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Automatic Generation control of interconnected hydrothermal power plant Using classical and soft computing Technique

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ABSTRACTS
Load-frequency control (LFC) is a part of the Automatic Generation Control (AGC) in power systems, the aim of which is to maintain the system frequency and tie line flow at their scheduled values during normal period in an interconnected system. This research paper is devoted to explore the interconnection of the load frequency control of hydro power system and the thermal system. The thermal system is comprised with governor dead band, generation rate constraint and boiler dynamics where as the hydro system is comprised with generation rate constraint. The conventional PID controller does not have adequate control performance with the consideration of nonlinearities and boiler dynamics. To overcome this drawback, Genetic Algorithm helps in solving optimization problems by exploitation of random search. The aim of the proposed expert controller is to restore the frequency to its nominal value in the smallest possible time whenever there is any change in the load demand etc.

Keywords: LFC (Load Frequency Control), AGC (Automatic Generation Control), Conventional Controllers like Integral Controller and PID Controller, genetic algorithm.

I. INTRODUCTION

The Generation system is basically the heart of any power system. The collapse of generation system leads to the biggest failure of the utility system, the recovery is not only time consuming but tougher than any other system such as Transmission and Distribution system. Increased industrialization and better standard of living become possible with increased availability and consumption of electrical energy. To satisfy the increased demand for electric power, it becomes necessary to use all the sources of power generation in the country for the development of maximum electric power. In modern power system network, there are number of generating utilities like gas, nuclear, hydro and thermal power generation and are inter connected together through tie-lines. In order to achieve integrated operation of a power system, an electric energy system must be maintained at a desired operating level characterized by nominal frequency, voltage profile and load flow configuration. In an interconnected power system, it is desirable to maintain the tie line flow at a given level irrespective of the load change in any area. To accomplish this, it becomes necessary to manipulate the operation of main steam valves or hydro gates in accordance with a suitable control strategy, which in turn controls the real power output of the generators [1]. The control of the real power output of electric generators in this way is termed as Automatic Generation Control (AGC). The main objectives behind the design of AGC are:

- The steady state frequency error following a step load perturbation should be zero.
- The steady state change in the tie flow following a step load change in an area must be zero.
- An automatic generation controller providing a slow monotonic type of generation

Responses should be preferred in order to reduce wear and tear of the equipment.

In a power system the load demand is continuously changing. In accordance with it the power input has also to vary. If the input- output balance is not maintained change infrequency will occur. Steam input to turbo generators (or water input to hydro-generators) must therefore, be continuously regulated to match the active power demand, failing which may be highly undesirable (maximum permissible change in power frequency is ± 0.5 Hz). Also the excitation of generators must be continuously regulated to match the reactive power demand with reactive generation, otherwise the voltages at various system buses may go beyond the prescribed limits. In modern large interconnected power system, manual regulation is not feasible and therefore automatic generation and voltage regulation equipment is installed on each generator. The controllers are set for particular operating conditions and they take care of small changes in load demand without frequency and voltage exceeding the prescribed limits. With the passage of time, as the change in load demand becomes large, the controllers must be reset either manually or automatically.

II. DYNAMIC MODELING OF INTERCONNECTED HYDRO-THERMAL SYSTEM

Modern power system network normally consists of a number of subsystems interconnected through tie lines. For each subsystem the requirements usually include pitching system generation to system load and regulating system frequency. This is basically known as load-frequency control problem. The Load Frequency control problem can be studied by considering coherent group of generators forming a control area that swing in unison under disturbance. Each control area is responsible for its native load and scheduled interchange with neighboring areas connected through tie lines. These tie lines are utilized for contractual exchange of power between areas and provide support in case of abnormal conditions. The main objective of Load Frequency Control is to maintain the system frequency and tie line flow at their scheduled values during normal period **[2], [3]**. Generation in large interconnected power systems consist of thermal and hydro power generation. However the characteristics of the hydro turbine differ from steam turbines in many respects:

