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Load Frequency Control of a Two-Area, Multi-Unit AGC Hybrid Power System Under Deregulated Environment using PI-PDF and CPI-PDF Tuner with Differential Evolution Algorithm

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Abstract- In this article, Load Frequency Control (LFC) via Automatic Generation Control (AGC) is applied in hybrid power systems everywhere in the world. In hybrid power system it is usual to locate several units in an area that is further linked to another area having various kinds of generating units or the same type of generating units. Automatic Generation Control (AGC) for multi-area power systems under a deregulated environment is analyzed and discussed in this study using the different types of fine tuners. In this work for energy management various generating units which are thermal, hydro, nuclear, gas, and diesel power plant have been integrated with the grid. The different fine tuners PDF, PI, PIDF, PI-PDF, CPI-PDF, CPIDF-PD are considered to obtain better results. Initially, a two-area, five-unit system without any physical constraints is considered, and the gains fine tuners are optimized utilizing a Differential Evolution (DE) algorithm with an ITAE criterion. Thereafter, an Automatic voltage controller, also termed an AVR, is applied to further improve the system voltage. The effectiveness of the new controller is examined in a deregulated environment. The simulation result obtained from the series connected PI-PDF and CPI-PDF are found better than other controllers in respect of settling time, rise time, peak value, and peak time. The settling time of frequency using PI-PDF for two areas is 10.39sec and 9.57sec which is the least as compared to other fine tuner. The settling time of tie-line response is 9.62sec. The hybrid system using different tuner are studied using MATLAB Simulink.

Keywords- *Automatic Voltage Regulator (AVR), Cascaded Integral and Derivative Controllers (CPID), Load Frequency Control (LFC), Series Connected Integral and Derivative Controller.*

I. Introduction

Nowadays, renewable and other sources(Hydro, Thermal, Gas, Nuclear, diesel)[8,15] are being integrated with conventional power systems which increases the complexity of the AGC, therefore energy management is more important. In a deregulated power system the, objective of the bidders are to increase their profit thereby causing more disturbance in system therefore steady state frequency response will be more challenging. Whenever size, structure of power system network increases because introduce in renewable energy sources, different operating environment, aspects and physical conditions AGC become more challenging therefore again role of energy management system is required. In modern power system all bidders work under control of independent system operator (ISO) [1].

The role of ISO become more under the deregulated environment. In competitive market it is not necessary that distribution company (DISCO) may purchase required power from generation company (GENCO) it may happened that they will contact any private bidders. The private bidder may be independent power producer (IPPs). To reduce transmission losses or cost price per unit ISO will allow to contact IPPs therefore steady state frequency, change in tie line power and system voltage is obtained. Independent system operator [1] is polarized in deregulated environment.

From coupled of years many researchers come up with different approaches in the field of AGC [1,7,8,10,12] to obtain overall system frequency and change in interlink line power up to expected range during usual operation in addition with small disturbances. Smooth operation is possible only

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when generation become equal to load demand and transmission losses.

Output power of thermal unit is controlled by controlling speed of flyball governor system by opening and closing of valve.

Load demand may change every instant which will be balanced by valve mechanism or load scheduling to the nearest generating unit therefore, opening and closing of valve depend upon demand power.

Different control mechanism is applied to control output power of hydro, nuclear, diesel and gas power unit. In this study the parameters of gas power, hydro and diesel power generation unit is considered by the Ali Ghasemi-Marzbali [1]. Whereas nuclear power plant explained by Krishna Chaitanya Diggavi [6].

Control strategy for interloop (LFC) is not enough to obtained chnage in frequency and deflection in interlink line power up to nominal value. Area control error (ACE) is controlled by controlling deflection obtained in interlink line in addition with deflection in frequency and frequency biased factor. For this different tanner PDF, PI, PIDF [5], PI-PDF [15], CPI-PDF and CPIDF-PDF are used to produce controlled signal for ACE.

Area participation factor come in picture that will describe how much percentage of the load share by each generating unit in given area therefore apf sum of particular area is unity. APF Control is another of simulator mechanisms for distributing an areas responsibility to server its load, losses and Interchange. It is particularly well suited to implementing AGC if guided information is not provided to generator in consider of economic. Area participation factor also depend upon load, generation and losses. ISO will open or close the valve of set point only when it will come in the range of APF otherwise ISO send command signal to nearest generating unit.

Load frequency loop (LFC) interconnected with automatic voltage regulator (AVR) controller [3,5] loop are used to obtained frequency and voltage respectively under nominal range. LFC control active power indirectly frequency whereas AVR control reactive power/voltage as shown in figure (1).

