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# OPTIMIZED INTEGRAL CONTROLLER FOR ECONOMIC LOAD DISPATCH IN A TWO AREA SYSTEM BASED ON HOOKE-JEEVES ALGORITHM

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## ABSTRACT

The classical approach to the Economic Load Dispatch Problem (ELDP) seeks to minimize the cost of generation subject to the usual constraints. If the transmission losses are to be taken care of, a common method (λ-iteration procedure) involves adding the cost of transmission losses charged at incremental cost of received power to the cost of generation. Hooke-Jeeves method offers a suitable and robust approach to meet the objectives of optimizing the integral controller in order to obtain better response of the system. This paper presents an improved fast programming technique to optimize the value of integral controller in a two area reheat hydrothermal system and also implementing the concept of Economic load dispatch in a system consisting of 'n' generating units. Simulation results show that the generating units in each area take up the extra load as per their respective participation factors.

**Keywords:** hydrothermal system, Hooke-Jeeves algorithm, participation factor, base power value, ELDP

## 1. INTRODUCTION

The fundamental requirement of power system economic load dispatch is to generate, at the possible lowest cost adequate quantity of electricity to meet the demand. To meet the stringent quality requirements accurate tools based realistic models with faster solution speed and a high degree of reliability is required. To achieve higher reliability, improved security, less environmental impact the utilities are implementing tighter control on the operation of their facilities [1]. These have brought about the necessity of greater sophistication in power system planning, operation and control. Traditional classical economic dispatch algorithms require the incremental cost curves to be monotically increasing or piecewise linear. The input output characteristics of modern units are inherently highly nonlinear and having multiple local minimum points in the cost function. However their characteristics are approximated to meet the requirements of classical dispatch algorithms leading to suboptimal solutions and therefore resulting in high revenue loss over the time. Consideration of highly nonlinear characteristics of the units demand for highly robust algorithms to avoid getting struck at local optima. Economic load dispatch problem is allocating the loads to plants having continuous fuel cost equations [2]. In this respect stochastic search algorithms like Hooke-Jeeves method, genetic algorithm, evolutionary strategy, evolutionary programming and simulated annealing may prove to be very efficient in solving highly nonlinear ELD problems without any restrictions on the shapes of cost curves [3]. Although heuristic methods do not always guarantee the global optimal solution, they provide a reasonable solution in a short period of time. Power systems consist of control areas with many generating units with outputs that must be set according to economics. So an economic dispatch calculation must be coupled to the control mechanism so it will know how much of each areas total generation is required from each individual unit. When using digital computers, it is desirable to be able to carry out the economic-dispatch calculations at intervals of one to several minutes. Either the output of economic dispatch calculation is fed to a digital computer. Since the economic-dispatch calculation is to be executed every few minutes, a means must be provided to indicate how the generation is to be allocated for values of total generation other than that used in the economic dispatch calculation. Attempts have been made until now so as to describe the two area system in a discrete mode along with nonlinearities [6-11]. But no attempts have been made so as to develop a model which implements the concept of economic load dispatch in a two area reheat system. Though many methods have come up in implementing the economic load dispatch problem, this method implements the problem in Matlab/Simulink. In view of the above, the main objectives of this study were:

1) To design a load frequency controller based on integral controller for a realistic AGC model in a continuous mode;
2) To build an economic load dispatch block along with two areas reheat system; and
3) To optimize the value of integral controller using Hooke-Jeeves algorithm.

## 2. GENERATION ALLOCATION

The allocation of individual generator output over a range of total generation values is accomplished using base points and participation factors. The economic-dispatch calculations are executed with a total generation

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equal to the sum of the present values of unit generation as measured. The result of this calculation is a set of base-point generations, $P_{ibase}$ which is equal to the most economic output for each generator unit. The rate of change of each unit's output with respect to a change in total generation is called the unit's participation factor. The base point and participation factors are used as follows:

$$P_{ides} = P_{ibase} + pf_i \times \Delta P_{total} \qquad \text{.....(1)}$$

Where $P_{ides}$ = new desired output from unit i

$P_{ibase}$ = base-point generation for unit i

$pf_i$ = participation factor for unit

$\Delta P_{total}$ = change in total generation

So according to the equation stated above all the three generators considered in each area will be generating the base power at normal steady state but when load change occurs the extra load will be shared in such a way according to the values of their participation factors. Modern implementation of automatic generation control schemes usually consist of a central location where information pertaining to the system is telemetered. Control actions are determined in the digital computer and then transmitted to the generation units via the same telemetry channels. After obtaining the required generation an optimization procedure is employed to determine the best value of the integral controller which varies between 0 and 1. Hooke-Jeeves method which is the best method in the traditional algorithms is used in order to optimize the value of integral controller. In this Hooke-Jeeves method both pattern search and exploratory move are being used. The two area system in the traditional case with identical areas can be optimized with respect to system parameters to obtain the best response.

