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Application of Load Following Control in Multi Area Hydrothermal Gas System under Reconstituted Scenario

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Abstract- *Variations in power system load causes deviations in system frequency and can be reduced by Automatic generation control (AGC). This paper presents the method in implementing the concept of load following adapted in an AGC in multi area hydro, thermal and gas system under reconstituted scenario. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affects the formulation of AGC problem. To reconcile new constraints associated with territorial of the traditional AGC two area system is modified to take into account the role of AGC in open market system. This paper investigates the performance of a load following controller on each generator involved in bilateral contracts. A suitable control strategy is also proposed for the generators taking part in load following to share a portion of the uncontracted power demanded by the customers. The concept of Disco Participation is employed and reflected in the two-area block diagram. The proposed system is tested for a two area hydro, thermal and gas system considering without and with contract violation. Simulation results show that the concept of load following is successfully implemented in the system*

Keywords-Automatic Generation Control, Load Following, Hydro, thermal and gas system, Disco Participation Matrix.

I. INTRODUCTION

A power system is the process of properly maintaining several sets of balances for its successful operation. Two of these balances are between load-generation and scheduled and actual tie line flows. These two balances are predominant factors to keep frequency constant. Constant frequency is identified as the primary index of healthy operation of system and the quality of supplied power to consumer as well. Both of these balances are maintained by adjusting generation keeping load demand in view. If frequency is low, generation is increased and if the actual outflow is greater than the scheduled outflow, generation is decreased. Since system conditions are always changing as load constantly varies during different hours of a day, precise manual control of these balances would be impossible. Automatic Generation Control (AGC) was developed to both maintain a (nearly) constant frequency and to regulate tie line flows [1-3]. 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 (Genco), transmission (Transco) and distribution (Disco). 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 assessment of Automatic Generation control in a deregulated environment is given in detail in [7-8] and also provides a detailed review over this issue and explains how an AGC system could be simulated after deregulation.A modified AGC schemes have been proposed for frequency regulation and load following as well [9-11]. A practical AGC model to cater the needs of a modern deregulated hydro, thermal and gas system is discussed in detail in [12-13].In view of this the main objectives of the present paper are the following:-

1. To consider an interconnected hydro, thermal and gas system in continuous mode strategy and to evaluate dynamic responses considering conventional integral controllers in both areas.
2. To implement the bilateral contracts into the thermal system thus designing the system under open market scenario.
3. This paper organized as follows. Dynamic mathematical model of two area system is described in section 2. Modified two area model is presented in Section 3. Section 4 covers simulated results and discussion and finally conclusion is given section 5.

II. DYNAMIC MATHEMATICAL MODEL

Electric power systems are complex, nonlinear dynamic system. The Load Frequency controller controls the control valves associated with High Pressure (HP) turbine at very small load variations. The system under investigation has tandem-compound single reheat type thermal system. Each

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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]. Figure 1 shows the transfer function block diagram of a two area interconnected network under deregulated scenario .The parameters of two area model are defined in Appendix.