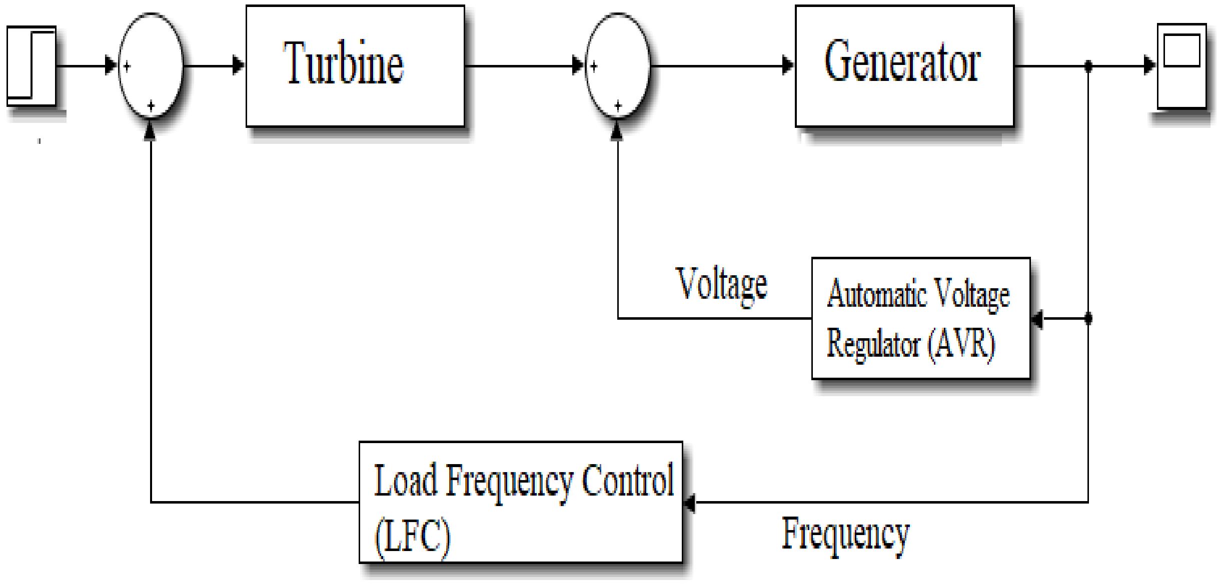

Fig 1 Interconnected AVR and LFC loop in AGC.

Due to unsubstantial connection between AVR and LFC loop, there is need of separate regulator for AVR. In this study type-2 AVR excitation system is considered which is explained by Elyas Rakshani [3]. From excitation system control mechanism, a steady state voltage unit for both area is obtained under nominal range.

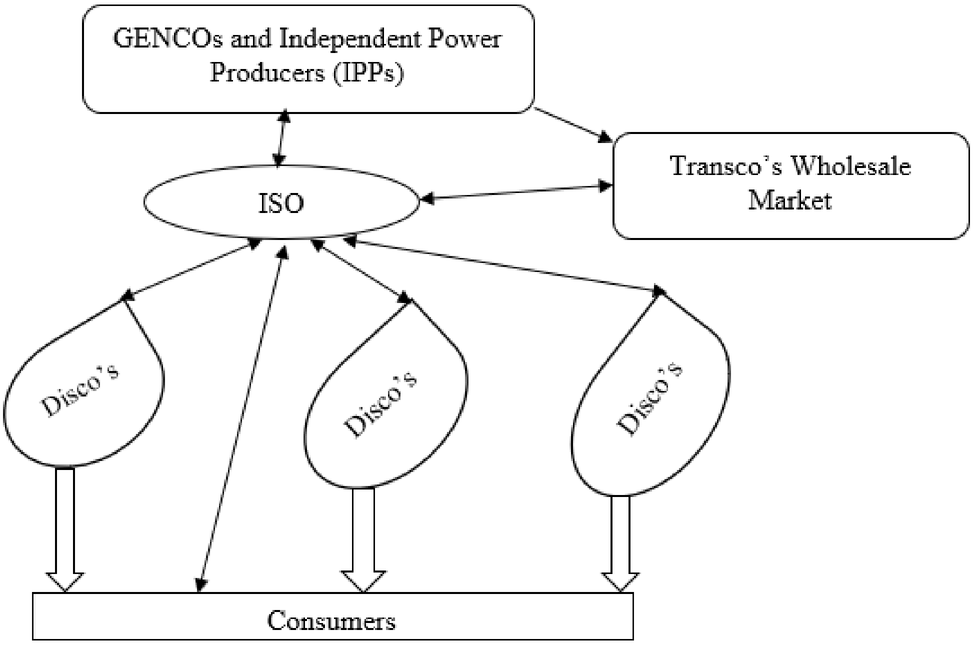

Fig 2 Deregulated Power system Network

II. Implementation of AGC under deregulated environment-

Every sector face competition, similarly, AGC migrate itself towards restructured in which every Genco might be free to generate electrical power or include itself in independent power producer (IPPs) [1] whereas Disco may purchase power to some degree of Genco with in area or to other area's Genco. Different bilateral contact takes place and are align in form of matrix named as Disco participation matrix (DPM).

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & \dots\dots\dots\dots\dots\dots & cpf_{1D} \\ cpf_{21} & cpf_{22} & \dots\dots\dots\dots\dots\dots & cpf_{2D} \\ \vdots & \vdots & & \vdots \\ cpf_{G1} & cpf_{G2} & \dots\dots\dots\dots\dots\dots & cpf_{GD} \end{bmatrix}$$

Where rows of DPM represent number of Genco and column represent number of Disco participate in interconnected network. Particular Disco share their total demand power from different Genco named as contract participation factor (cpf) therefore, sum of each column is unity.

For example, cpf_{mn} where m=1,2, . . . G

And n= 1,2…….D.

G= total number of Genco's.

D= Total number of Disco's.

Every disco sends a command signal to Genco from where it already makes power purchase contact. Concern governor of Genco must respond to disco and generate required signal so that required load must be match with generated power.

For each control area the power of Genco may calculate using

$$Genco_m = \sum_{n=1}^{D} cpf_{m,n} * Disco_n$$

The apf of a particular area is unity.

$$\sum_{a=1}^{n} apf = 1 \ Where\ a\ is\ the\ area$$

The value of apf for particular area is shown in table-1.