## 3. DYNAMIC MATHEMATIC MODEL

The load frequency controller controls the control valves associated with High Pressure (HP) turbine at very small load variations [11, 12]. The system under investigation has tandem-compound single reheat type thermal system. Each element (Governor, turbine and power system) of the system is represented by first order transfer function at small load variations in according to the IEEE committee report [12]. Two system nonlinearities likely Governor Deadband and Generation Rate Constraint (GRC) are considered here for getting the realistic response. Governor Deadband is defined as the total magnitude of the sustained speed change within which there is no change in the valve position [5]. It is required to avoid excessive operation of the governor. GRC is considered in real power systems because there exits a maximum limit on the rate of change in the generating power. Figure-1 shows the transfer function block diagram of a two area interconnected network .The parameters of two area model are defined in Appendix. The governor deadband is represented by the nonlinear backlash block and the GRC is taken into account by adding a limiter to the turbine as shown in the Figure-1.

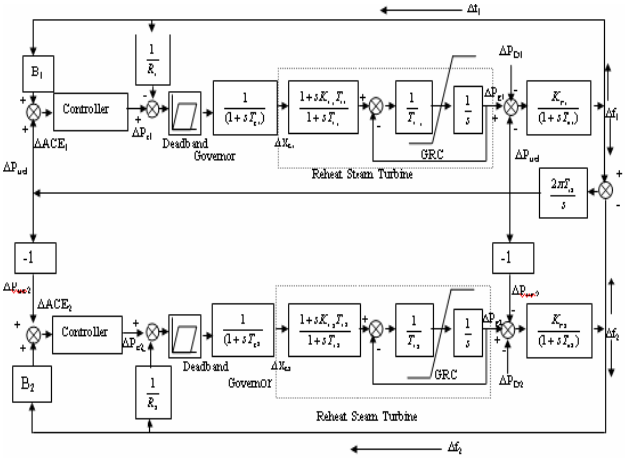


**Figure-1.** Interconnected hydrothermal two area system with GRC and deadband.

## 4. OPTIMIZATION OF INTEGRAL GAIN SETTINGS

Hooke-Jeeves method is used to obtain the optimum integral gain settings. A performance index which is denoted by $J = \int_0^t (\alpha \Delta f_1^2 + \beta \Delta f_2^2 + \Delta P_{tie12}^2)dt$ is minimized to obtain the optimum values of $K_{i1}$ and $K_{i2}$. A value of 0.65 is considered for both $\alpha$ and $\beta$. The algorithm for Hooke-Jeeves method can be written as shown below:

Step 1: Choose a starting point $x^{(0)}$, variable increments $\Delta_i$ (I = 1, 2,…….., N), a step reduction factor $\alpha > 1$, and a termination parameter, $\varepsilon$. Set k = 0.

Step 2: Perform an exploratory move with $x^{(k)}$ as the base point. Say '$x$' is the outcome of the exploratory move. If the exploratory move is a success, set $x^{(k+1)} = x$ and go to Step 4; **Else** go to Step 3.

Step 3: Is $\|\Delta\| < \varepsilon$? If yes, **Terminate;** Else set $\Delta_i = \frac{\Delta_i}{\alpha}$ for i = 1, 2,….,N and go to Step 2.

Step 4: Set k = k+1 and perform the pattern move: $x_p^{(k+1)} = x^{(k)} + (x^{(k)} - x^{(k-1)})$.

Step 5: Perform another exploratory move using $x_p^{(k+1)}$ as the base point. Let the result be $x^{(k+1)}$.

Step 6: Is $f(x^{(k+1)}) < f(x^{(k)})$? If yes, go to Step 4; **Else** go to Step 3.

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## 5. DYNAMIC RESPONSES AND DISCUSSIONS

To validate the proposed method, a numerical simulation has been carried out in MATLAB-SIMULINK environment. The data considered for area1 is given below [4].

