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Implementation of Load Frequency Control of Multi Area Hydrothermal System under Deregulation Considering Generation Rate Constraint

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Abstract—*This paper deals with the improvement of dynamic response of Load Frequency Control (LFC) of interconnected multi area hydrothermal system under deregulation provided with Generator Rate Constraint (GRC). The GRC is imposed to both thermal and hydro area respectively. The variations in area frequencies and tie-line power with 0.4% step load disturbances in both areas are considered. The simulation results are compared without and with GRC; which shows that better dynamic response in terms of peak time, overshoot and settling time with GRC.*

Keywords*: Load Frequency Control, Generator Rate Constraint, Dynamic Response, Hydrothermal System*

1. INTRODUCTION

In an interconnected power system, the area frequency and tie-line power varies with load variations. The successful operation of a power system is the process of properly maintaining several sets of balances. Two of these balances are between load-generation and scheduled and actual tie line flows. One of the functions of Automatic Generation Control (AGC) is to minimize these deviations and to ensure zero steady state error. The LFC was developed to both maintain constant frequency and to regulate tie line power flow. Kirchmayer et. al [1] has studied the LFC of a hydro-thermal system considering non-reheat type thermal system neglecting generation rate constraints. Kothari et. el [2] have investigated the LFC problem of a hydro-thermal system provided with integral type supplementary controllers. It is to be appreciated that in a realistic situation, the system works in the continuous mode whereas the controllers work in the discrete mode. J. Nanda et. al [3] is the first to present comprehensive analysis of LFC of an interconnected hydrothermal system in continuous-discrete mode with classical controllers.

The electric power industries has been transformed to deregulated market and provide power at regulated rates to an industry that will incorporate competitive companies selling unbundled power at lower rates. Under open market system (deregulation) the power system structure changed in such a way that would allow the evolving of more specialized industries for generation (GENCOs), transmission (TRANSCOs) and distribution (DISCOs). A detailed study on the control of generation in deregulated power systems is given in [4]. The concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has also emerged [5, 6]. The detailed assessment and issues on AGC in a deregulated environment is given in [7] and also explains how an AGC system could be simulated after deregulation. The effect of bilateral contracts in an AGC system after restructuring is simulated and discussed in [8]. The AGC parameters are simulated and optimized after deregulation is given in [9]. The bilateral contract between two area hydrothermal system under open market scenario is simulated [10]. There is no attempt has been made LFC of multi area system with GRC under restructured network. This paper investigates the effect of GRC in multi area hydrothermal system under deregulated environment.

In view of this, the paper is organized as follows: Section-2 explains the mathematical model of hydrothermal system. The generation rate constraint has been presented in Section-3. Section-4 presents the results and discussions and some conclusions are drawn in Section-5.

2. MATHEMATICAL MODEL OF HYDROTHERMAL SYSTEM

The Load Frequency controller controls with High Pressure (HP) turbine at very small load variations. 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 [11]. Two system nonlinearities likely Governor Dead band and Generation Rate Constraint (GRC) is considered here for getting the realistic response. Governor Dead band is defined as the total magnitude of the sustained speed change within which there is

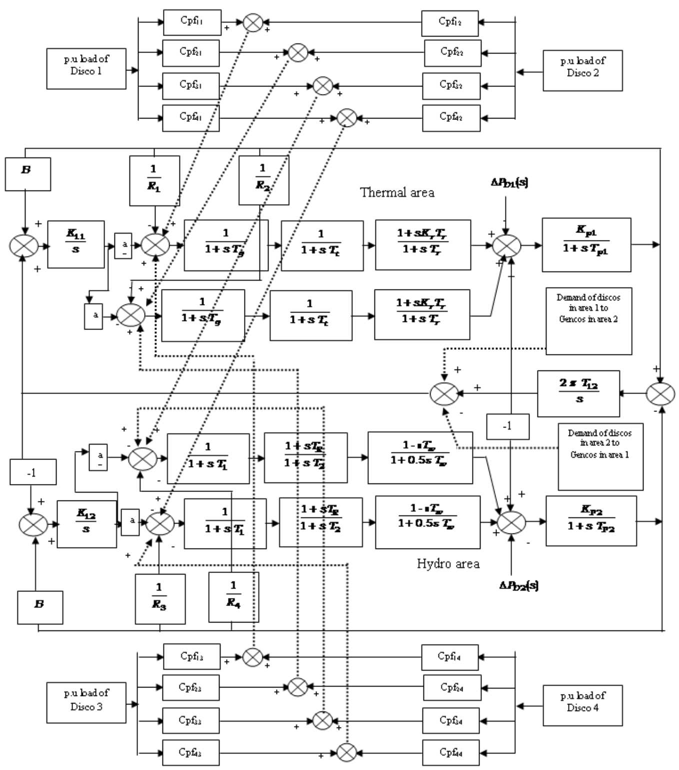


Fig. 1: Two area hydrothermal LFC block diagram under Open Market Scenario.

no change in the valve position [11]. It is required to avoid excessive operation of the governor. GRC is considered in real power systems because there exist a maximum limit on the rate of change in the generating power. Fig. 1 shows the two area hydrothermal LFC block diagram under open market scenario.

