# FREQUENCY REGULATION OF DEREGULATED POWER SYSTEM HAVING GRC INTEGRATED WITH RENEWABLE SOURCE

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## Abstract

*This paper addresses the automatic generation control of deregulated multi area power system including one of the most important renewable energy resource viz. wind power plant. The interconnected two area power system is thermal-hydro system with two GENCOs in thermal area and one GENCO in hydro area. Generation rate constraint (GRC) is considered in all the GENCOs separately. Integral square error technique is used to optimize the gains of various integral controllers. It is seen that system response becomes poorer in terms of peak overshoots and settling time by considering GRC. DISCO participation matrix is chosen on the basis of open market strategy which is continuously changing. So, effect of changing DPM on dynamic responses is studied, following a step load perturbation. It is revealed that there is no effect of changing DPM on system's dynamic responses.*

***Keywords –*** *Automatic generation control (AGC), deregulated power system, DISCO participation matrix (DPM), wind turbines, generation rate constraint (GRC).*

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## 1. INTRODUCTION

Automatic generation control (AGC) or megawatt frequency control involves the problems of transient load perturbations that make the frequency and tie line power to deviate from their nominal values. These perturbations also lead to the mismatch in generation of power system and overall load demand. But these are the most important parameters of power system that are needed to be controlled to their nominal values even after the disturbances [1]. So, synthesis of AGC controllers is required like integral controllers, proportional integral controllers, proportional integral derivative (PID) controllers and fuzzy logic controllers etc. that provide the secondary control in the overall AGC. Primary control is provided by governor-turbine speed regulation model only. Now a days, focus is shifted towards the restructuring of power system. Initially, a single entity namely vertically integrated unit (VIU) owned the overall power system structure but now independent power producers (IPPs) have evolved and independent organizations like generation companies (GENCOs), transmission companies (TRANCOs) and distribution companies (DISCOs) have come up which generate and sell power at their own regulated rate. There are no geographical domain restrictions for these companies to operate [2, 3]. Conventional power plants like thermal, hydro, nuclear etc pose a threat to the environment and lead to the global warming due to harmful gas emissions. So, it is of great importance to include cleaner sources of power into the power system like solar power, wind power etc. Solar power plants have low energy conversion efficiency and are more expensive than wind power plants, so focus is mainly shifted towards wind power plant [4, 5, 6].

The objective of the paper is to present a two area deregulated hydro-thermal power system having GRC including wind power plant. However, with large penetration of wind power into the power system, the grid frequency will be more vulnerable to disturbances because wind power converters mostly do not participate in the frequency regulation or AGC services. But again in the view of continuous depleting conventional energy resources, it becomes important to shift our focus to such non-conventional resources. There are some advanced techniques like doubly fed induction generators (DFIG) based wind turbines that support the system inertia and participate in the overall AGC. But these advanced techniques are ignored here for time being. The main objectives of the paper are:

a) To study the effect of changing DPM on the dynamic responses of the system.
b) To study the effect of GRC on system's dynamic responses.

## 2. SYSTEM UNDER INVESTIGATION

A two area hybrid deregulated power system as shown in Fig. 1 is considered as a test system to study the AGC problem. An interconnected hybrid system comprising of thermal-hydro-wind has been used for simulation studies.