**Generator 1: Coal-fired steam unit**
Max output = 600 Mw; Min output = 150 Mw
Input-output curve:

$$H_1\left(\frac{MBtu}{h}\right) = 510.0 + 7.2P_1 + 0.00142P_1^2$$

**Generator 2: Oil-fired steam unit**
Max output = 400 Mw; Min output = 100 Mw
Input-output curve:

$$H_2\left(\frac{MBtu}{h}\right) = 310.0 + 7.85P_2 + 0.00194P_2^2$$

**Generator 3: Oil-fired steam unit**
Max output = 200 Mw; Min output = 50 Mw
Input-output curve:

$$H_3\left(\frac{MBtu}{h}\right) = 78.0 + 7.97P_3 + 0.00482P_3^2$$

The data considered for area2 is given below [4].

**Generator 1: Coal-fired steam unit**
Max output = 600 Mw; Min output = 150 Mw

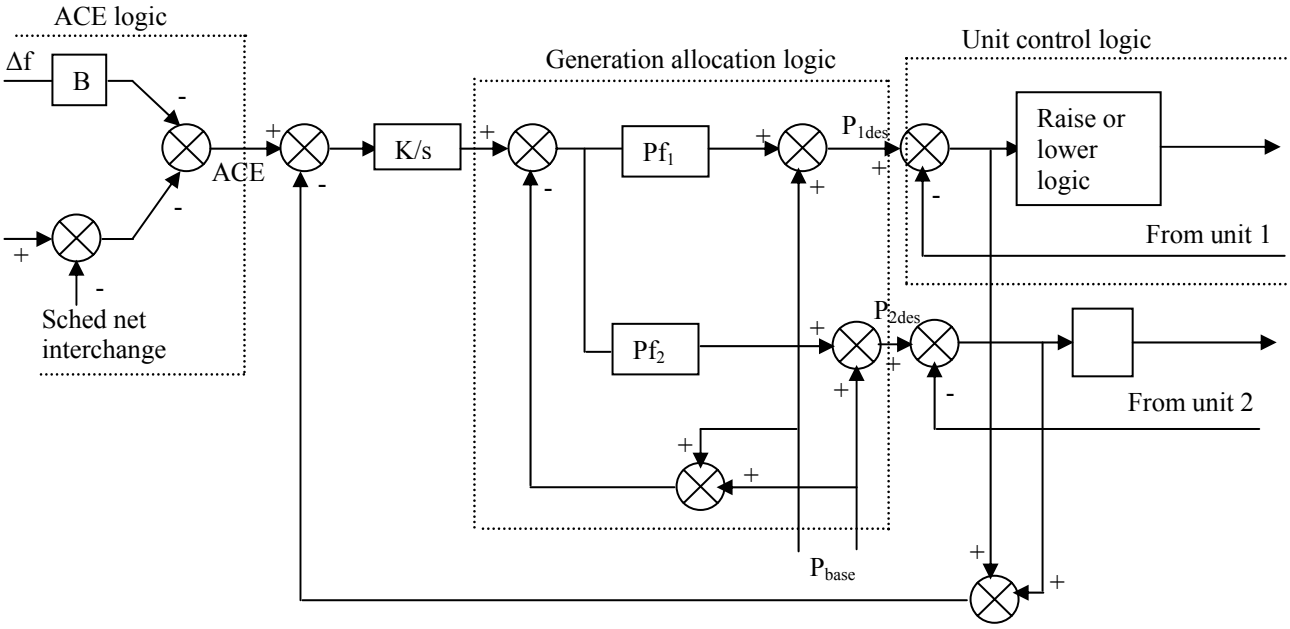



**Figure-2.** Implementation of logic of ELD in AGC concept.

Input-output curve:

$$H_1\left(\frac{MBtu}{h}\right) = 561.0 + 7.92P_1 + 0.001232P_1^2$$

**Generator 2: Oil-fired steam unit**
Max output = 400 Mw; Min output = 100 Mw
Input-output curve:

$$H_2\left(\frac{MBtu}{h}\right) = 310.0 + 7.85P_2 + 0.00354P_2^2$$

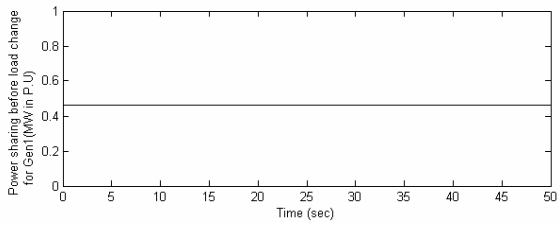
**Generator 3: Oil-fired steam unit**
Max output = 200 Mw; Min output = 50 Mw
Input-output curve:

$$H_3\left(\frac{MBtu}{h}\right) = 78.0 + 7.97P_3 + 0.001302P_3^2$$

The fuel costs for the units considered in area 1 and area 2 are given below:

**Generator 1:** fuel cost = 1.1 R/MBtu; **Generator 2:** fuel cost = 1.0 R/MBtu; **Generator 3:** fuel cost = 1.0 R/MBtu

A two area system is used to illustrate the behavior of the proposed AGC scheme. The theoretical base point generations obtained with the help of λ-iteration procedure and the obtained simulated values for the above units in area 1 for a load of 850 MW and 950 MW are shown in Table-1 which is represented by Figures 3 and 4.

