Automatic Generation Control of Three Area Hydro-Thermal Power Systems considering Electric and Mechanical Governor with conventional controller and Ant Colony Optimization technique

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A B S T R A C T
This paper presents the dynamic performance of interconnected three area hydrothermal power systems with conventional controllers. In this work, area 1 and area 2 consists of thermal power plant while area 3 consists of hydro power plant. The thermal and hydro power plant incorporate with reheat turbine and either mechanical governor or electric governor respectively. The conventional PI and PID controller is used in load frequency control. The Integral Time Absolute Time Error (ITAE) objective function is used for the design of conventional controller gain and Ant Colony Optimization technique is considered for tuning of PID controller gain with ITAE objective function. Performance of mechanical and electric governor is compared with and without considering generation rate constraint effects. Also the performance of Electric governor is studied with conventional I, PI controller and ACO based PID controller. The simulation result shows that electric governor improves the control performance more efficiently than the mechanical governor and ACO optimization technique give better controlled performance. One percentage of step load has been considered in either area of the system for this investigation.

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INTRODUCTION

Nowadays electrical device has become the basic need of human day to day life. But going on to the technical way due to this need there is a huge variation in the load as the number of users will vary from time to time. In order to fulfill these variations in load, n number of power systems (generally hydropower systems or thermal power systems) are connected to each other through tie lines (Report, I.C, (1973); Nagrath and Kothari (1994); Elgerd (1970)). Interconnecting the control areas are useful because,

1. It makes the system more reliable by delivering the power to the system. Even if there is any damage to any of the area.
2. It makes small frequency deviations during change in load by exchanging the load among the areas through tie lines.

During the variations in load, these n number of areas distribute the load among themselves. When load to a system varies, the speed of the turbine starts varying which effects the generation of desired amount of power. Thus there arises fluctuations and disturbance in the frequency. These fluctuations depend on the maximum or minimum overshoot and settling time. The main aim of this paper is to decrease the maximum or minimum overshoot and reduce the settling time near to zero. This paper deals with three area power plant in which two are thermal plant and one is hydro power plant. 1% of load is applied to any one of the power plant and the variation in frequency of the areas and tie lines are observed. ACO optimized PID controller is introduced in the system to modify the error signal and to produce a control signal so as to control the variations and fluctuations in frequency. Optimized value of gain is calculated using ITAE optimization technique so as to get better system performance (Jagatheesan and Anand (2012)).
Two control loops, which are used to maintain the voltage and frequency variations are Automatic Voltage Regulator (AVR) and Automatic Load Frequency Control loop (ALFC) (Nagrath and Kothari (1994); Kundur (1994); Elgerd (1970)). The primary objective of load frequency control is to regulate the frequency to a specified nominal value and to maintain the interchange power between control areas.

System Investigated:

The investigated system consists of three generating areas. Area1, area2 and area3 are thermal, thermal and hydro power system respectively. Fig.1 shows the simulink AGC model of three area hydro-thermal power system (Jagatheesan and Anand (2012); Nanda and Mishra (2010)). In practical, there exists a maximum and minimum limit on the rate of change in the generating power. A GRC of the order of 0.0017puMW-1 for thermal power system and 4.5% sec-1 for rising generation and 6% sec-1 for lowering generation is considered for this present work (Nanda and Mishra (2010); Anand and Ebenezer Jeyakumar (2009a)).

![Block diagram for AGC of Three area Hydro-Thermal power systems with Reheater, Mechanical, Electric Governor and Generation Rate Constraint](image)

Fig. 1: Block diagram for AGC of Three area Hydro-Thermal power systems with Reheater, Mechanical, Electric Governor and Generation Rate Constraint

The thermal and hydro plants are equipped with single stage reheat turbine and either mechanical or electric governor respectively. The advantage of replacing mechanical governor with electric governor is that the electronic components are used to perform low power with speed sensing and droop compensation. Electronic components deliver greater flexible and improved performance in the presence of dead band and dead time. So the selection of suitable electric governor parameter is very important (Nanda et al. (2006); Anand and Ebenezer Jeyakumar (2009b)) . Otherwise improper selection of these parameters yields instability in system response. The interconnected power system parameters are given in the appendix of (Anand and Ebenezer Jeyakumar (2009a); Anand and Ebenezer Jeyakumar (2009b)).

