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GENETIC ALGORITHM BASED PID CONTROLLER FOR A TWO-AREA DEREGULATED POWER SYSTEM ALONG WITH DFIG UNIT

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ABSTRACT

This paper deals with the various methods for reduce the load frequency control (LFC) issues in an interconnected power system under deregulated environment. The effect of inclusion of doubly fed induction generators (DFIG) in both control area for load frequency control applications in a deregulated power system. For analyzing the load flowing application, the test system consists of a two area interconnected power system under deregulated environment having to GENCOs and two DISCOs in each area. To minimize the objective function, PID controller parameters are tuned by using Genetic Algorithm (GA). Simulations results under Matlab/Simulink environment validates that inclusion DFIG unit effectively it improve the LFC application for different contract scenarios under deregulated power system.

Keywords: LFC, deregulation, genetic algorithm, doubly fed induction generator.

1. INTRODUCTION

Around the world, the electric power industry has been undergoing reforms from vertical integrated utility (VIU) to competitive deregulated markets. Generation companies (GENCO) distribution companies (DISCO), transmission companies (TRANSCO) and independent system operator (ISO) are all the major market players in a deregulated market structure [1]. In a large power system network having so many GENCOs and DISCOs and also each GENCOS and DISCOs having different contract with each other for power transactions [2]. At the same time ISO provide a certain number of ancillary services for provide the smooth operation of deregulated markets. The different types of contract available in deregulated markets [2] and various types of LFC issues in a restructured power system are explained in [1].

Nowadays, more researches focusing the application of renewable in the conventional power system [3]. If we add more renewable into the conventional power system, the grid frequency will be more prone to disturbances, as some renewable power sources do not participate in the frequency regulation services. The DFIG-based wind turbine can efficiently use for frequency related control applications. The main idea of frequency regulation is occurred through inertial control, pitch control, and speed control [4]. The power control scheme is applied on the DFIG to use it in the frequency regulation services [5]. The DFIG operates according to a deloaded optimum power extraction curve, such that the active power injected increases or decreases according to the variations in the system frequency [8]. The dynamic participation of the DFIG in the frequency control is analyzed through modified inertial control which responds proportionally to the frequency deviation and uses the kinetic energy of the turbine blades to improve the frequency [9-11].

The proposed Genetic algorithm based PID controller (GAPID) tuning method is applied in a two area hydro-thermal restructured power system with and without DFIG unit. Matlab/ Simulink has been used for simulation studies [14]. For minimizing the fitness function for GA, integral square error (ISE) technique has been used. The population size 100 has been chosen for GA to obtain the optimal values of PID controller.

2. DEREGULATED POWER SYSTEM

LFC in deregulated power system having three possible contracts, such as Poolco based transaction, bilateral transactions, and hybrid transaction. In Poolco based transaction contract between GENCOs and DISCOs in same area and in the case of bilateral contract any DISCOs have the freedom to choose any GENCOs in their own area or any other control area. In order to meet the various types of contracts in restructured power system is visualized through DISCO participation matrix (DPM) [2]. The number of rows and columns in a DPM represents the number of GENCOs and DISCOs respectively [2]. Each entry in the DPM is noted as contract participation factor (CPF), which represents the fraction of total power contracted by j^{th} DISCO from i^{th} GENCO.

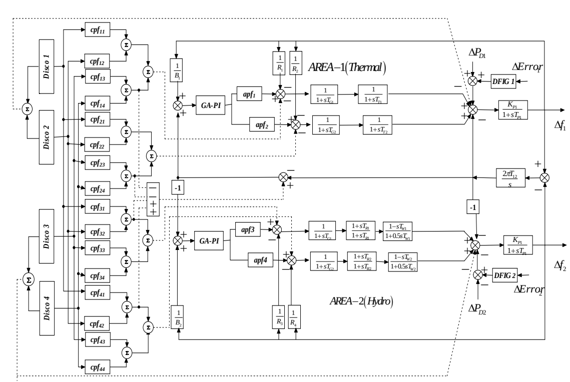

Figure-1. Linearized model of two area hydro-thermal system under deregulated environment.