In the restructured environment, Gencos sell power to various Discos at competitive prices. Thus, Discos have the liberty to choose the Gencos for contracts. They may or may not have contracts with the Gencos in their own area. This makes various combinations of Genco-Disco contracts possible in practice. The concept of a Disco Participation Matrix (DPM) is a matrix with the number of rows equal to the number of Gencos and the number of columns equal to the number of Discos in the system. Each entry in this matrix can be thought of as a fraction of total load contracted by a Disco (Column) towards a Genco (row). Thus, the ij^{th} entry corresponds to the fraction of the total load power contracted by Disco 'j' from a Genco 'i'. The sum of all the entries in a Column in this matrix is unity. DPM shows the participation of a Disco in a contract with Genco; hence the name "Disco Participation Matrix". Whenever a load demanded by a Disco changes it is reflected as a local load in the area to which this Disco belongs. This corresponds to the local loads ΔP_{L1} and ΔP_{L2} which should be reflected in the deregulated AGC system block diagram at the point of input to the power system block. As there are many Gencos in each area, Area Control Error signal has to be distributed among them in proportion to their participation in the AGC. Coefficients that distribute ACE to several Gencos are termed as "ACE participation factors" (apfs). It should be noted that $\sum_{j=1}^{m} apf_j = 1$ where m is the number of Gencos. Unlike in the traditional LFC system a Disco demands a particular Genco for load power. These demands must be reflected in the dynamics of the system. Turbine and governor units must respond to this power demand.

Thus as a particular set of Gencos are supposed to follow the load demanded by a Disco, information signals must flow from a Disco to the particular Genco specifying corresponding demands. The demands are specified by contract participation factor (cpf) and the p.u. Mw load of a Disco. These signals carry information as to which Genco has to follow a load demanded by which Disco. The scheduled steady state power flow on the tie line is given as

$\Delta P_{tie12,scheduled}$ = (demand of Discos in area 1 to Gencos in area 2) - (demand of Discos in area 2 to Gencos in area 1)

At any time the tie line power error $\Delta P_{tie12,error}$ is defined as

$$\Delta P_{tie12,error} = \Delta P_{tie12,actual} - \Delta P_{tie12,scheduled} \quad (1)$$

$\Delta P_{tie12,error}$ vanishes in the steady state as the actual tie line power flow reaches the scheduled power flow. This error signal is used to generate the respective ACE signals as in the traditional scenario. In the steady state the generation of each Genco matches the demand of Discos in contract with it. For example if a Disco'd' demands 1p.u. from Genco 1 then at the steady state it would generate as follows:

$$\sum_{d=1}^{n} \text{(p.u. load of Disco 'd') X } cpf_{1d} = 1\text{p.u.} \quad (2)$$

3. GENERATOR RATE CONSTRAINTS

The main reason to consider GRC is that the rapid power increase would draw out excessive steam from boiler system to cause steam condensation due to adiabatic expansion. As the temperature and pressure in the turbine are very high with marginal upper boundary, it is expected that the steam condensation would not occur with about 20% steam flow change unless the boiler steam pressure itself does not drop below a certain level. Thus, it is possible to increase generation power up to about 1.2 p.u of normal power during the first tens of seconds. After the generation power has reached this marginal upper boundary, the power increase of the turbine should be restricted by GRC. If these constraints are not considered, system is likely to chase large momentary disturbances. This results in undue wear and tear of the controller.

The presence of generation rate constraint results in larger deviation in ACE as the rate at which generation can change in an area is constrained by the limits imposed. Therefore, the duration for which power needs to be imported increases considerably as compared to the case where generation rate constraint is not considered. Further the dynamic response of the system with the presence of GRC has larger overshoot, compared to the system without considering GRC. Figures 2 and 3 show the implementation of generation rate constraint to reheat unit and hydro unit respectively.

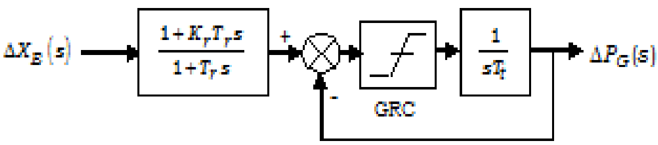


Fig. 2: GRC to reheat units.