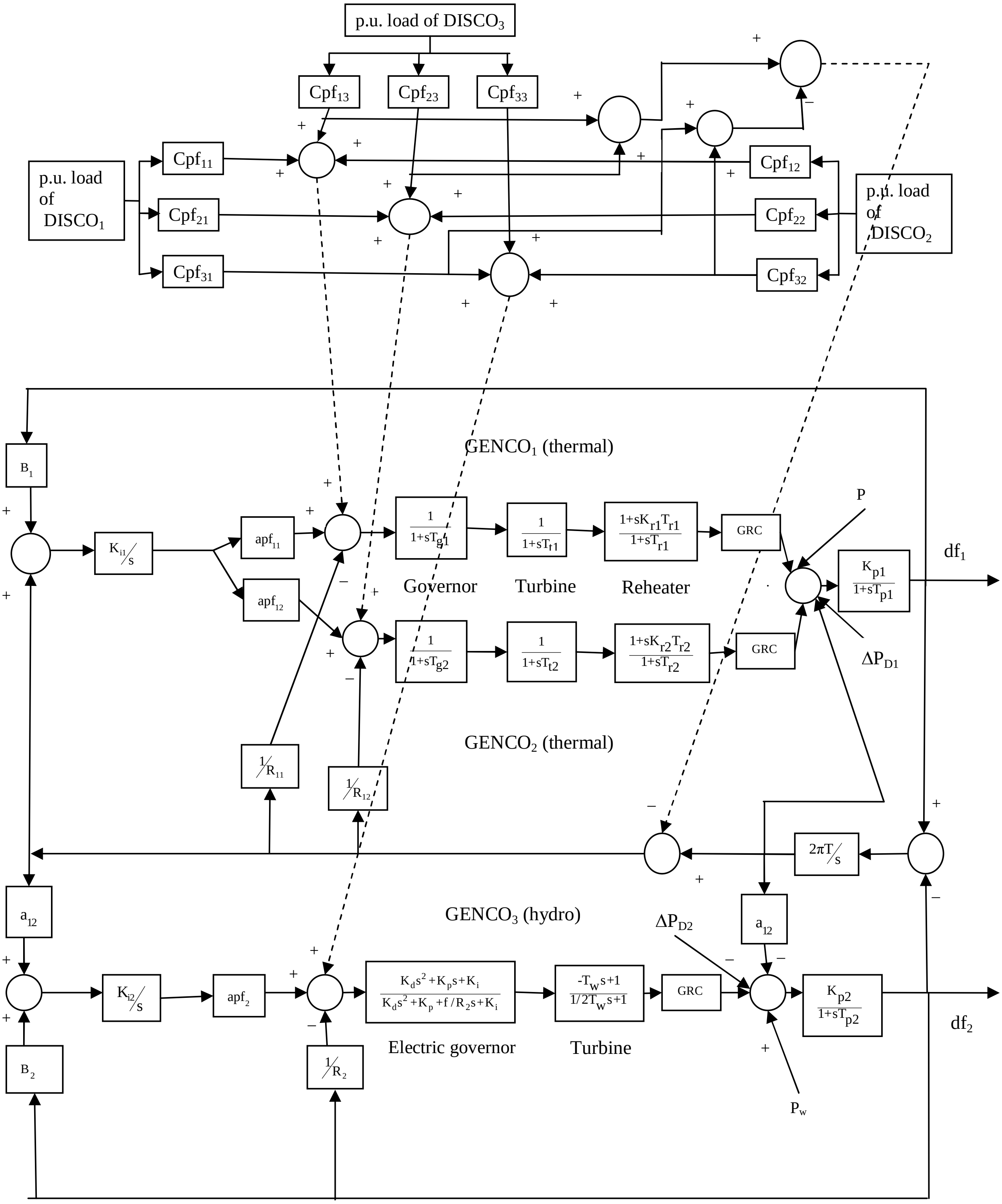


**Fig.1** Two area hydrothermal deregulated system having GRC including wind turbine.

Area1 is thermal system and has two GENCOs each equipped with reheat turbine and area2 is a hydro system having one GENCO equipped with electric governor. GRC is added in each of the GENCOs separately. It is 3%/minute for thermal units. For hydro units, it is 270%/minute (maximum limit) and 360%/minute (minimum limit) [2]. In addition to thermal and hydro plants, fixed speed wind power plant is also integrated into the each area of the system. Wind speed varies with time and is related to the wind speeds of the previous time [7]. In this paper, it is considered that the output power of wind generators depends on the wind speed at that time. The output power of wind turbine Pw is calculated as:

$$P_w = 0,\ V_s < V_i \text{ and } V_s > V_o$$

$$P_w = P_{wr}*[(V_s-V_i) / (V_r-V_i)],\ V_s \geq V_i \text{ and } V_s \leq V_r$$

$$P_w = P_{wr},\ V_s \geq V_r \text{ and } V_s \leq V_o$$

Where $V_i$, $V_r$ and $V_o$ are the cut-in wind speed, rated wind speed and cut-out wind speed respectively. Their values are taken as 5, 15, 45 m/s respectively. $V_s$ is wind speed at any instant. $P_{wr}$ is the rated power output of wind turbine.