Steady state tie line power can be calculate using

$$\Delta P_{tie,1-2}^{Schedule} = (Demand\ power\ by\ area\ Two\ from\ Genco\ of\ Area\ one)$$
$$-(Demand\ power\ by\ Area\ one\ from\ Genco\ of\ area\ two)$$

Error in interlink line power can be calculated using

$$\Delta P_{tie,1-2}^{Error} = \Delta P_{tie,1-2}^{Actual} - \Delta P_{tie,1-2}^{Schedule}$$

At steady state position real tie-line power become equal to expected tie line power, therefore error in interlink line become zero.

Further different controller are study and applied to reduce area control error which are proportional controller with derivative filter (PDF), proportional integrator(PI), proportional integral controller with derivative filter PIDF, series connected proportional integral and proportional controller with derivative filter (PI-PDF), cascade proportional integrator cascade with proportional derivative filter (CPI-PDF) and proportional integral controller with derivative filter cascade with proportional derivative filter (CPIDF-PDF) are used to formulate performance of AGC and compare response of all controllers. CPIDF-PDF give better response as compared to non-cascade PID controller.

To get better response of AGC, third controller must have to tunned with in permissible range. Therefore, mathematical approach differential evolution(DE) algorithm is used to obtained optimized controller gain. In literature like BFO [8], GA[13], PSO [13], firefly algorithm[14] etc. have been flourishing to optimize controller parameter in AGC.

If small disturbance takes place the respond of tuner are very fast that's why it is more sensitive as compared to primary (LFC) and secondary loop(AVR). The structure of interconnected two area are shown in table 1.

Table 1 Structure of Two Area Multi-unit

	Genco's	**APF**	**Disco's**
Area-1	Gen-co-1	0.1	Dis-co-1
	Gen-co-2	0.1	Dis-co-2
	Gen-co-3	0.4	Dis-co-3
	Gen-co-4	0.3	Dis-co-4
	Gen-co-5	0.1	
Area-2	Gen-co-6	0.1	Dis-co-5
	Gen-co-7	0.6	Dis-co-6
	Gen-co-8	0.3	Dis-co-7

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

III. Proposed Controller-

Proportional derivative (PD), proportional integral (PI) and proportional integral controller with derivative filter (PIDF) are already implemented [8]. Proportional integral is cascaded with proportional derivative filter in which two control tuner are in sequences. The parameters of two control loops named as primary and replicas are highly sensitive. ACE signals provide to primary and the output of primary in reference to frequency deviation is applied to second tuner/replicas whose combination reject disturbance quickly.

Similarly Proportional integral derivative filter is cascaded with proportional derivative filter in which PIDF work as master and PDF work as slave. The block diagram of CPI-PDF is shown in figure-3 and block diagram of CPIDF-PDF is shown in figure-4.