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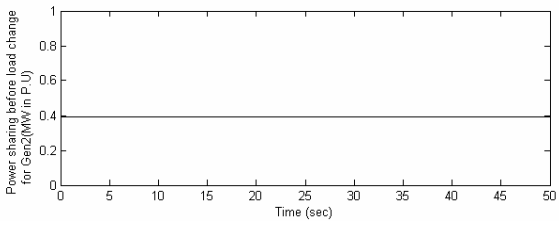


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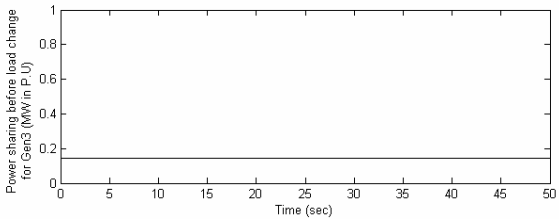


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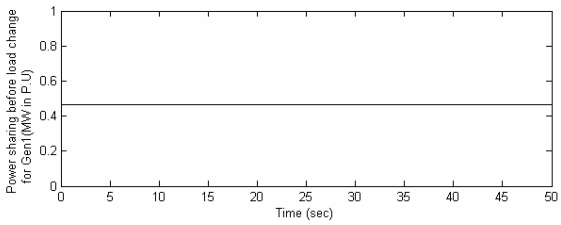
**Figure-3.** Load shared by each generator in area-1 for a load of 850 MW.

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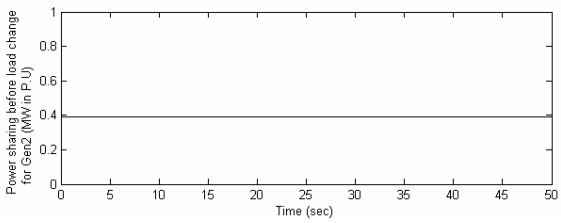


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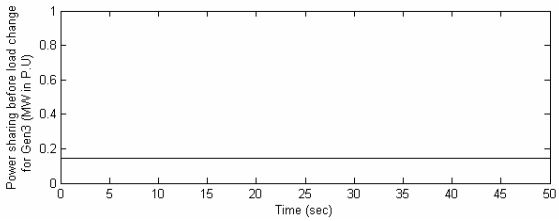


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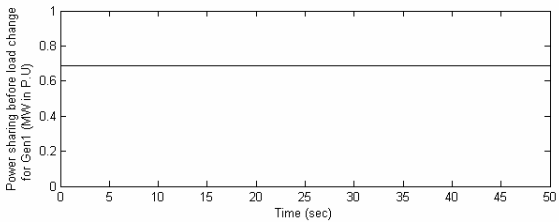
**Figure-4.** Load shared by each generator in area-1 for a load of 950 MW.

The theoretical base point generations and the obtained simulated values for the above units in area 2 for a load of 850 MW and 750 MW are shown in Table-2 which is graphically represented by Figures 5 and 6.

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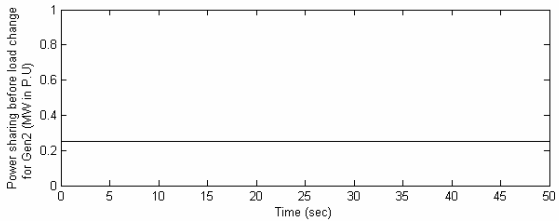


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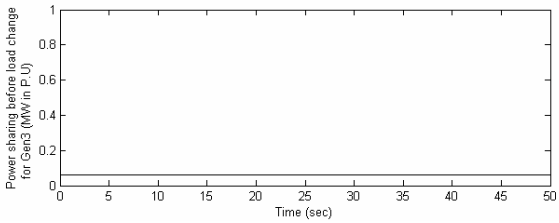


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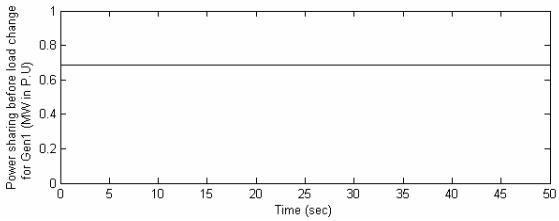
**Figure-5.** Load shared by each generator in area-2 for a load of 850 MW.