In figures 2 and 3, the frequency deviations of area1 and the tie-line power deviation for a 1% step load perturbation in thermal area 1 are shown, respectively. In the figures, the results shows the open loop comparisons of mechanical and electric governor without considering GRC non-linearity.
The figures 4 and 5, show the open loop frequency deviation in area1 and tie-line power deviation in area 1 respectively. These responses clearly indicate that the electric governor always yields minimum damping oscillations with better settling and less steady state error compared to the mechanical governor with and without considering Generation Rate Constraint (Anand and Ebenezer Jeyakumar (2009b)).
Fig. 5: Open loop response comparisons with GRC (ΔP_{tie})

Conventional Controllers:  
A controller is a device introduced in the system to modify the error signal and produce a control signal. The controllers basically modify or control the variations in the response Constraint (Anand and Ebenezer Jeyakumar (2009b); Nagrath and Gopal (2007); Gopal (2002)).

Integral Controller:  
The integral controller is a device that produces a control signal u(t) which is proportional to integral of the input error signal e(t) (Gopal (2007)).

In I-controller,
\[ u(t) = K_i \int_0^t e(t) \, dt \]  
(1)

Where, \( k_i \) = integral gain constant,

On taking Laplace transform of the above equation with zero initial condition,
\[ U(S) = K_i \frac{E(S)}{S} \]  
(2)

Transfer function of I-controller,
\[ \frac{U(S)}{E(S)} = \frac{K_i}{S} \]  
(3)

The main aim of integral controller is to remove or reduce the steady state error, but the minimum or maximum overshoot is not controlled by this controller which makes the system unstable.

Proportional Plus Integral Controller:  
The proportional plus integral controller (PI-controller) produces an output signal consisting of two terms: one proportional to the error signal and the other proportional to the integral of error signal (Gopal (2007)). In PI controller,
\[ u(t) = K_p e(t) dt + \int_0^t e(t) \, dt \]  
(4)

Where, \( k_p \) =proportional gain, \( T_i \) = integral time.

On taking the Laplace transform of the above equation with zero initial condition,
\[ U(S) = K_p E(S) + \frac{K_p}{T_i} E(S) \]  
(5)

Transfer function of PI-controller,
\[ \frac{U(S)}{E(S)} = K_p \left(1 + \frac{1}{T_i S}\right) \]  
(6)

The advantage of both P and I controller are combined in PI-controller. The proportional controller increases the loop gain which makes the system less sensitive to load variations i.e. reduces the maximum or minimum overshoot value, while the integral action reduces the steady state error. The integral control action is adjusted by varying the time integral. The change in value of \( k_p \) affects both the proportional and integral parts of control action.

The integral and proportional controller gain values are optimized by using ITAE criterion(Jagatheesan and Anand (2012)). The cost function of ITAE is given by the equation 9.

\[ J = \int_0^T e(t) \, dt \]  
(7)

Where
\( e(t) \) =Error signal, \( dt \) =Small time interval during sample

The optimal values of Integral and Proportional-Integral controller gain values are chosen here, on the basics of a performance index(Eqn. 9). The performance index curves are shown in Fig.6 and Fig. 7.
Proportional Gain $K_p$
Performance Index $J$

Fig. 6: Performance Index Curve for Electric Governor without GRC using ITAE objective function

Ant Colony Optimization technique:

Ant colony optimization technique was introduced by M.Dorigo and colleagues in early 1900s as a novel nature inspired metaheuristic for the solution of combinatorial optimization problem [Omar et al. 2013; Ying et al. 2004]. The behavior of real ant in searching the source of food, it evident that shortest path having large pheromone concentrations, so more ants tends to choose and travel in the path. There are there major phase in Ant Colony Algorithm namely

- Initialization
- Constructing ant solution
- Updating pheromone

The optimal gain values of PID controller using Ant Colony Optimization technique with Integral Time Absolute Error (ITAE) cost function is given in Table 1.