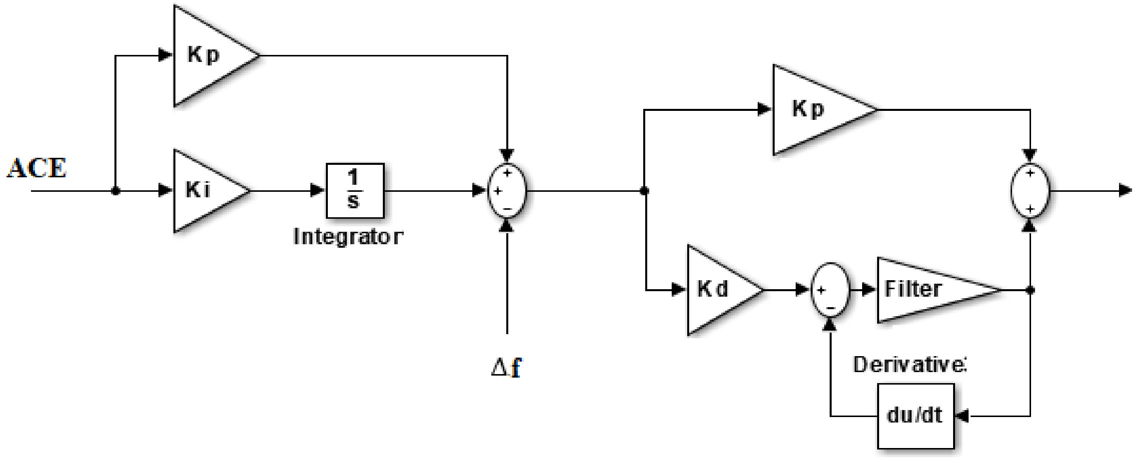

Fig 3 Structure of Cascaded PI-PIDF controller

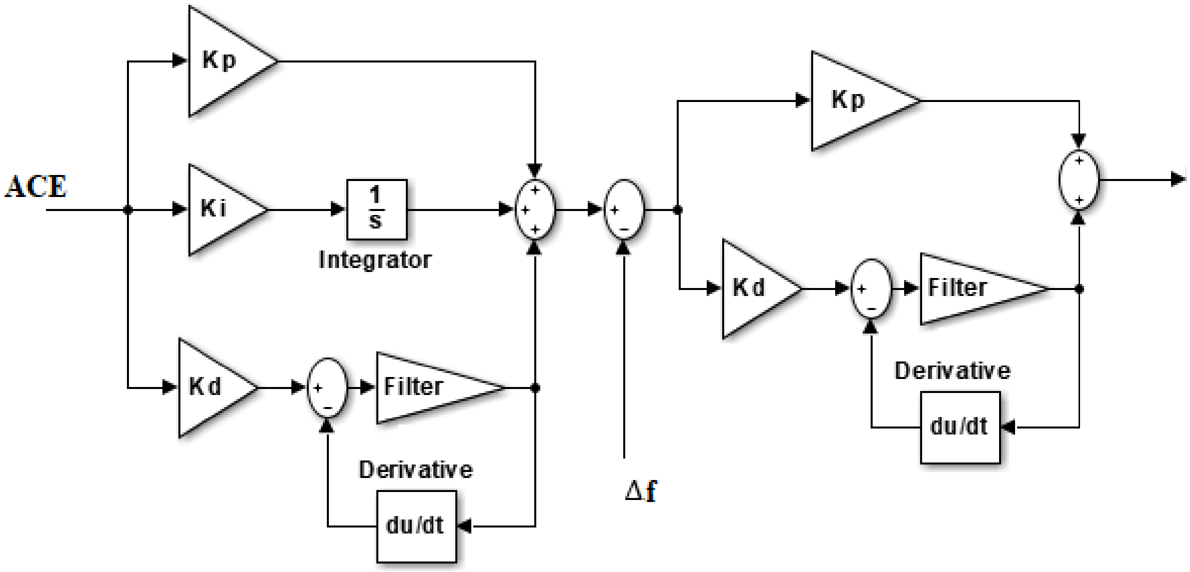

Fig 4 Structure of Cascaded PIDF and PDF controller

IV. Controller Structure and Objective Function-

Two different controllers at a time are applied to area-1 and area-2. Structure of different tuner PDF, PI, PIDF, series connected PI-PDF, CPI-PDF and CPIDF-PDF are applied. To obtained optimum parameters $K_{p,}$ $K_{d,}$ K_i and Filter constant N, differential evolution (DE) algorithm is used. Steady state response of frequency, interlink line power, voltage is obtained using optimum value. of these parameters in frequency, voltage and Tie-line power. The flow chart of differential evolution algorithm is shown in figure 5.

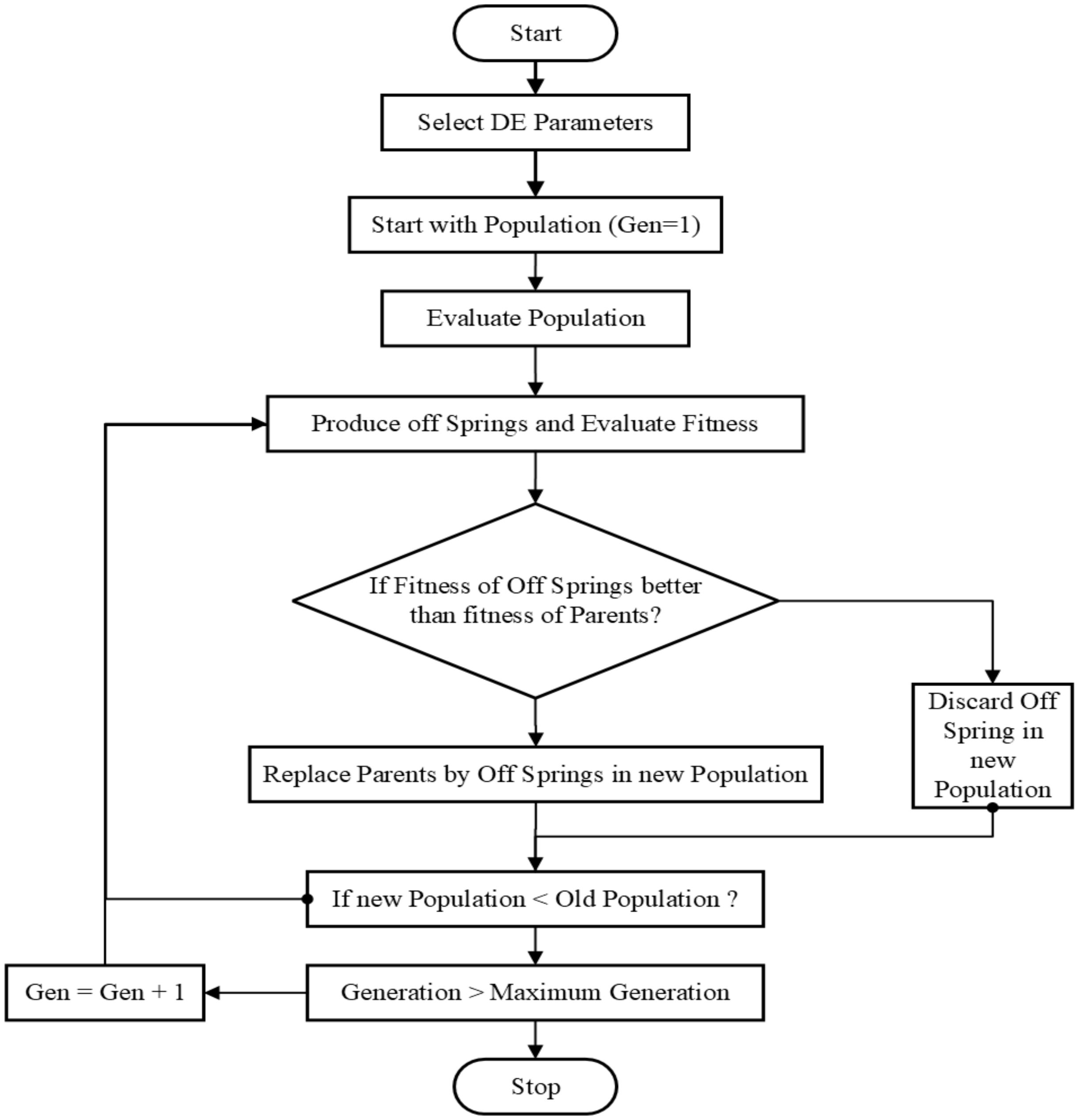

Fig 5. Structural outline of DE Optimization approach

$$J = ITAE = \int_0^{t_{sim}} (|\Delta F_1| + |\Delta F_2| + |\Delta V|_1 + |\Delta V|_2 + |\Delta P|_{tie}).t.dt$$