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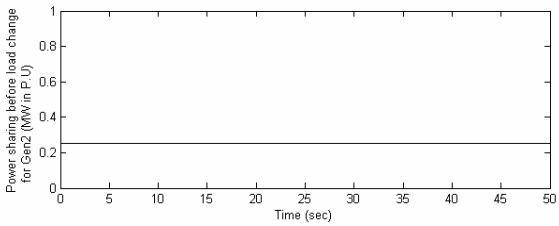


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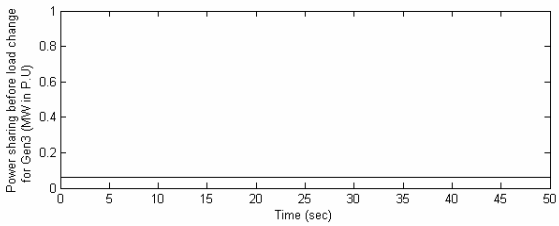


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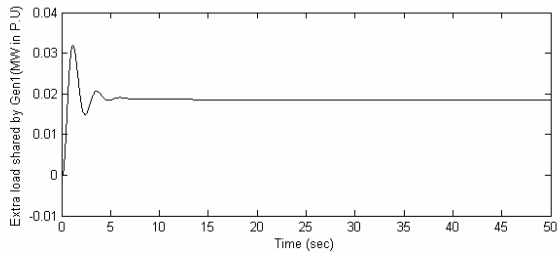
**Figure-6.** Load shared by each generator in area-2 for a load of 750 MW.

The participation factors and the extra load generations for the above units in area 1 for a load of 900 MW and 1000 MW are shown in Table-3 which is graphically represented by Figures 7 and 8.

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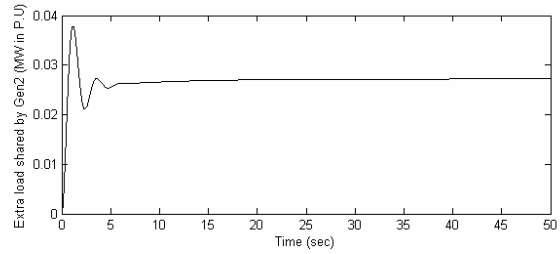


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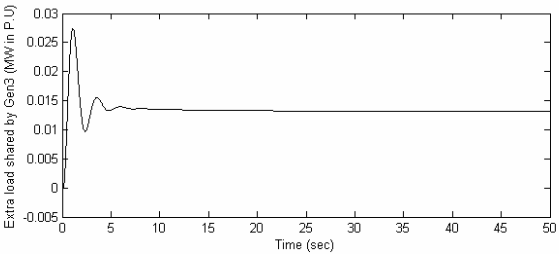


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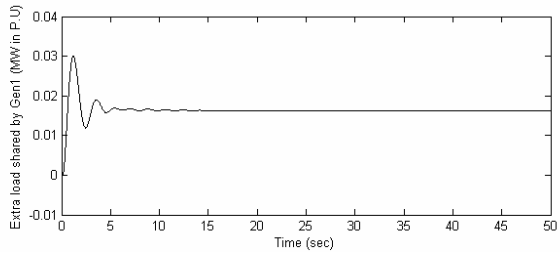
**Figure-7.** Extra load generation in area-1 for a load change of 50 MW.

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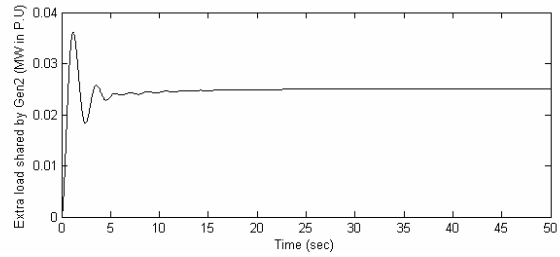


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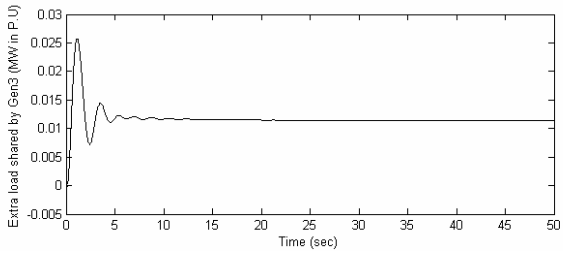


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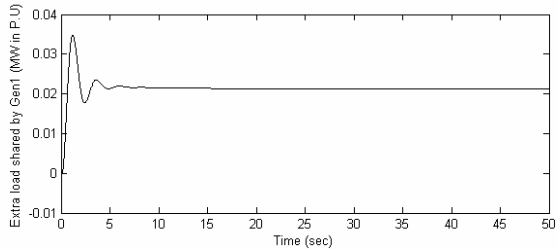
**Figure-8.** Extra load generation in area-1 for a load change of 50 MW.