Figure-1 shows the restructured model of a two area system in which area-1 consists of two thermal GENCOs and two DISCOs and area-2 consists of two hydro GENCOs and two DISCOs. The corresponding DPM will become

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (1)$$

The sum of all the entries in a column matrix (DISCO) must be unity. ie.,

$\sum_{j=1}^{n} apf_j = 1$ where m is the number of GENCOs.

In a restructured power system, a DISCO asks/demands a *particular* GENCO or GENCOs for load power. These power demands affect the system dynamics [12].
The scheduled steady state power flow on the tie line is given as

$\Delta P_{tie12,scheduled} =$ (demand of DISCOs in area II from GENCOs in area I) - (demand of DISCOs in area I from GENCOs in area II) (2)

At any instant, the tie line power error signal is defined as

$$\Delta P_{tie12,error} = \Delta P_{tie12,actual} - \Delta P_{tie12,scheduled} \quad (3)$$

When the actual tie-line power flow reaches the scheduled power flow the error become vanishes.
This error signal is used to generate the respective ACE signals as in the traditional scenario ie.,

$$ACE_1 = B_1 \Delta f_1 + \Delta P_{tie12,error} \quad (4)$$

$$ACE_2 = B_2 \Delta f_2 + a_{12} \Delta P_{tie12,error}$$

Where $a_{12} = -\dfrac{P_{r1}}{P_{r2}}$

P_{r1} and P_{r2} are the rated capacity of areas I and II, respectively. The total loads demand of DISCOs in ith area is denoted as ΔP_{Di}, which is the sum of contracted and un contracted load demand in that particular area.

3. DFIG MODELLING

The DFIG-based wind turbines can produce power with variable mechanical speed and extract kinetic energy to support the primary frequency regulation [4], [11]. Although, the steady-state active power delivered to the grid by a DFIG depends on the wind speed, the power can be dynamically controlled to a certain extent by utilizing the stored mechanical energy. Dynamic model of DFIG is shown in Figure-2. [11]. An additional control signal is created to adapt the power set points ΔP_f^* as a function of deviation and rate of change of frequency in emulation control of the DFIG. The controllers try to keep the turbine at its optimal speed in order to produce the maximum power. A power set point ΔP_ω^* based on measured speed and measured electrical power is provided by the controller. The power reference point, ΔP_{fw} has two components; ΔP_f^* the additional reference point based on the frequency change Eq. (8), and ΔP_ω^* which is based on optimum turbine speed as a function of wind speed and given as

$$\Delta P_\omega^* = -K_{wp}(\omega^* - \omega) + K_{wi}\int(\omega^* - \omega)dt + K_{wd}\frac{d}{dt}(\omega^* - \omega), \quad (5)$$

$$\Delta P_{fw} = \Delta P_f^* + \Delta P_\omega^*, \quad (6)$$

where K_{wp} and K_{wi} are constants of PI controller, which provides fast speed recovery and transient speed variation, which helps non conventional generators to supply the required active power to reduce deviations, respectively.
The contribution of the DFIG towards system inertia is given by

$$\frac{2H}{f}\frac{d\Delta f}{dt} = \Delta P_f - D\Delta f$$
$$= \Delta P_g + \Delta P_{fw} - \Delta P_{12} - \Delta PD - D\Delta f \quad (7)$$

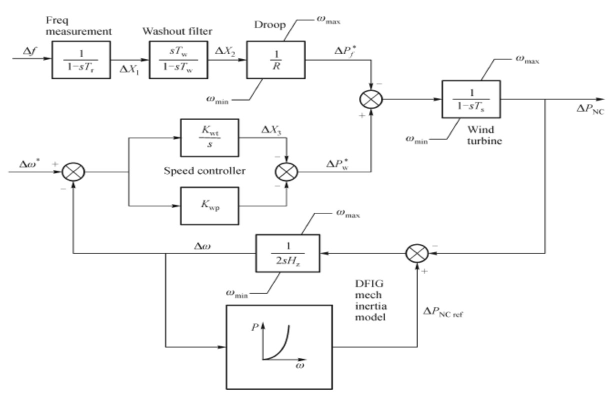

Figure-2. DFIG based on wind turbine control for frequency change.