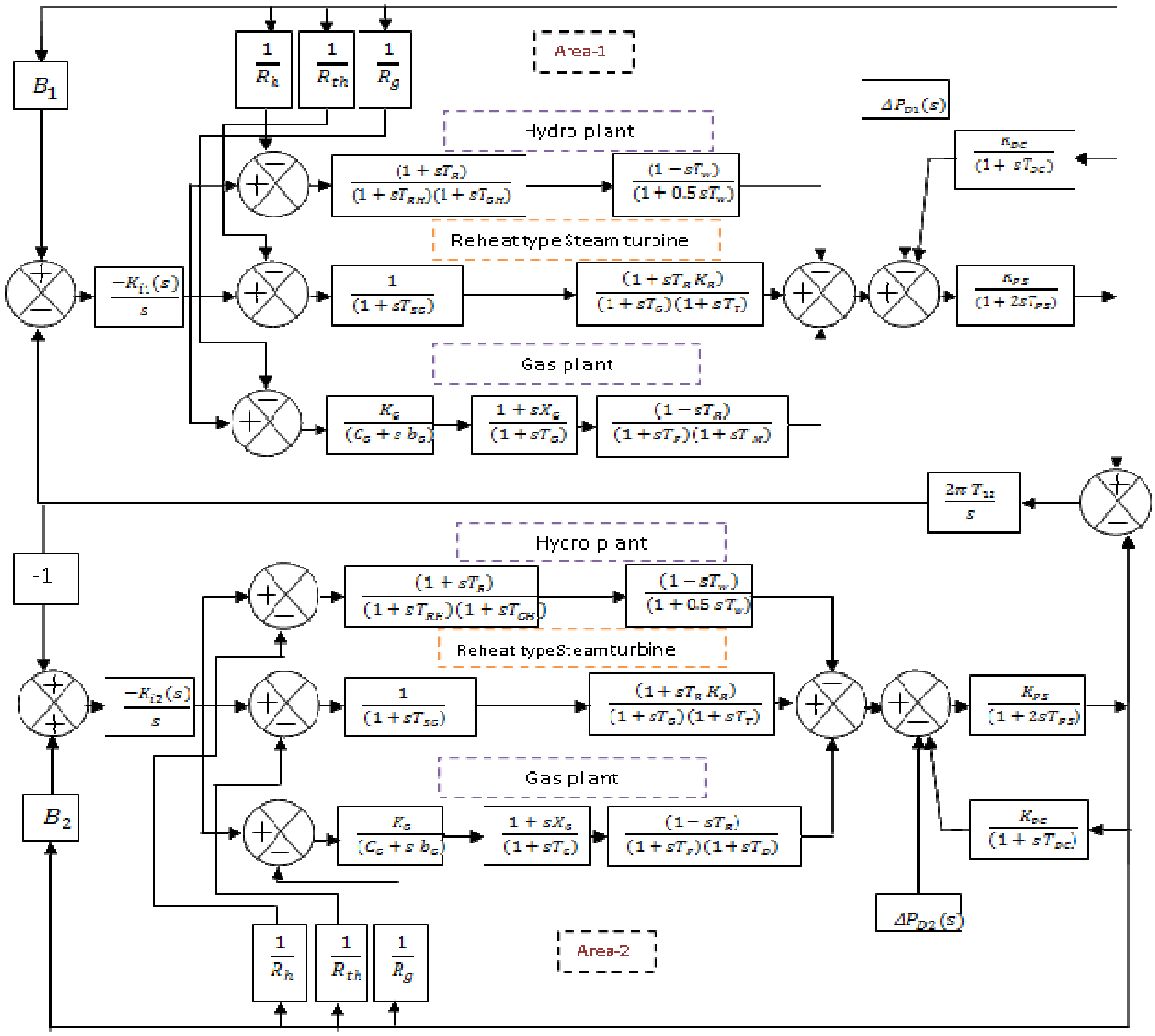

Figure 2. Two Area load following Hydrothermal Gas system

III. FORMULATION OF BLOCK DIAGRAM UNDER DEREGULATION

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 considered to make the visualization of contracts easier. 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". DPM shows the participation of a Disco in a contract with any 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.