The participation factors and the extra load generations for the above units in area 2 for a load of 900 MW and 800 MW are shown in Table-4 which is graphically represented by Figures 9 and 10.

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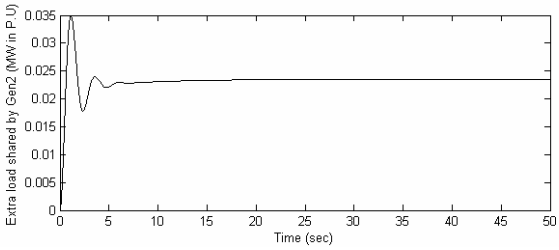


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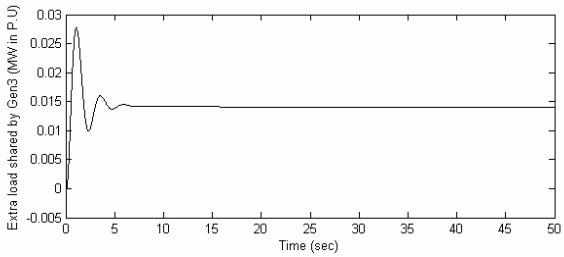


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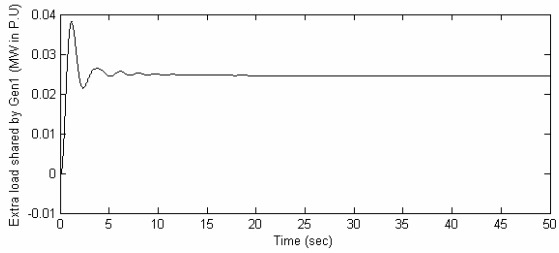
**Figure-9.** Extra load generations in area-2 for a load change of 50 MW.

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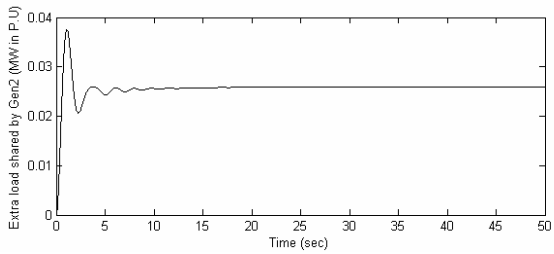


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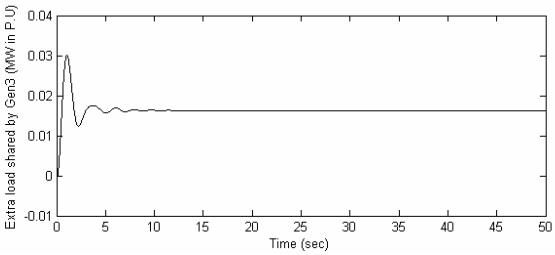


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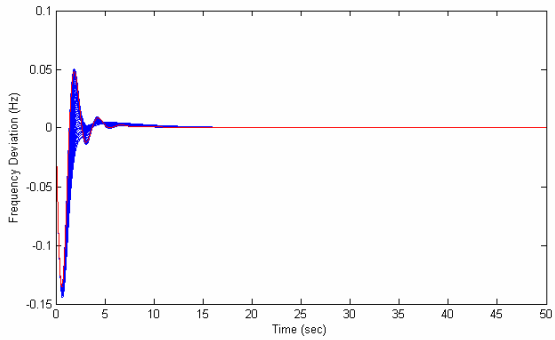
**Figure-10.** Extra load generations in area-2 for a load change of 50 MW.

The frequency deviations for above cases with the Hooke-Jeeves method are given in Figure-11.