The swing Equation (7) gives an idea about the contribution of the DFIG towards system inertia. It has an additional reference power setting which is built based on the change in frequency using a washout filter with time constant, T_w that relies on a conventional primary regulation performance in a transient.

$$\Delta P_f^* = \frac{1}{R}\Delta X_2 \quad (8)$$

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where, R is the droop constant as used conventionally and ΔX_2 is the frequency change measured where the wind turbine is connected to the network.

The DFIG responds to frequency deviations during transients by using their stored kinetic energy, and cannot act in a permanent system frequency deviation. For this reason, the frequency term ΔX_2 used in Equation (8) is the result of a washout filter, as illustrated in Figure-2.

In this approach, the DFIG inertia contributes to that of the rest of the system. The controller proposed makes use of the frequency deviations instead of the derivative of frequency as in the control law to provide fast active power injection control. The active power injected by the wind turbine is ΔP_{fw}. The power injected is compared with ΔP_{fwref} so as to obtain the maximum power output, which is obtained by maintaining reference rotor speed where maximum power is obtained.

4. PID CONTROLLER TUNING WITH GENETIC ALGORITHM (GA)

The optimum values of proportional, integral and derivative gain settings of the PID controller are obtained using integral square error technique (ISE). The quadratic performance index can be represented as

$$J = \int_0^t (\Delta f_1^{\,2} + \Delta f_2^{\,2} + \Delta P_{tie12}^{\,2})dt \quad (9)$$

Genetic Algorithms are based on Darwin's theory of natural selection and survival of the fittest. It is a heuristic optimization technique for the most optimal solution (fittest individual) from a global perspective but more importantly, it provides a mechanism by which solutions can be found to complex optimization problems fairly quickly and reliably [6]. Following are the important terminology in connection with the genetic algorithm as given in Goldberg D.E (1989):

a) Individual

An individual is any point to which objective function can be applied. It is basically the set of values of all the variables for which function is going to be optimized. The value of the objective function for an individual is called its *score*. An individual is sometimes referred to as a *genome* and the vector entries of it as *genes*.

b) Population

It is an array of individuals. For example, if the size of the population is 100 and the number of variables in the objective function is 3, population can be represented by a 100-by-3 matrix in which each row correspond to an individual.

c) Generation

At each iteration, the genetic algorithm performs a series of computations on the current population to produce a new population by applying genetic operators. Each successive population is called a new generation.

d) Parents and children

To create the next generation, the genetic algorithm selects certain individuals in the current population, called parents, and uses them to create individuals in the next generation, called children.

In GA's the value of fitness represents the performance which is used to rank 0 and the ranking is then used to determine how to allocate reproductive opportunities. This means that individual with a higher fitness value will have a higher opportunity of being selected as a parent. The fitness function is essentially the objective function for the problem [13]. Interconnected power system model as shown in Figure-1 has been created in MATLAB/Simulink. Area Control Error (ACE) for each area is calculated by running this model with PID controller. Initially, parameters (KP, KI and KD) of PID controller area selected using Least Square Minimization method, which gives stable results. ACE is further minimized using the GA optimization toolbox GAOT in MATLAB proposed by Houck *et al* (1995) to obtain the optimal PID parameters.

Table-1. GA parameters.