Where ΔF_1 *and* ΔF_2 are incremental frequency of area 1 and 2 respectively. Similarly, ΔV_1 *and* ΔV_2 are incremental change in voltage per unit and ΔP_{tie} is incremental change in power in tie line.

$$K_{pmin} \leq K_p \leq K_{pmax}$$

$$K_{Imin} \leq K_I \leq K_{Imax}$$

$$K_{dmin} \leq K_d \leq K_{dmax}$$

$$N_{min} \leq N \leq N_{max}$$

V. Results and Discussion

Balancing of dynamic response of PDF, PI, PIDF, series connected PI-PDF, CPI-PDF and CPIDF-PDF controllers are made using bilateral contact. In which any Disco may contact any of Genco depending upon their cost, losses and demand. The demand is modelled using DPM. During Simulink modelling 10% change in real power demand is considered. Two area interconnected hybrid power system Simulink model is prepared in which eight Genco's and seven Disco are used under deregulated environment. The AVR excitation loop is applied to obtain the required reactive power. By considering the number of iteration and population size of differential evolution algorithm parameter of different tuner is obtained which is shown in table 2. The parameter and transfer function required to make two area multi-unit simulation are given in table 6. By considering all the parameters an interconnected hybrid power system simulink model is prepared which is shown in figure6.

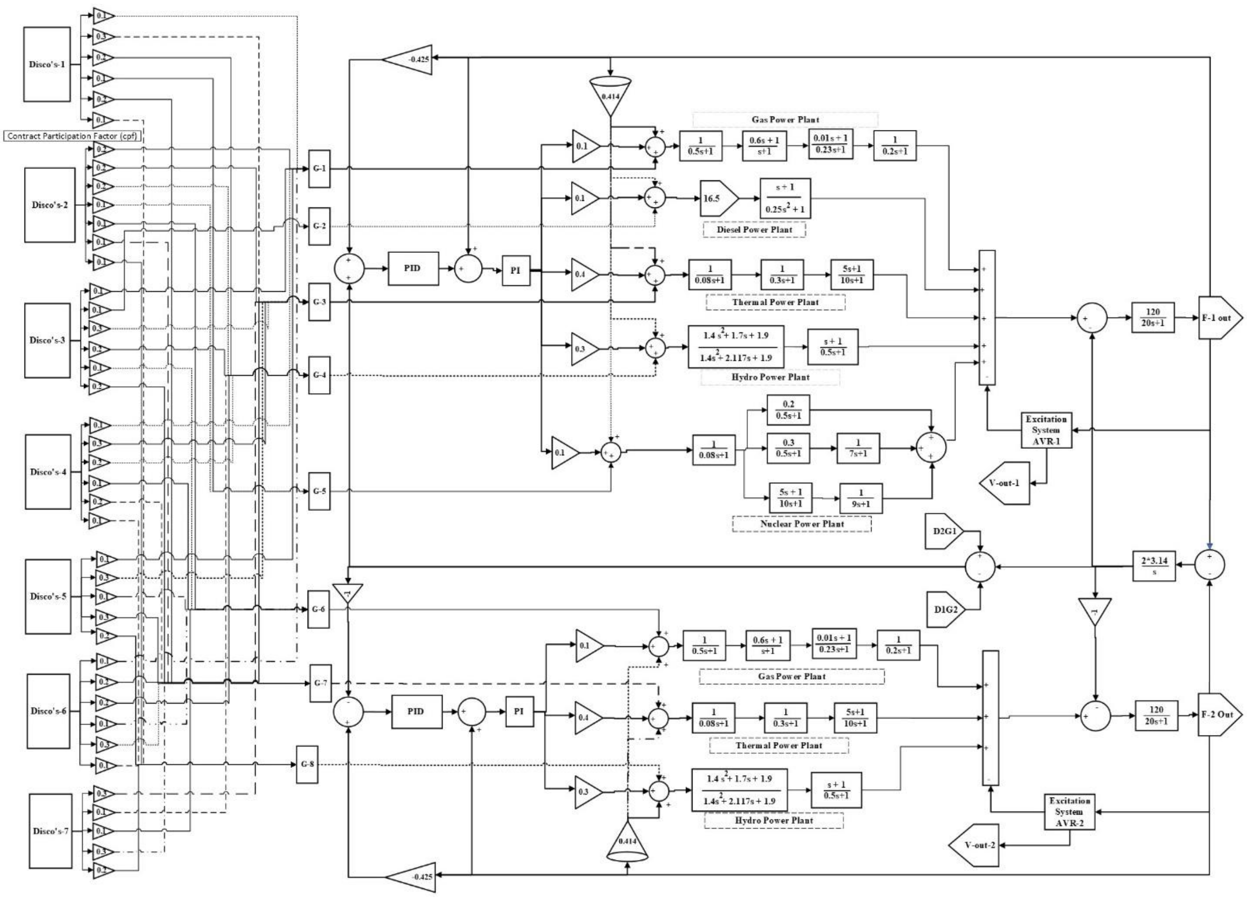

Fig 6. Simulink Model of Two-Area Hybrid System.