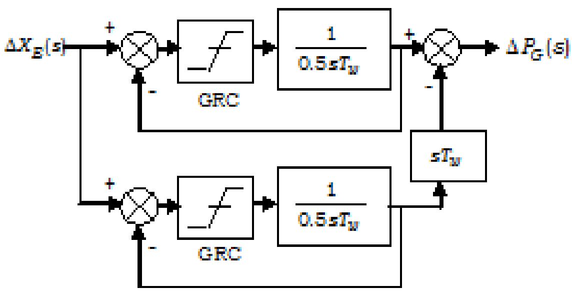


Fig. 3: GRC to hydro units.

4. RESULTS AND DISCUSSIONS

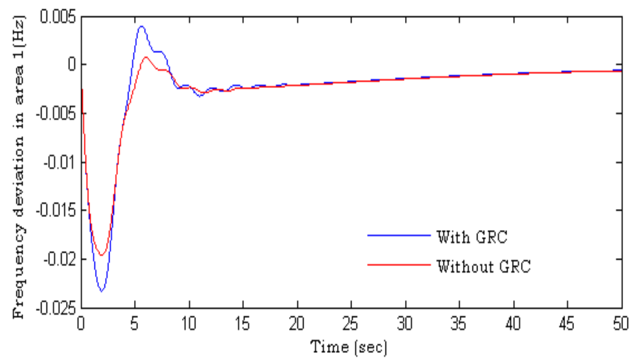
Simulation studies are performed to investigate the performance of the two-area hydrothermal system under open Environment with the presence of GRC using MATLAB. It is to be noted that each Genco participates in LFC as per the area participation factors (apfs): apf_1=0.5, apf_2=0.25, apf_3=0.25, apf_4=0.5, apf_5=0.25 and apf_6=0.25. A step load disturbances of 0.4% is considered in either of the areas. The Discos contract with the Gencos as per the following Disco Participation Matrix:

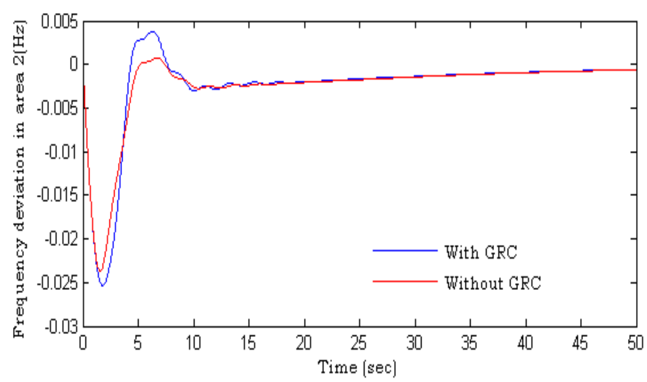
$$DPM = \begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.0 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 \end{bmatrix}$$

Table 1: Comparison of system performance without and with generation rate constrain.

Type of the System	Thermal area			Hydro area		
	Peak time (sec)	Overshoot (Hz)	Settling Time (sec)	Peak time (sec)	Overshoot (Hz)	Settling Time (sec)
Without GRC	1.985	0.01963	22.74	1.565	0.02368	21.71
With GRC	1.95	0.02329	20.65	1.795	0.02535	20.945
% Improvement	1.763	-18.66	9.19	-14.69	-7.034	3.52

A nominal value of 0.5 is considered for the gain setting of integral controller in both the areas. Table 1 shows the comparison between the dynamic performance of the system without and with generation rate constraint with respect to frequency deviation of both areas. It is to be observed that the system with GRC has better dynamic response in terms of peak time, overshoot and settling time than the system without GRC. A nominal value of 0.5 is considered for the gain setting of integral controller in both the areas.





The effect of GRC on a two area hydrothermal system can be viewed from Figures 4 - 6. Fig. 4 shows the variation of frequency and tie-line power flow deviations with step load disturbance of 0.4% in each area. Fig. 5 shows the outputs of both thermal and hydro turbines following the step load disturbance. Fig. 6 shows the variation of generation rate constraint in both thermal and hydro areas respectively. The nominal values of the various parameters are given in the Appendix.