Population size	100
Cross over	0.8
Elite count	2
Mutation	0.2
No. of generations	100
Initial penalty	10
Penalty factor	100

5. SIMULATIONS AND RESULTS

The proposed two area hydro-thermal power system model along with DFIG unit is placed in both the control area for reducing the tie-line power oscillations and frequency deviations under deregulated environment as shown in Figure-1. In area -1GENCO-1 and GENCO-2 both are thermal units and in area-2 both GENCO-3 and GENCO-4 are hydro units. The system parameters are given in Appendix. It is assumed that all the GENCOs participate in the LFC with their corresponding area participation factor (apf) values summation of apf in a particular area becomes unity. The total local load of i^{th} control area is the sum of contracted and uncontracted load demands of the DISCOs of i^{th} control area only.. The optimum values of controller gains are obtained by using GA. MATLAB /Simulink[15-16] is used to simulate the power system model and to obtain dynamic responses of the system for different contract scenarios (case-1and 2) with and without DFIG unit. GA parameters are used in Table-1.

A. Case-1: Poolco based transactions

In Poolco based transactions, the contract between GENCOs and DISCOs only in their own control areas [7]. It is assumed that the load change occurs only in

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control area-1. Thus, the load is demanded only by DISCO-1 and DISCO-2 equally supplied from GENCO-1, and GENCO-2. Assume that

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0. & 0 & 0 \end{bmatrix} \quad (10)$$

Note that the DISCO-3 and DISCO-4 do not have any power from any GENCOs, and hence the corresponding *cpf* values are zero. From Eqn.2, the scheduled steady state tie line power flow is zero. The frequency and tie line power deviation in each control area settles to zero in the steady state. In the steady state, generation of a GENCO must match the demand of DISCOs in contract with it. In general, the desired power generation of each GENCOs is calculated in terms of cpf and the total load demand of each DISCOs are expressed as

$$\Delta P_{Gi} = \sum_{j=1}^{NDISCO} cpf_{ij}\Delta P_{Lj}; \text{ for i=1,2,…..,NGENCO} \quad (11)$$

Where ΔP_{Lj} is the total load demand of DISCO.

For a two area system Equation (11) becomes

$$\Delta P_{Gi} = cpf_{i1}\Delta P_{L1} + cpf_{i2}\Delta P_{L2} + cpf_{i3}\Delta P_{L3} + cpf_{i4}\Delta P_{L4} \quad (12)$$

In Poolco based contract, load demand of DISCO-1 and DISCO-2 is zero so $\Delta P_{L3} = \Delta P_{L4} = 0$.

Then Equation (12) will becomes

$$\Delta P_{Gi} = cpf_{i1}\Delta P_{L1} + cpf_{i2}\Delta P_{L2} \quad (13)$$

From above Equation (13) the power generated in each GENCOs are:

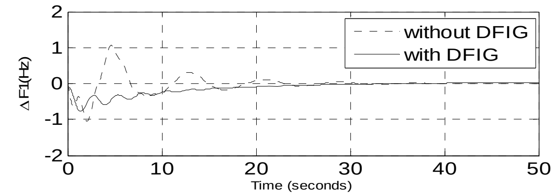
$\Delta P_{G1} = 0.1$ pu MW,

$\Delta P_{G2} = 0.1$ pu MW,

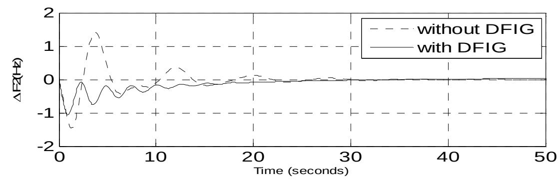
$\Delta P_{G3} = 0$ pu MW,

$\Delta P_{G4} = 0$ pu MW.

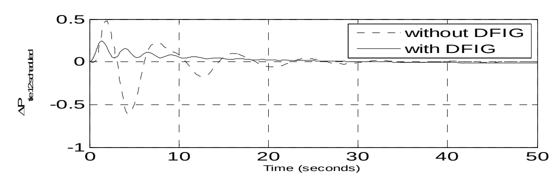
The generated powers (actual powers) of various GENCOs in response to contract with DISCOs are given in Figure-3. The actual generated powers of the GENCOs reach the desired values in the steady state. GENCOs of control area-2 do not transact the power; hence, their change in generated power is zero at steady state. Frequency and tie-line power deviation with and without DFIG are also plotted in Figure-4.