Table-2 Gain of different tuner with differential Algorithm.

Controller	Parameter	Area-1	Area-2
PI	K_p	1.2	1.1
	K_i	2.55	0.6
PDF	K_p	2	0.25
	K_D	5.8	5.87
	N_s	100	100
	K_P	1.6	1.8

PIDF	K_i	1.5	1.2
	K_D	0.65	0.4
	N_s	100	100
PI-PDF	$K_{p,m}$	0.55	0.68
	$K_{i,m}$	1.65	7.8
	$K_{p,s}$	4.48	0.55
	$K_{D,s}$	0.012	0.76
	N_s	100	100
CPI-PDF	$K_{p,m}$	3.9	5.1
	$K_{i,m}$	1.65	1.6
	K_p, s	4.6	3.53
	$K_{D,s}$	0.124	0.24
	N_s	100	100
CPIDF-PDF	$K_{p,m}$	0.5	0.6
	$K_{i,m}$	1.6	1.65
	$K_{D,m}$	0.64	0.45
	N_m	100	100
	$K_{p,s}$	0.6	0.7
	$K_{D,s}$	0.32	0.2
	N_s	100	100

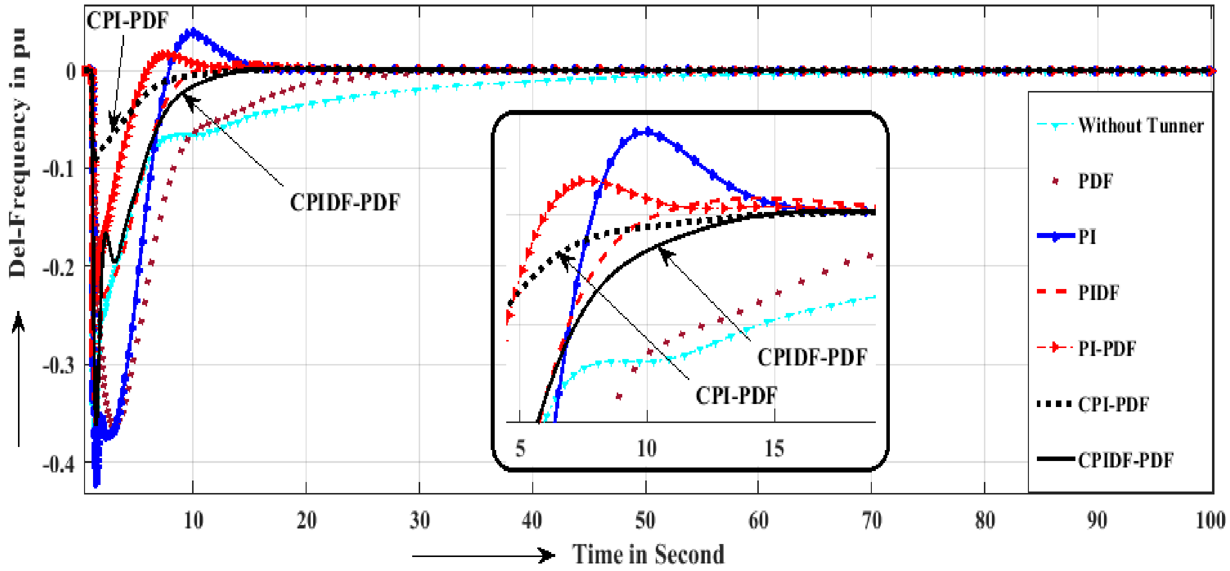

Fig 7 Frequency response of Area-1

Table-3 Comparison of different parameter for frequency of area-1

Controller	Without Tuner	PDF	PI	PIDF	PI-PDF	CPI-PDF	CPIDF-PDF
Rise Time(second)	0.0013	2.1559e-05	4.0478e-06	3.8623e-06	5.7459e-07	9.5736e-07	3.9799e-06
Settling Time	46.823	24.67	14.087	15.6916	10.3908	12.7595	11.9604
Peak Value	0.3673	0.3642	0.4203	0.3584	0.2878	0.0926	0.3625
Peak Time	1.3933	2.988	1.4108	1.3106	1.0692	1.2685	1.4180