1. The transfer function of the hydro-turbine represents a non-minimum phase system.
2. In a hydro turbine relatively large inertia of water, used as the source of energy, causes a considerable greater time lag in the response of the changes in the prime mover torque to a change in the gate position. Moreover, there is an initial tendency for the torque to change in a direction opposite to that finally produced.
3. In hydro turbine the response contains oscillating components caused by the compressibility of the water (and expansion of piping) or by surge tanks.
4. The hydro governor is provided with a relatively large temporary droop and long washout time. Modern hydro units are normally equipped with electric governors in which the electronics apparatus is used to perform low power functions associated with speed sensing and droop compensation. The electronic apparatus provides greater flexibility and improved performance in both dead band dead times.
5. The typical value of permissible rate of generation for hydro plant is relatively much higher (a typical value of generation rate constraints (GRC) being 270% per minute for raising generation and 360% per minute for lowering generation), as compared to that for reheat type thermal units having GRC of the order of 3% per minute.

2.1 Dynamic Model of Inter-connected Hydro-thermal System in Conventional Mode of LFC The LFC system investigated consists of two generating areas of equal size, area 1 comprising a reheat thermal system and area 2 comprising a hydro system. Hydro system is considered with electric governor. Generation Rate Constraint of the order of 3% per minute for thermal area and 270% per minute for rising and 360% per minute for lowering generation in hydro area has been considered. Fig.1 shows the LFC model with single stage reheat turbine in thermal 16 areas and electric governor in hydro area. The system model is considered for continuous-discrete mode operation. Generally ACE (Area Control Error) signal is not available in continuous form rather it is available in sampled form; therefore zero order hold is used before controller. Nomen clatur for various symbols is given below. The optimum values of derivative, proportional and integral gains for the electric governor have been taken from the work of Nanda et al. **[9].**

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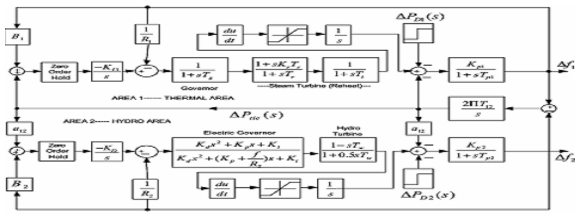
[9].2.2: system model:



Nomenclature:
F = (Nominal System Frequency)= 60 Hz
i = Subscript referred to area i (1, 2)
* = Superscript denotes optimum value
Pri = (Area rated Power)= 2000MW
Hi = (Inertia constant)= 5sec
ΔPDi = Incremental load change in area i
ΔPtie = Incremental tie power
Di = ΔPDi/ Δfi= 8.33 x 10-3 Pu MW/ Hz
T12 = Synchronizing coefficient= 0.086 Pu MW/radians
Ri = Governor speed regulation parameter= 2.4 Hz/PuMW
Tg = Steam governor time constant, second= 0.08 sec
Kr = Steam turbine reheat constant=0.5
Tr = Steam turbine reheat time constant= 10sec
Tt = Steam turbine time constant= 0.3 sec
Bi = Frequency bias constant= 0.424
Tpi = 2Hi/fDi= 20 sec
Kpi = 1/Di = 120Hz/Pu MW
KIi = Integral gain
KPi = Proportional gain
KDi = Derivative gain
Kd,Kp,Ki = Electric governor derivative, proportional, and integral gains, respectively
Bi = (Di + 1/Ri); area frequency response characteristics= 0.424
Tw = Water starting time= 1 sec
ACEi = Area control error of area i
A12 = −Pr1/Pr2 = -1
J= Cost index
2.3 Problem Formulation
For the system mentioned in Fig.1, the aim is to find the best control strategy such that following objectives are met:
1. The steady state frequency error following a step load perturbation should be zero.
2. The steady state change in the tie flow following a step load change in an area must be zero.
3. An automatic generation controller providing a slow monotonic type of generation responses should be preferred in order to reduce wear and tear of the equipment. When control structure is a major known our objective is to adjust the control parameter so as to achieve the best dynamic performance and this is only achieved by proper optimization of controller parameter[**12**]

The objective function used for controller design is that which is used in ISE criterion and this is as follows:

$J=\int t\ f\ (e12, e22, e32 \ldots en2)\ dt$

Where e1, e2, e3 … en are different errors.