(a) Frequency deviation in area-1

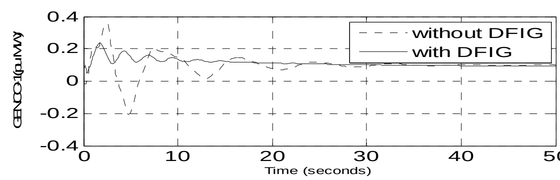


(b) Frequency deviation in area-2

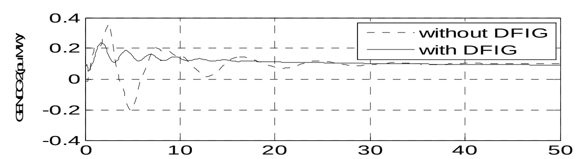


(c) Tie-line power deviation

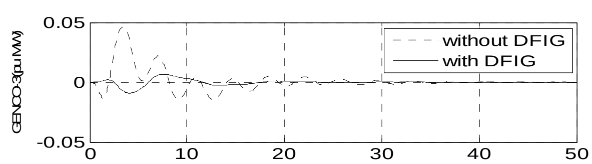
Figure-3. Frequency and tie-power deviation responses for case-1.



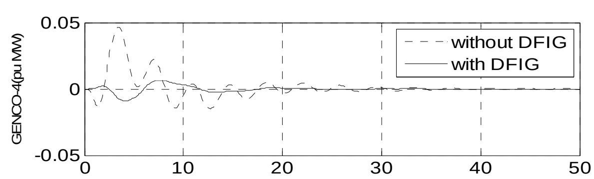
(a) Power output response of GENCO-1



(b) Power output response of GENCO-2



(c) Power output response of GENCO-3



(d) Power output response of GENCO-4

Figure-4. Generator power output response for case-1.

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B. Case-2: Bilateral transactions

In bilateral transactions, DISCOs have the freedom to contract with any GENCOs in its own area or other control areas. A case of bilateral based contracts between DISCOs and available GENCOs is simulated based on the following DPM:

$$DPM = \begin{bmatrix} 0.45 & 0.35 & 0 & 0.15 \\ 0.4 & 0.2 & 0.35 & 0.6 \\ 0 & 0.15 & 0.1 & 0 \\ 0.15 & 0.3 & 0.55 & 0.25 \end{bmatrix} \quad (14)$$

It is assumed that $\Delta P_{L1} = \Delta P_{L2} = \Delta P_{L3} = \Delta P_{L4} = 0.1$ pu MW and the cpf values are given in the DPM matrix. The system in Figure-1 is simulated using this data and the results are shown in Figure-5 and 6. In this case, power generated by each GENCOs are calculated from the Eqn.12 as;

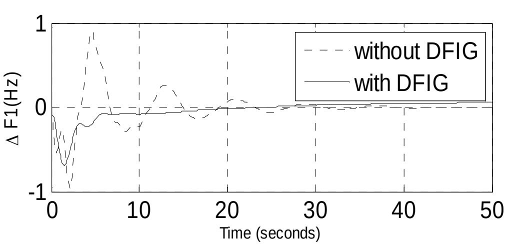
$\Delta P_{G1} = 0.095$ pu MW,

$\Delta P_{G2} = 0.155$ pu MW,

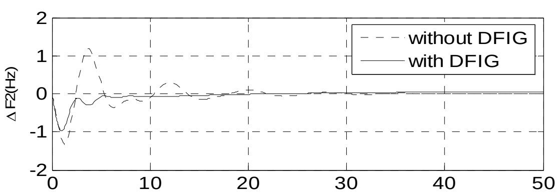
$\Delta P_{G3} = 0.025$ pu MW,

$\Delta P_{G4} = 0.125$ pu MW.