Simulation model has been developed in MATLAB 7.0 to obtain dynamic responses for various parameters for different step load perturbations (1% or 2%) in each area or in both the areas. The power system parameters used in the model are given in appendix. The optimum values of integral controller gains have been found using ISE technique, considering step perturbation in any one area, keeping all other areas uncontrolled. The objective function (cost function) J for ISE technique [6] is

$$J = \int [df_1^2 + df_2^2 + dP_{tie}^2]\, dT$$

Where,
dT = small time interval during sample
$df_1$ & $df_2$ = incremental change in frequency of area1 & area2.
$dP_{tie}$ = incremental change in tie line power of area.

In the control application, we use integral method to decrease the rise time and reduce the steady state error. The speed changer setting can be adjusted automatically by monitoring the frequency changes. The signal fed to the integral controller is called ACE (area control error). The integrator output, thus the speed-changer position, attains a constant value only when the frequency error has been reduced to zero.

## 3. EFFECT OF DPM

In deregulated environment, DPM is chosen on the basis of open market strategy [3, 8]. As the market strategy changes every day, so is the DPM. So it becomes important to see the effect of changing DPM on the dynamic responses of the system involving wind power plant. Also, controllers are to be optimized for different DPMs, again using ISE technique. Table I shows the optimized values of integral controller gains and electric governor parameters for the following two DPMs:

$$DPM_A = \begin{pmatrix} 0.6 & 0 & 0.3 \\ 0 & 0.7 & 0.3 \\ 0.4 & 0.3 & 0.4 \end{pmatrix}$$

$$DPM_B = \begin{pmatrix} 0.5 & 0.8 & 0.5 \\ 0.5 & 0.1 & 0.3 \\ 0 & 0.1 & 0.2 \end{pmatrix}$$

**Table 1** Optimized Value of Various Gains

| DPM | Electric Governor Parameters | | | Integral Controller Gains | |
|---|---|---|---|---|---|
| | $K_d$ | $K_p$ | $K_i$ | $K_{i1}$ | $K_{i2}$ |
| A | 3.6 | 3.3 | 4.6 | 0.472 | 0.041 |
| B | 1.2 | 3.4 | 3.1 | 0.3435 | 0.044 |

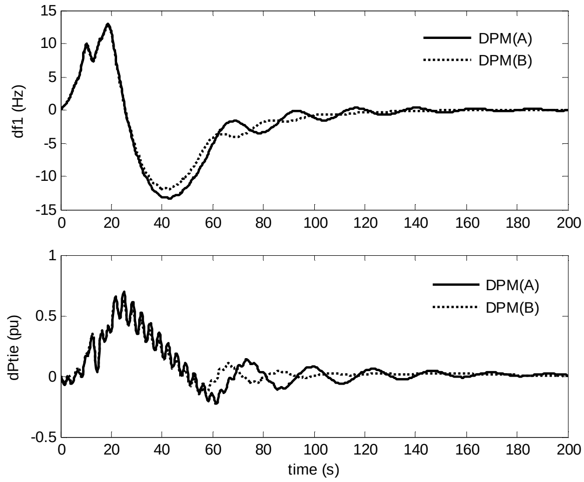


**Fig.2** Dynamic responses comparison for sets of DPMs

In present system, area contro error (ACE) participation factors i.e (apfs) are chosen as follows:

- For thermal area, the apf of GENCOs are proportional to their respective generations. So, $apf_{11} = P_{g1}/ (P_{g1}+P_{g2})$ and $apf_{12} = P_{g2}/ (P_{g1}+P_{g2})$
- For hydro area, apfs of various GENCOs are considered to be equal. So, $apf_2 = 1$

**Analysis:** The two sub-figures of Fig. 2 show the dynamic response comparison of $df_1$ and $dP_{tie}$ for two DPMs corresponding to their respective optimum gains from Table 1.