Table 1: Optimal Gain values of PID controller by using Ant Colony Optimization Technique

<table>
<thead>
<tr>
<th>Proportional Gain ($K_p$)</th>
<th>Integral Gain($K_i$)</th>
<th>Derivative Gain($K_d$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{p1}$</td>
<td>$K_{p2}$</td>
<td>$K_{p3}$</td>
</tr>
<tr>
<td>5.8</td>
<td>6.2</td>
<td>0.033</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Matlab version 7.5.0(R2007b) has been used to obtain the dynamic responses for a SLP (Step Load Perturbation) of 1% in thermal area 1. The simulation incorporates with electric and mechanical governor with and without Generation Rate Constraint effects. The conventional PI controller is implemented in this investigation and comparisons are made between the electric and mechanical governor with SLP. Also, the performance of I and PI controller is compared with electric governor.
Fig. 8: Change in frequency in area 1 without GRC

Fig. 9: Change in Tie-line Power without GRC

The figures 8 to 9 show the comparison of performance of mechanical and electric governor. The various frequency deviations and tie line power deviations in thermal area 1 and hydro area 3 without presence of GRC are shown in the figures. It can be seen from the figures that the system with Electric governor has better controlled performance in terms of peak overshoot and settling time than that of Mechanical governor.

Fig. 10: Change in frequency in area 1 with GRC
Fig. 11: Change in Tie-line Power with GRC

The figures 10 to 11 show the performance comparison of mechanical and electric governor. The various frequency deviations and tie line power deviations in thermal area 1 with presence of GRC are shown in the figures. It can be seen from the figures that the system with Electric governor has better controlled performance in terms of peak overshoot and settling time than that of Mechanical governor.

Fig. 12: Response with I and PI controller ($\Delta f_1$)

Fig. 13: Response with I and PI controller ($\Delta P_{tie}$)

The figures 12-13 shows the comparison of performance of conventional I and PI controller. The various frequency deviations, tie line power deviations in thermal area 1 and hydro area 3 with presence of GRC as shown figures. It can be seen from the figures that the system with conventional PI has better controlled performance in terms of peak overshoot and settling time than that of conventional I controller.

Fig. 14: Response with conventional PI and ACO-PID controller ($\Delta f_1$)
The frequency deviations in area 1 and tie line power deviations between thermal area 1 and hydro area 3 with presence of GRC as shown figures. It can be seen from the figures that the system with ACO-PID controller has better controlled performance in terms of settling time than that of conventional PI controller. Overshoots in the tie line power deviations are effectively reduced by ACO-PID controller. But in frequency response oscillations are reduced but overshoots are effectively reduced compare to conventional controller.

Table 2: Performance comparison of I, PI and ACO-PID controller

<table>
<thead>
<tr>
<th>Controller</th>
<th>Frequency Deviation in area 1</th>
<th>Tie-line power deviation in area 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Settling Time (sec)</td>
<td>PI</td>
</tr>
<tr>
<td>Settling Time (sec)</td>
<td>91</td>
<td>84</td>
</tr>
<tr>
<td>Peak Overshoot</td>
<td>0.0001</td>
<td>0.005</td>
</tr>
<tr>
<td>Peak Undershoot</td>
<td>-0.011</td>
<td>-0.023</td>
</tr>
</tbody>
</table>

Table shows the comparison performance of the Interconnected hydro-thermal AGC system with the presence of conventional I, PI and ACO-PID controller. It can be pragmatic that system with conventional I and PI controller has poor performance than that of the system with ACO-PID controller which demonstrates the superiority of the system in the presence of mechanical governor and I and PI controller.

Conclusion:

The performance for mechanical and electric governors are obtained with and without considering the effect of Generation Rate Constraint. Dynamic performance of AGC system shows that the electric governor always yields better controlled response compared to mechanical governor with and without GRC non-linearity. Similarly conventional Integral(I), Proportional-Integral(PI) and ACO optimization technique based PID controllers are implemented in AGC system. The simulation results reveal that Ant Colony Optimization (ACO) controller guarantee for minimum damping oscillation with good settling compared to Integral and Proportional - Integral controller response with and without considering the effects of non-linearity.

REFERENCES