In this case $J=\int t\ (\Delta f12 + \Delta f22 + \Delta Ptie2)$

2.4 System response with conventional controller

Here for two area hydrothermal LFC model, we have used ISE criteria to optimize the supplementary controllers. In the LFC model first we have chosen our control structure as integral one. ΔPtie (1,2) , Δf1 and Δf2 are consider as errors, 1% step load perturbation is consider in either thermal or hydro area. In the beginning consider second area as uncontrolled one and vary the integral controller gain for the first area and observe the performance index J by simulating the model. Plot performance index V/s Gain and select that value of gain for which Performance index is minimum. This is the suboptimal value of controller gain for first area. Similarly follow the same procedure for second are a keeping first area uncontrolled and find the Sub optimal gain for second area.[**16**][**17**][**18**][**19**] The value obtained for both areas are suboptimal values on Individual basis. However there is a coupling between optimal gains for two areas, which is to be fined tuned. In the second iteration the controller gains of first area is varied considering suboptimal gain for second area. Take plot for performance index V/s gain and find any change in first area gain for minimum performance index. Follow the same procedure for second area and carryout little iteration so as to get best values for optimum controller gain for both areas. In same Manner we have tuned the parameters of the PI controllers. Tuning of the PID controller has Been tried but when we plot the cost function for various values of derivative gain with different values of proportional and integral gain, it has been found that cost function is minimum for derivative gain equal to zero. [**12**] Therefore PI and PID controller will give the same response.

Therefore hereafter we are going to consider only integral and PI controller for dynamicresponse study.

3. Results and Analysis:

3.1 Simulation model hydro thermal system with PI controller

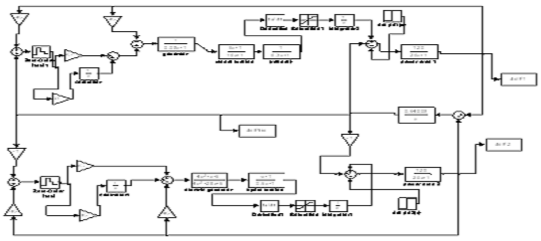


Figure 2. Model of hydrothermal system

Optimization of K_{i1}

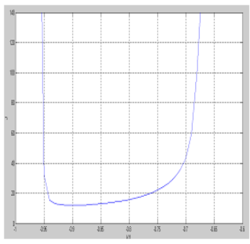


Figure 3: plot j v/s k_{i1}

Optimization of K_{i2}

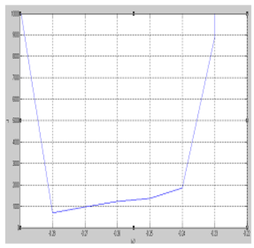


Figure 4 plot j v/s ki_2

In Figure 3, the graph between cost index (j) and integral controller (ki1) then choose the value of ki1 for optimum value of cost index (j). In this case we can choose the value for ki1= -0.94.

In Figure 4, the graph between cost index (j) and integral controller (ki2) then choose the value of ki2 for optimum value of cost index (j). In this case we can choose the value for ki2= -

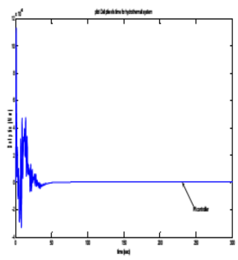


Figure 5: Variation of frequency for 1% step load change in thermal area

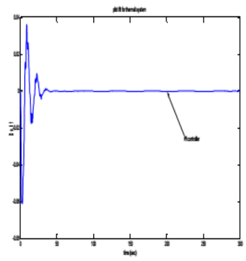


Figure 6: Variation of frequency for 1% step load change in hydro area

In Figure 5, the value find out of PI controller kp1= -0.061 and ki1= -0.43 and kp2= -0.11, ki2= -0.15, this graph shows the effect of PI controller on frequency change in thermal area In fig.6, the value find out of PI controller kp1= -0.061 and ki1= -0.43 and kp2= -0.11, ki2= -0.15, this plot shows variation in frequency for hydro area.