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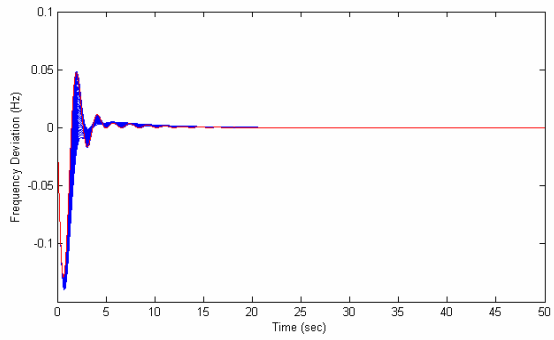
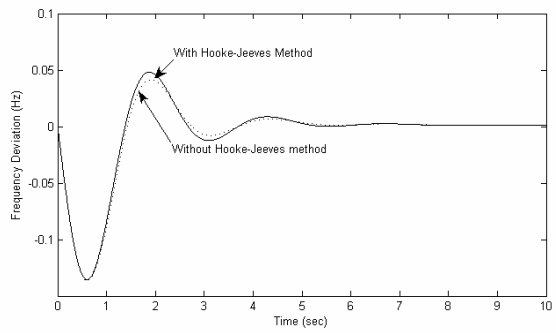



(b)

**Figure-11.** Frequency deviations (a) with equal loads of 850 MW (b) with unequal loads of 950 MW and 750 MW.

In the proposed method, to get the optimal value for integral controllers, Hooke-Jeeves method was used. For the Hooke-Jeeves method the starting step has been taken as 0.5 and 0.5. The perturbation factor has been taken as 0.05 and the termination factor has been taken as 0.001. In Figure-11, the blue lines indicate the frequency deviation for each iteration and the red colored line indicates the frequency deviation at the optimum value of integral controller. The optimal values of integral controllers in both areas obtained through Hooke-Jeeves method for equal loads of 850 MW and unequal loads of 950 and 750 MW are shown in Table-5.

The frequency deviations with and without the Hooke-Jeeves method have been compared and shown in Figure-12. The performance indices for the loads of 850 MW and 950 MW with and without the Hooke-Jeeves method have been compared and shown in Figure-13. From Figures 12 and 13, it can be observed that the proposed Hooke-Jeeves method gives the better performance.

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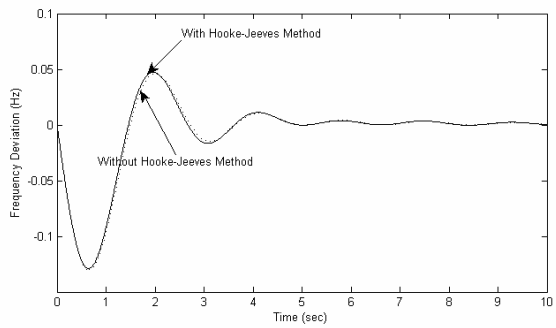


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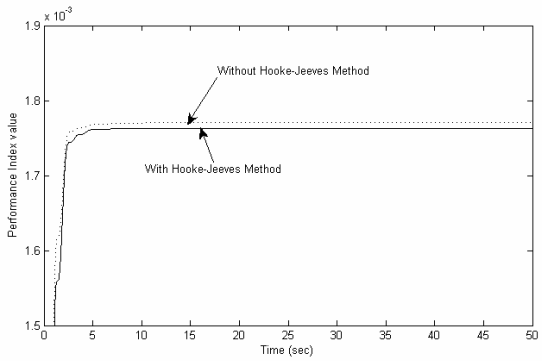
**Figure-12.** Comparison of frequency deviations with and without Hooke-Jeeves method for the loads of 850 MW and 950 MW.

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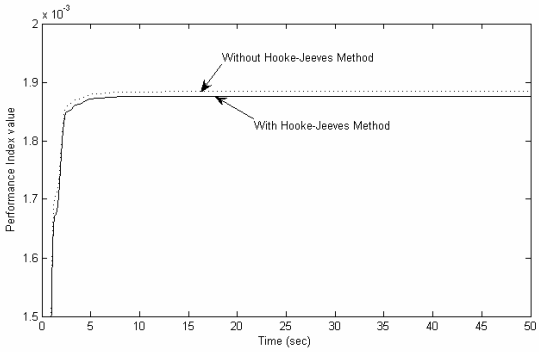
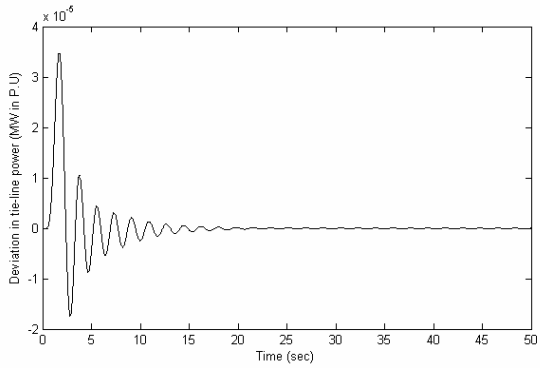



(b)

**Figure-13.** Comparison of performance index (error) values with and without Hooke-Jeeves method for the loads of 850 MW and 950 MW.