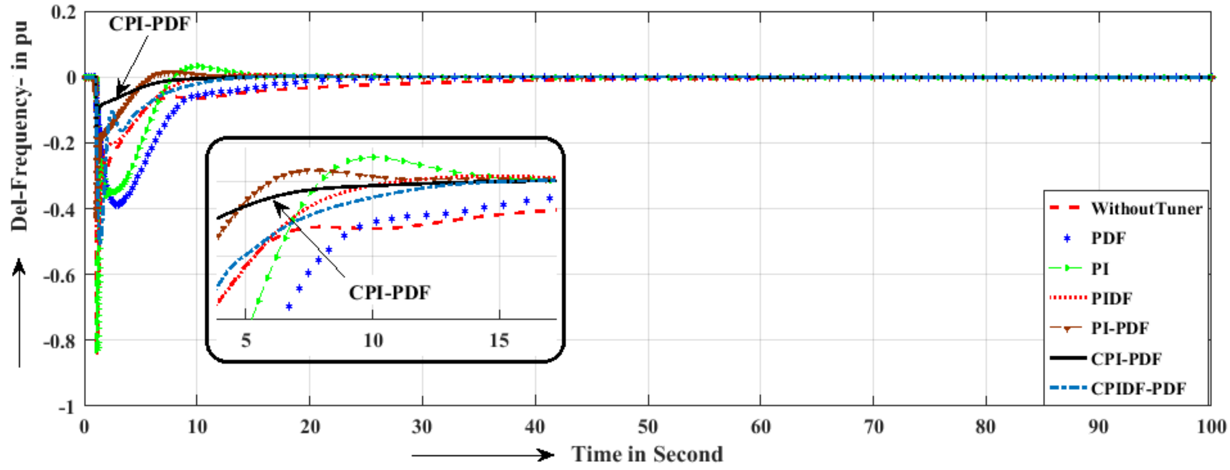

Fig 8 Frequency response of Area-2

Table-4 Comparison of different parameter for frequency of area-2

Controller	Without Tuner	PDF	PI	PIDF	PI-PDF	CPI-PDF	CPIDF-PDF
Rise Time(second)	0.0017	4.1501e-05	8.0672e-06	7.7230e-06	1.1498e-06	1.9095e-06	7.9983e-06
Settling Time	31.1424	23.4064	12.6555	15.12	9.5721	11.8688	11.7212
Peak Value	0.8414	0.3878	0.8301	0.5063	0.4270	0.1489	0.5064
Peak Time	1.1334	2.9887	1.1326	1.1260	1.1072	1.0936	1.4180

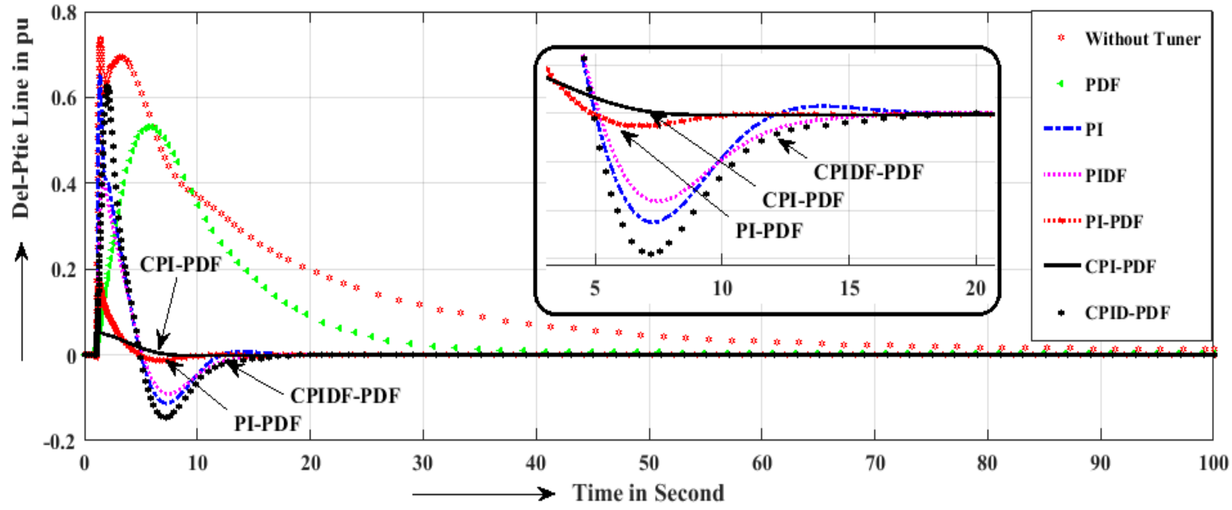

Fig 9 Change in tie-line power Ptie1-2

Table-5 Comparison of different parameter for tie line power

Controller	Without Tuner	PDF	PI	PIDF	PI-PDF	CPI-PDF	CPIDF-PDF
Rise Time(second)	0.0232	0.0353	6.6229e-07	1.2916e-07	3.0652e-06	6.7723e-06	0.0012
Settling Time	64.1580	33.2775	11.2790	13.4216	9.6282	18.2373	13.3040
Peak Value	0.7376	0.5329	0.6528	0.4004	0.1667	0.0525	0.6255
Peak Time	1.4115	5.6902	1.3739	1.6879	1.3436	1.3491	2.0432