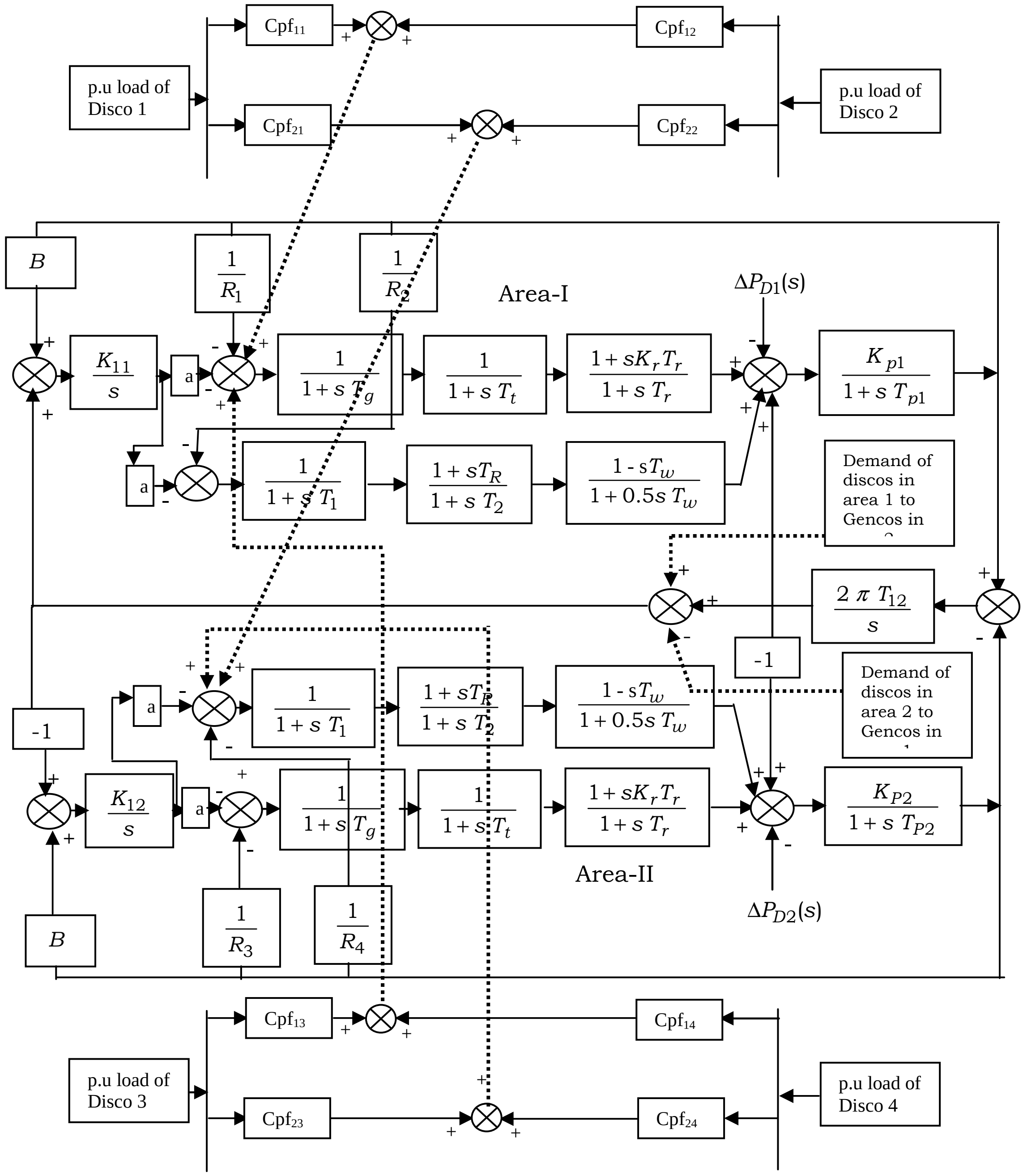

Figure 3. Two area Hydro-thermal-gas system under Load following of restructured environment

Unlike in the traditional AGC 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 cpf's (elements of DPM) 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 $\Delta P_{tie12,error} = \Delta P_{tie12,actual} - \Delta P_{tie12,scheduled}$ ----(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 MW from Genco 1 then at the steady state it would generate as follows

$\sum_{d=1}^{n}$ (p.u_ MW load of Disco 'd')$\times$ cpf_{1d} = 1p.u MW -----(2)

Contract Violation

It may happen that a Disco may violate a contract by demanding more than that specified in the contract. This excess power is not contracted out to any Genco. This uncontracted power must be supplied by the Gencos in the same area as that of the Disco. It must be reflected as a local load of the area but not as the contract demand

IV. RESULTS AND DISCUSSIONS

Simulation studies are performed to investigate the performance of the two-area hydrothermal system under deregulated Environment. Here in the two-area hydrothermal system three Gencos and two Discos are considered in each area. It is assumed in this work that one Genco in each area is under AGC only and the remaining Gencos participate in the bilateral contracts. It is assumed that there is 0.2% step load disturbance of each Disco, as a result of which the total step load disturbance in each area and accounts to 0.4% and each Genco participates in AGC as defined by following area participation factors (apfs):

apf_1 =0.25, apf_2 =0.25, apf_3 =0.5, apf_4 =0.25, apf_5 =0.25, apf_6 =0.5 and the Discos contract with the Gencos as per the following Disco Participation Matrix

$$DPM = \begin{bmatrix} 0.25 & 0.3 & 0.1 & 0.3 \\ 0.25 & 0.1 & 0.4 & 0.4 \\ 0 & 0 & 0 & 0 \\ 0.25 & 0.4 & 0.3 & 0.1 \\ 0.25 & 0.2 & 0.2 & 0.2 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