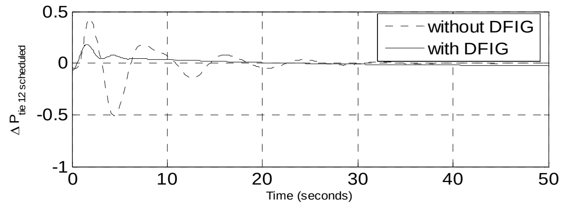
From Eqn.2 the scheduled power flow on the tie-line in the direction from area-1 to area-2 is, $\Delta P_{tie12,scheduled} = -0.05$ pu MW at steady state as shown in Figure-5c, which matches with the calculated (desired) value. The generated powers (actual powers) of various GENCOs in response to contract with DISCOs are given in Figure-6.



(a) Frequency deviation in area-1

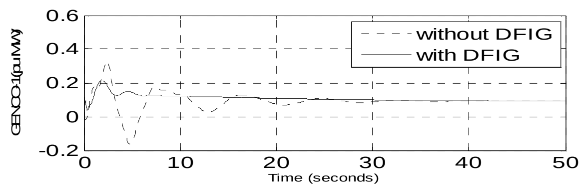


(b) Frequency deviation in area-2

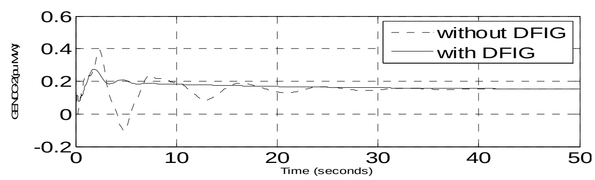


(c) Tie-line power deviation

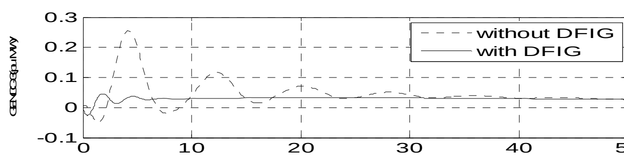
Figure-5. Frequency and tie-power deviation responses for case-2.



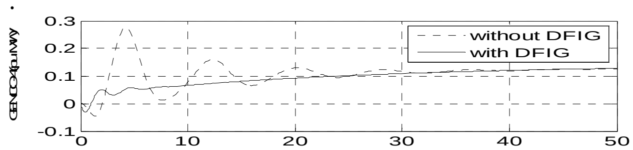
(a) Power output response of GENCO-1



(b) Power output response of GENCO-2



(c) Power output response of GENCO-3



(d) Power output response of GENCO-4

Figure-6. Generator power output response for case-2.

6. CONCLUSIONS

Application of the genetic algorithm based PID controller is implemented for tuning the gain parameters in a two area deregulated power system with DFIG unit in each control area and analyses how effectively it damp out the control performance parameters for Poolco and bilateral based transactions in restructured power system. It is found that in both cases, the area frequency error becomes zero in the steady state which satisfy the LFC requirements. It is found that actual values of generations and tie-line power exchanges of GENCOs obtained by MATLAB/Simulink model matches with the corresponding calculated (desired) values.

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Appendix

$P_{R1} = P_{R2} = 1200$ MW
$T_{P1} = T_{P2} = 20$ s
$K_{P1} = K_{P2} = 120$ Hz / p.u MW
$T_{R1} = T_{R2} = 10$ s
$K_{R1} = K_{R2} = 0.5$
$T_{TI} = T_{T2} = T_{T3} = T_{T4} = 0.3$ s
$T_{12} = 0.0866$ s
$T_{G1} = T_{G2} = T_{G3} = T_{G4} = 0.08$ s
$R_1 = R_2 = R_3 = R_4 = 2.4$ Hz / p.u MW
$D_1 = D_2 = 8.33\times10^{-3}$ p.u MW / HZ
$B_1 = B_2 = 0.425$ p.u MW / Hz
$P_{D1} = 0.01$ p.u MW
$P_{D2} = 0$ p.u MW
$T_1 = T_3 = 41.6$s
$T_2 = T_4 = 0.513$s
$T_{w1} = T_{w2} = 1$s

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