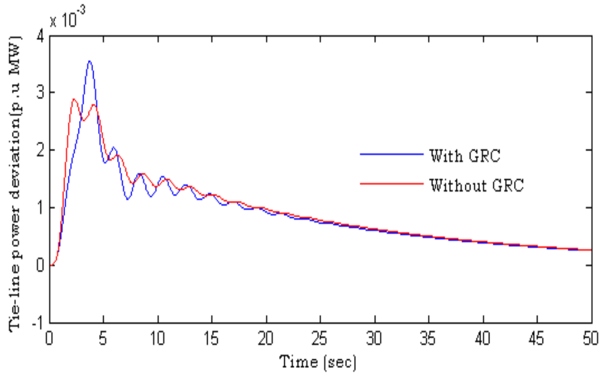


Fig. 4: Variation in area frequencies and tie-power in both the areas

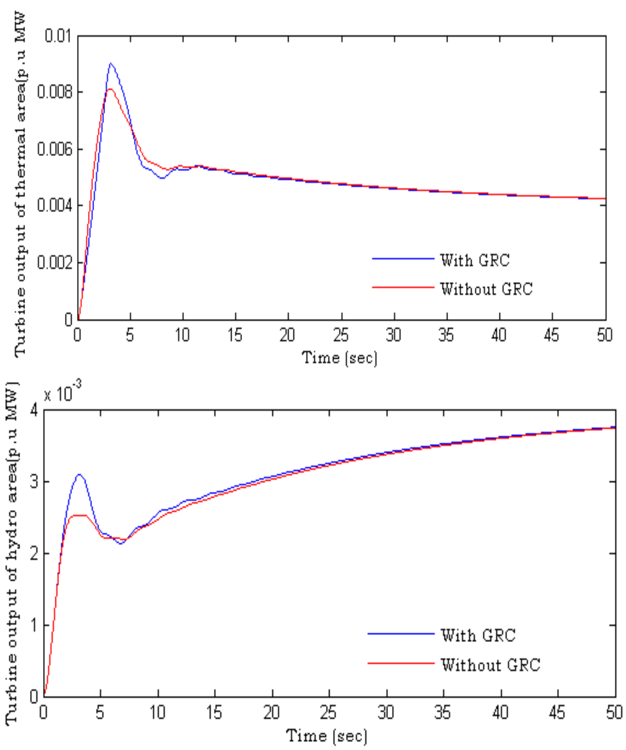
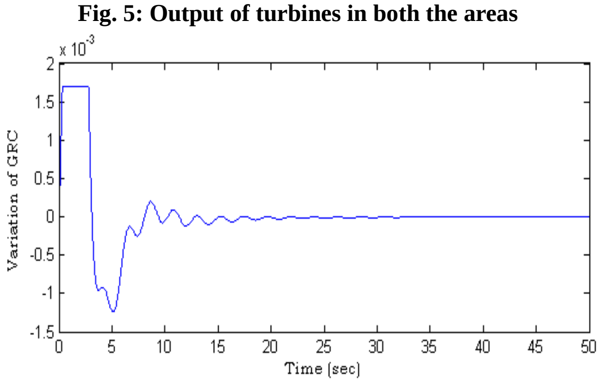


Fig. 5: Output of turbines in both the areas



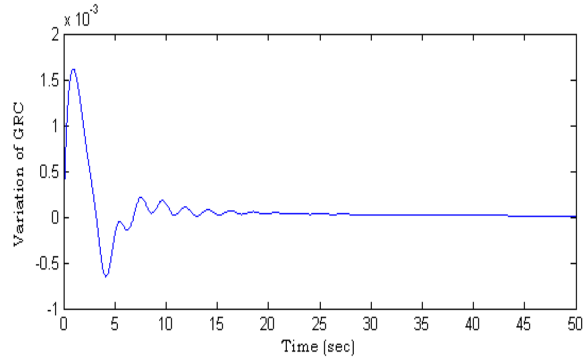


Fig. 6: Variation of generation rate constraint in thermal and hydro areas respectively

5. CONCLUSIONS

AGC provides a relatively, yet extremely effective method of adjusting generation to minimize frequency deviations and regulate tie-line flows. Incorporation of RC along with AGC visualizes a realistic model of AGC of hydrothermal system. Bilateral contracts can exist between Discos in one area and Gencos in other areas. The concept of Disco Participation Matrix has been used in this work which provides a compact yet precise way of summarizing bilateral contracts in a multi area hydrothermal system under restructured scenario. The simulation results indeed show that the system with GRC has the better dynamic response in terms of peak time, overshoot and settling time.

APPENDIX

System data

T_{p1}, T_{p2} =20s; K_{p1}, K_{p2} =120Hz/p.u. Mw; P_{r1}, P_{r2} =1200Mw; T_t =0.3s; T_g =0.08s, T_w =1s; $T_r = 5s$, $T_1 = 41.6s$, T_2 =0.513s; R_1, R_2 = 2.4Hz/pu Mw; T_{12} = 0.0866s; $B_1, B_2 = 0.4249$p.u Mw/Hz;

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