As mentioned earlier in the steady state, theoretically the Gencos must generate

$$\Delta P_{g1} = 0.25\times0.002 + 0.3\times0.002 + 0.1\times0.002$$
$$+0.3\times0.002 = 0.0019$$

Where 0.002 is the 0.2% step load disturbance of respective Disco. Similarly

ΔP_{g2} = 0.0023 p.u ; ΔP_{g3} = 0.0 p.u ; ΔP_{g4} = 0.0021 p.u ; ΔP_{g5} = 0.0017 p.u ; ΔP_{g6} = 0.0 p.u

A nominal value of 0.5 is considered for the gain setting of integral controller in both the areas.Table1 gives the error between the theoretical and simulated values of generation for the above case.

Table 1.Error value between theoretical and simulated values

	Type of Genco	Theoretical Values	Simulated Values	Error
Area 1	Genco 1	0.0019	0.00209	-0.00019
	Genco 2	0.0023	0.00209	0.00021
	Genco 3	0.0	0.0	0.0
Area 2	Genco 4	0.0021	0.00215	-0.00005
	Genco 5	0.0017	0.001804	-0.000104
	Genco 6	0.0	0.0	0.0

Where *Error= Theoretical values –Simulated values*

Contract violation case has also been considered in this work. In this case it is considered that $Disco_1$ demands additional load of 0.3% after 30 sec and $Disco_4$ in area 2 demands additional load of 0.3% after 60 sec. It can be seen that the uncontracted power is supplied by the Gencos in the same area as that of the Disco which has demanded for additional power. Table 2 gives the generations of Gencos during contract violation.

Table 2.Generation of Gencos during contract violation

	Type of Genco	Simulated Values
Area 1	Genco 1	0.003326
	Genco 2	0.003326
	Genco 3	0.0006207
Area 2	Genco 4	0.003222
	Genco 5	0.003108
	Genco 6	0.0006778

Figures 4-7 show the variation of frequency deviation of both areas, tie line power error deviation and generation of Gencos of both areas during the base case. **Figures 8-11** show the variation of frequency deviation of both areas, tie line power

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error deviation and generation of Gencos of both areas during the contract violation