From the figures, it is clear that there is hardly any difference in the responses when different DPMs are considered with their respective optimum controller gains. However, the optimum gains corresponding to different DPMs are quite different.

## 4. EFFECT OF GRC

It is more realistic to add the physical constraints in the power system. One such constraint is GRC. Fig. 3 shows the comparison of dynamic responses with and without GRC for deregulated wind integrated power systems.

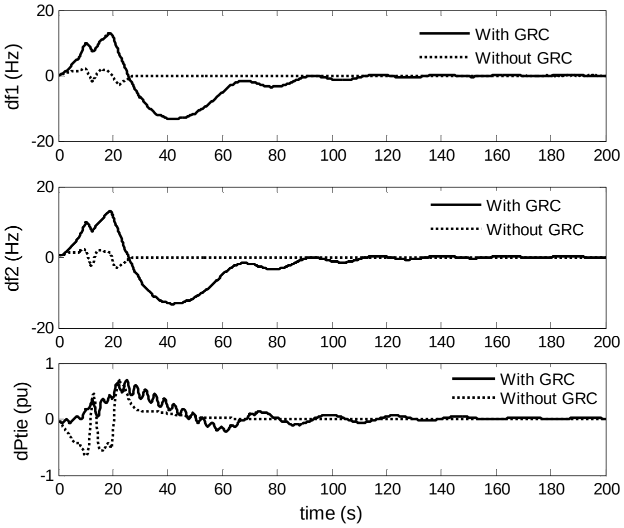


**Fig 3** Dynamic responses comparison in terms of GRC

**Analysis:** Various sub-figures of Fig. 3 show the comparison of dynamic responses in terms of GRC. It is clearly seen that the responses become poorer in terms of overshoots and undershoots and settling time. But it is the more practical way to include GRC into the power system.

## CONCLUSIONS

Frequency is one of the most important parameter to determine the stability of a system. To improve the overall dynamic performance in the presence of the plant parameters changes and system non linearities, the conventional integral controller based AGC problem has been formulated as an optimization problem based on system performance index ISE for multiple operating conditions. Wind power plant is included in the system for taking care of continously increasing load demands and in the view of depleting conventional energy resources. The overall power plant is analysed in deregulated or restructured scenario. Transient responses hardly vary for varying DPM in terms of peak deviations (overshoots and undershoots) and settling time. The AGC system balances it well in terms of frequency deviations and tie line power deviations. So, any DPM can be chosen based on the market economy. It is also analysed that although the responses become poorer in terms of peak deviations (undershoots and overshoots) and settling time, it is more realistic and practical appraoch to include GRC in the system.

## APPENDIX

The various system parameters and their description in given in Table 2

**Table 2** System Parameters

| Name | Description | Value |
|---|---|---|
| $P_{r1}$, $P_{r2}$ | Rated power | 2000MW |
| $T_{g1}$, $T_{g2}$ | Speed governor time constant | 0.08 sec |
| $T_{t1}$, $T_{t2}$ | Steam turbine time constant | 0.3 sec |
| $K_{r1}$, $K_{r2}$ | Reheater gain | 0.5 |
| $T_{r1}$, $T_{r2}$ | Reheater time constant | 10 sec |
| $K_{p1}$, $K_{p2}$ | Power system gain | 60 Hz/puMW |
| $T_{p1}$, $T_{p2}$ | Power system time constant | 20 sec |
| $B_1$, $B_2$ | Frequency bias constant | 0.4249 |
| $R_{11}$, $R_{12}$, $R_2$ | Speed regulation parameter | 2.4 Hz/puMW |
| $a_{12}$ | $- P_{r1}/P_{r2}$ | -1 |
| $T_w$ | Water time constant | 1 sec |
| T | Synchronizing time constant | 0.0866puMW/rad |
| $\Delta P_{D1}$, $\Delta P_{D2}$ | Step load perturbation | Can be varied |
| $P_{wr}$ | Rated wind power output | 1 pu |
| f | Nominal frequency | 60 Hz |

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