3.3 Simulation model of hydrothermal system with Genetic Algorithm

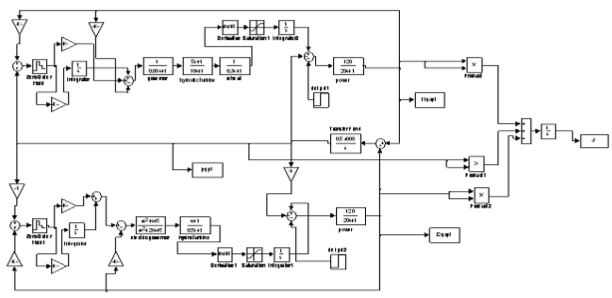


Figure 9. Simulation model of hydrothermal system with GA

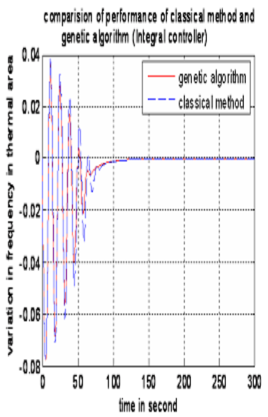


Figure 10. Performance curve between frequency V/s time

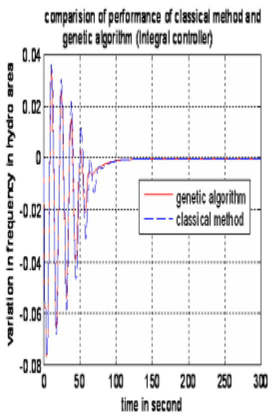


Figure 11. frequency in hydro area v/s time

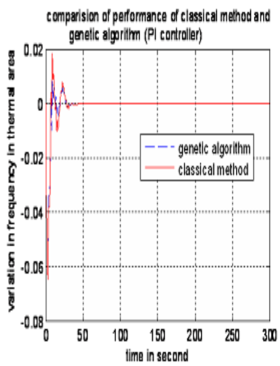


Figure 12. Frequency in thermal area v/s time

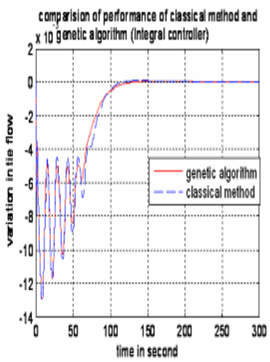


Figure 13. Variation in flow v/s time

n Figure 11, 12 & 13, the plot of frequency or flow with respect to time shows the
performance curve is very near to zero and steady state error is reduced by using Genetic Algorithm as compared to classical methods like Integral controllers.

IV. CONCLUSION

The Load Frequency Control of a two area power system having power generation from thermal sources in area-1 and from hydro sources in area-2 has been studied. The dynamic system responses have been simulated considering a 1% step load perturbation in either or simultaneous areas. The scheduled power generationsfrom thermal or Hydro are adjusted tomatch the system normal operating load. The PI or PID controller gains have been optimized .using genetic algorithm for various cases. The simulation results conclude that:

• Genetic algorithm yields fast settling time which advocates the smooth settlement of the quality power supply.

Genetic algorithm shows very good dynamic response than conventional integral controllers.

• Genetic algorithm explore very good result as compared to all the other controllers The presence of genetic algorithm in both the areas and a small step load perturbation in one area provides small steady state error.

REFERENCES

[1] O. I. Elgerd, C. E. Fosha, "Optimum Megawatt Frequency Control of Multi-area Electric Energy Systems", IEEE Trans. on Power Apparatus and Systems, vol.PAS-89, No.4, pp. 556-563, Apr. 1970.