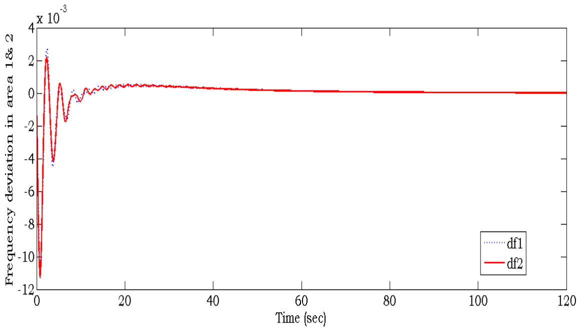

Figure. 4. Frequency deviations of both areas during base case

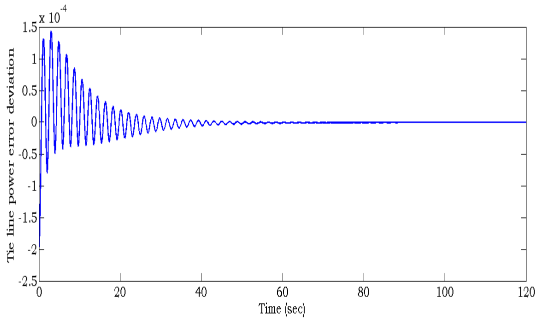

Figure. 5. Tie line power error deviation

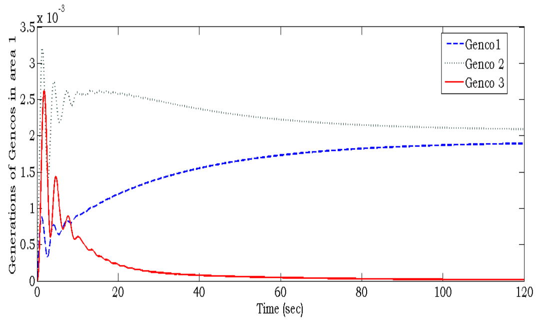

Figure. 6. Generation of Gencos in area 1

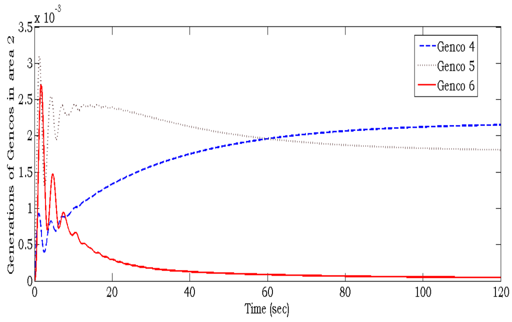

Figure. 7. Generation of Gencos in area 2

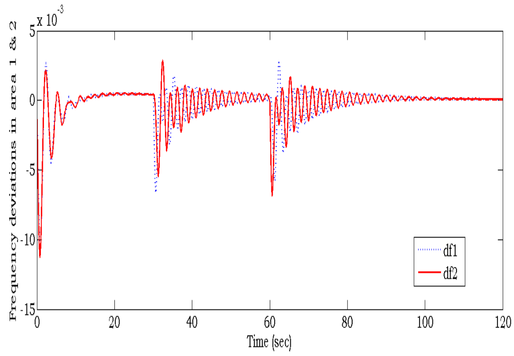

Figure. 8. Frequency deviations of both areas during contract violation

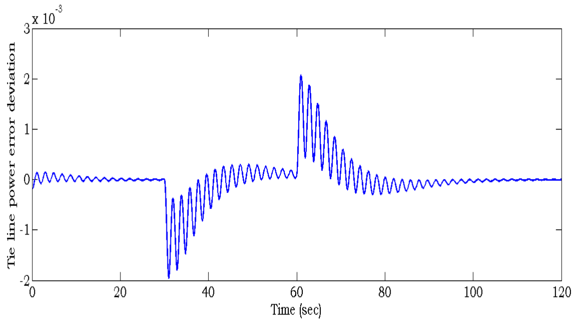

Figure. 9. Tie line power error deviation during contract violation

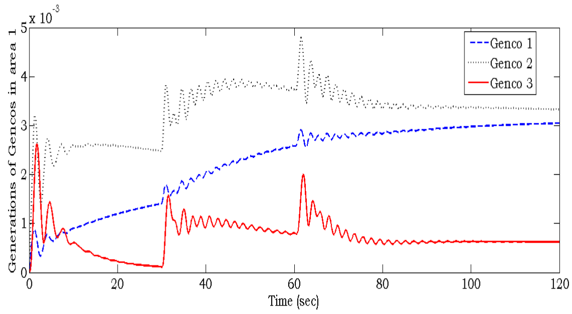

Figure. 10. Generation of Gencos in area 1 during contract violation

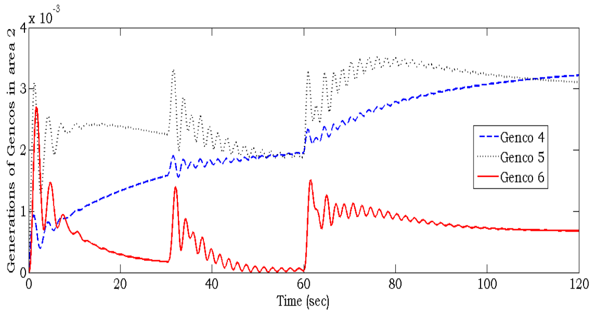

Figure. 11. Generation of Gencos in area 2 during contract violation

V. CONCLUSIONS

Yet extremely effective method of adjusting generation to minimize frequency deviations and regulate tie-line flows is provided by AGC. This important role of adjusting generation also continues in restructured electricity markets. 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 hydro, thermal and gas system under restructured scenario. Load following has been examined and it was took note that the generating unit under in load following generates the required contracted power in the steady state and also that, at least one generating unit in each area must be under AGC to draw the frequency deviation and tie power error to zero in the steady state. The modeling of AGC in a restructured environment must take into account the information flow relating to bilateral contracts..

APPENDIX

R =2.4 Hz/p.u.MW; D = 8.33×10^{-3} p.u. MW/Hz; K_g =1; T_g =0.08 sec; K_t =1; T_t =0.3 sec; K_r =0.5; T_r =10 sec; T_1, T_2, T_R =41.6, 0.513, 5 sec; T_w =1 sec; K_p =120 Hz/p.u. MW; T_p =:20 sec; B =0.425 p.u. MW/Hz; c_g=1; b_g=0.05; X_G=0.6; Y_G=1;

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