The tie-line power deviations with the equal load of 850 MW for area-1 and area-2 and with unequal loads 950 MW and 750 MW for area-1 and area-2, respectively are shown in Figure-14.

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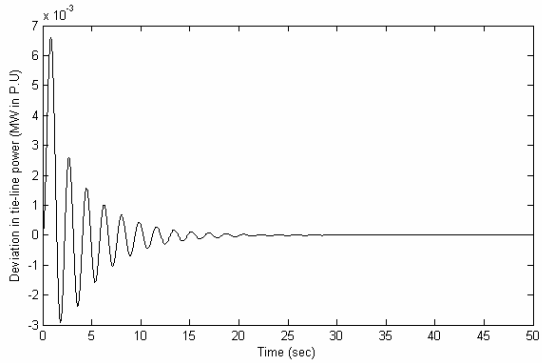


(b)

**Figure-14.** Deviation in the tie-line power (a) with equal load of 850 MW (b) With unequal loads of 950 MW and 750 MW.

## 6. CONCLUSIONS

The integral gain has been optimized by Hooke-Jeeves algorithm and the performance of the controller in two area system along with economic load dispatch has been reported. The determination of actuating signal to governor is rather easier in a normal two area system because the only goal is to satisfy the load demand at all time. But the task of AGC is becoming complicated when the concept of economic load dispatch is considered along with it. The author has considered all the aspects of economic load dispatch along with the AGC of a two area system.

**Table-1.** Comparison of base point generations for area-1.

| S. NO. | Total Load | Load shared by each generator in area-1( theoretically) | | | Load shared by each generator in area-1(Simulated values) | | |
|---|---|---|---|---|---|---|---|
| | | Gen1 | Gen2 | Gen3 | GEN 1 | GEN 2 | GEN 3 |
| 1 | 850(1PU) | 0.4623 | 0.3936 | 0.1437 | 0.463 | 0.4 | 0.153 |
| 2 | 950 (1pu) | 0.4633 | 0.3920 | 0.1446 | 0.4599 | 0.410 | 0.145 |

**Table-2.** Comparison of base point generations for area-2.

| S. NO. | Total Load in area-2 | Load shared by each generator in area-2( theoretically) | | | Load shared by each generator in area-2(Simulated values) | | |
|---|---|---|---|---|---|---|---|
| | | GEN 1 | GEN 2 | GEN 3 | GEN 1 | GEN 2 | GEN 3 |
| 1 | 850(1PU) | 0.6866 | 0.2506 | 0.0627 | 0.690 | 0.261 | 0.0631 |
| 2 | 750 (1pu) | 0.6858 | 0.2518 | 0.06233 | 0.695 | 0.263 | 0.0631 |

**Table-3.** Participation factors and the extra load generations in area-1.

| S. NO. | New load in area-1 | Participation factors | | | Load shared by each generator | | |
|---|---|---|---|---|---|---|---|
| | | PF1 | PF2 | PF3 | GEN 1 | GEN 2 | GEN 3 |
| 1 | 900 | 0.4697 | 0.3781 | 0.1522 | 0.4901 | 0.4158 | 0.1527 |
| 2 | 1000 | 0.4697 | 0.3781 | 0.1522 | 0.4880 | 0.4119 | 0.1526 |

**Table-4.** Participation factors and the extra load generations in area-2.

| S. NO. | New load in area-2 | Participation factors | | | Load shared by each generator | | |
|---|---|---|---|---|---|---|---|
| | | PF1 | PF2 | PF3 | GEN 1 | GEN 2 | GEN 3 |
| 1 | 900(1PU) | 0.6932 | 0.2412 | 0.0656 | 0.7274 | 0.2648 | 0.0665 |
| 2 | 800 (1pu) | 0.6932 | 0.2412 | 0.0656 | 0.7320 | 0.2679 | 0.0667 |

**Table-5.** Integral controller values for area-1 and area-2.

| S. No | Type of Load | Integral controller( $K_{I1}$ ) | Integral controller( $K_{I2}$ ) |
|---|---|---|---|
| 1 | For equal load of 850Mw | 1.0672 | 1.0656 |
| 2 | For unequal loads of 950 and 750 MW | 1.0961 | 0.9859 |

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