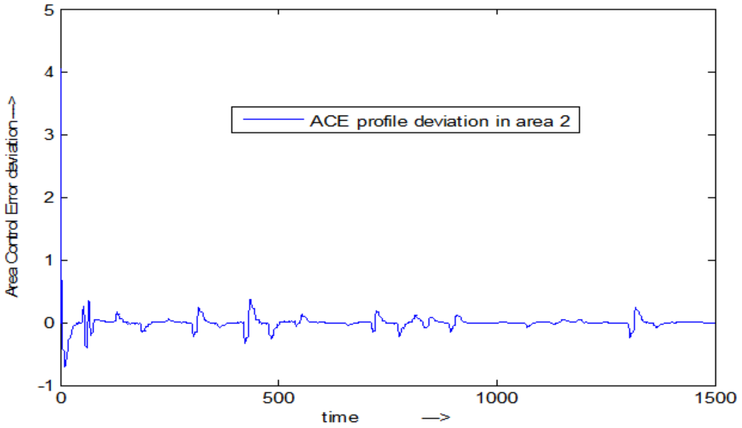

Figure 10. Area Control Error (ACE) graph with time (in minutes) of area 2.

## 8. Conclusion

This paper present a control mechanism, incorporates the concepts of load forecasting approach&economic load dispatch for load frequency control of simulated power system. Load forecasting task has been accomplished via Kalman filter recursive estimation technique. Power generating units will participate or distribute the total forecast load according to their participation factors in view of economic load dispatch calculations. The different graphs of the frequency deviation, ACE deviation and Comparison between actual load & forecasted load of the simulated system, demonstrate the implemented technique isquite effective & gives better, improved system transient response which help in stabilising the frequency (nearly at constant value of 50 Hz in India) against the fast fluctuating electric load demand of the power system for multi generating power units of the power system.

## Appendix and Nomenclature:

*Steam Turbine:*

$K_r$= (Coefficient of re-heat steam turbine) = 0.3, $T_r$ = (re-heat time constant) = 10 sec.

$T_t$ = (Turbine time constant) = 0.3 sec, $R_{th}$ = (speed governor regulation) = 2.4 Hz/pu MW

$T_g$=(Speed governor time constant) = 0.08 sec., $t_w$ = (water time constant) = 1.0 sec

*Gas Turbine:*

$X$ = (Speed governor lead time constant) = 0.6 sec, $Y$ = (speed governor lag time constant) = 1.0 sec., Valve positional constant $a = 1, b = 0.05$ and $c = 1$, $T_F$ (Fuel time constant) = 0.23 sec.

$T_{CR}$ = (Combustion reaction time delay) = 0.3 sec., $T_{CD}$= (Compressor discharge volume time constant) = 0.2 sec., $R_G$= (Speed governor regulation) = 2.4 Hz/pu MW

*Hydro Turbine:*

$T_R$ (Speed governor rest time) = 5.0 sec., $T_{RH}$ (Transient droop time constant) = 28.75

$T_{GH}$ = (Main servo time constant) = 0.2 sec.

*Nuclear power unit:*

$KHI = 2$, $KRI = 0.3$, $T_{GN} = 0.08$ sec., $T_{r1}$= 0.5 sec., $T_{RHI} = 7$ sec., $T_{RH2} = 9$ sec.

*Power system:*

(Gain of the power system) $k_{P1} = k_{P2} = 120 Hz/pu$

(Time constant of the power system) $T_{P1} = T_{P2} = 20\sec.$

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