[2] C. Concordia, L. K. Kirchmayer, "Tie-Line Power & Frequency Control of Electric Power Systems", AIEE Trans., vol. 72, part III, pp. 562-572, , 1953.

[3] C. Concordia, L. K. Kirchmayer, "Tie-Line Power & Frequency Control of Electric Power Systems- Part II", AIEE Trans., vol. 73, part III-A, pp. 133-141, 1954.

[4] C. E. Fosha, O. I. Elgerd, "The Megawatt Frequency Control problem: A New Approach via Optimal Control Theory", IEEE Trans. on Power Apparatus and Systems, vol. PAS-89, No.4, pp. 563-574, Apr. 1970.

[5] L. K. Kirchmayer, "Economic Control of Interconnected Systems", John Wiley, New York, 1959.

[6] Nathan Cohn, "Control of Generation & Power Flow on an Interconnected Power Systems", John Wiley, New York, 2ndEdition, July 1971.

[7] Nathan Cohn, "Some Aspects of Tie-Line Bias Control on Interconnected Power Systems", AIEE Trans., vol. 75, pp. 1415-1436, , Feb. 1957.

[8] IEEE Committee Report, "IEEE Standard Definition of Terms for Automatic Generation Control of Electric Power Systems", IEEE Trans. Power Apparatus and Systems, vol. PAS-89, pp. 1358-1364, Jul. 1970.

[9] J. Nanda, B. L. Kaul, "Automatic generation Control of an Interconnected Power System", IEE Proc.,vol. 125, No.5, pp. 385-391, May 1978.

[10] J. Nanda, M. L. Kothari, P. S. Satsangi, "Automatic Generation Control of an Interconnected Hydrothermal System in Continuous and Discrete modes considering Generation Rate Constraints", IEE Proc., vol. 130, pt. D, No.1, pp 17-27, Jan. 1983.

[11] Power plant responses," IEEE Committee report, IEEE Trans. Power Apparatus & Systems, vol. PAS-86, pp. 384-395, Mar. 1967.

[12] IEEE Committee Report, "Dynamic Models for steam and Hydro Turbines in Power System Studies", IEEE Trans. Power Apparatus & systems, pp. 1904-1915, Dec. 1973.
[13] D.G. Ramey, J. W. Skooglund, "Detailed Hydro governor representation for System stability Studies", IEEE Trans. on Power Apparatus and Systems, vol. PAS-89, pp. 106-112, Jan. 1970.
[14] M. Leum, "The Development and Field Experience of a Transistor Electric Governor for Hydro Turbines," IEEE Trans. Power Apparatus & Systems, vol. PAS-85, pp. 393-402, Apr. 1966.
[15] M. L. Kothari, B. L. Kaul, J. Nanda, "Automatic Generation Control of Hydro-Thermal System", Journals of Institute of Engineers (India), pt. EL-2, vol. 61, pp. 85-91, Oct. 1980.
[16] M. L. Kothari, J. Nanda, P. S. Satsangi, "Automatic Generation Control of Hydro-Thermal System considering Generation Rate Constraint", Journals of Institute of Engineers (India), pt. EL, vol. 63, pp. 289-297, June 1983.
[17] F. R. Schleif, A. B. Wilbor, "The Co-ordination of Hydraulic Turbine Governors for Power System Operation," IEEE Trans. Power Apparatus and Systems, vol. PAS-85, No.7, pp. 750-758, Jul. 1966.
[18] L. Hari, M. L. Kothari, J. Nanda, "Optimum Selection of Speed Regulation Parameter for Automatic Generation Control in Discrete Mode considering Generation Rates Constraint", IEEE Proc., vol. 138, No.5, pp. 401-406, Sept 1991.
[19] P. Kundur, "Power System Stability & Control," McGraw-Hill, New York, pp. 418-448, 1994.
[20] Richard D. Christie, Anjan Bose, "Load Frequency Control Issues in Power System Operations after Deregulation", IEEE Transactions on Power Systems,