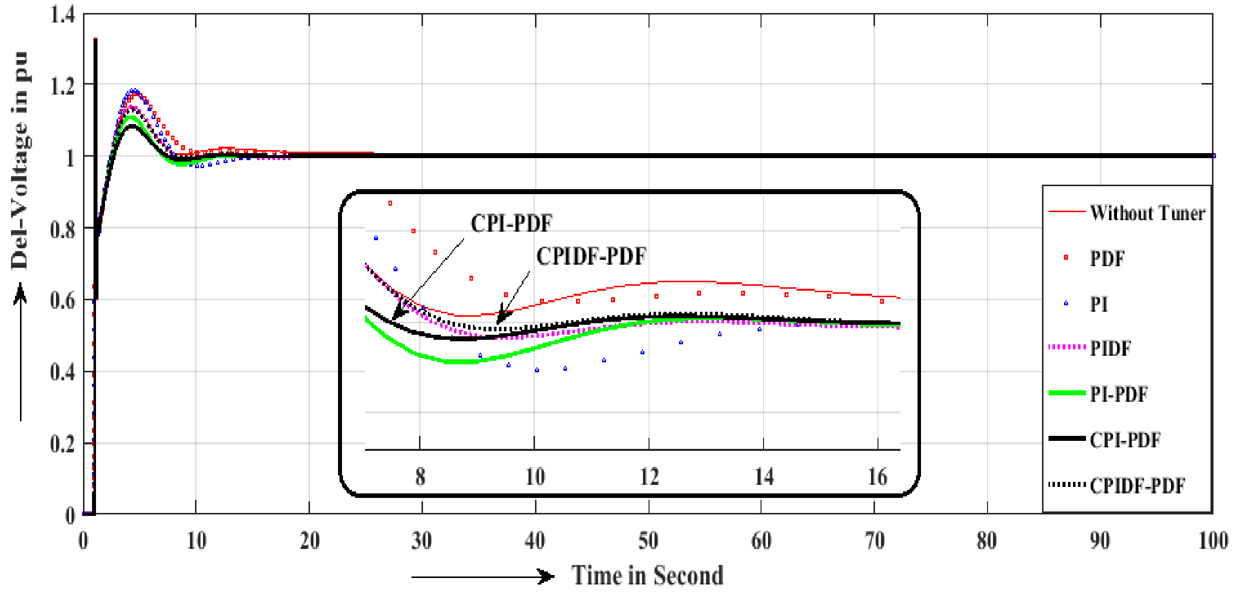

Fig 10 Voltage per unit of Area-1

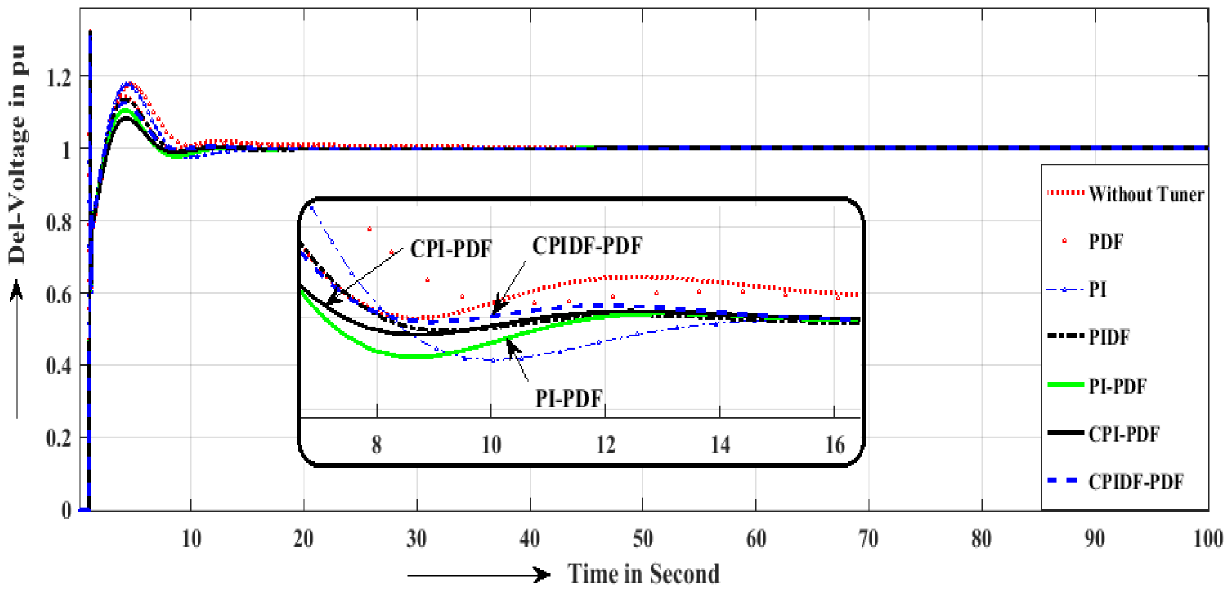

Fig 11 Voltage per unit of Area-2

The gain of proportional(kp), derivative(kd), integral(ki) and derivative filter(N) optimized using differential evolution algorithm are shown in table-3. Steady state response for two area in term of rise time, settling time, peak value and peak time are obtained for frequency, tieline power and system voltage all these are in per unit. The frequency response of area-1 & 2 is shown in figure-7 and figure-8 respectively in which series connected PI_PDF and CPIDF-PDF give better response as compared to another tuner which is shown in table-3 and 4.

For two area interconnected system there is a tie line between area-1 & 2. Change in Interlink tie line power is shown in figure-9 in which series connected PI_PDF and CPIDF-PDF give better response as compared to another tuner which is shown in table-2. AVR loop is applied therefore voltage response for area-1 & 2 are shown in figure-10 and figure-11 respectively.

VI. Conclusion

In this paper LFC, AVR and two degree of cascaded optimizing controller are applied for maintaining the frequency of the system. LFC loop is used to control active power where as AVR loop is used to control reactive power

In this paper multi-unit hybrid system in which thermal, hydro, nuclear, gas power and diesel power plants are considered. In both the area eight Genco and seven Disco have been considered. Total demand is shared in proportion of apf by considering demand, generation, cost, and losses.

To obtained optimum gain of proportional(kp), integral(ki), derivative(kd) and derivate filter(N) differential evolution algorithm is applied by considering number of iteration and population size.

The simulation result obtained from the series connected PI-PDF and CPI-PDF are found better than other controllers in respect of settling time, rise time, peak value, and peak time. The settling time of frequency using PI-PDF for two areas is 10.39sec and 9.57sec which is the least as compared to other fine tuner. The settling time of tie-line response is 9.62sec. The gain is optimized using differential algorithm.

To analysis frequency, voltage, and interchange in interlink line power for two area, multi-unit Simulink for hybrid power system is designed in Matlab 2016. In which different parameters such as settling time, rise time, peak time and peak value are compared.

Nomenclature-

B	Frequency Biased Factor
R	Speed Regulation
K_P	Equivalent Gain of Power System
T_p	Is used for Time Constant of Power System
T_t	Is used for Time Constant of Turbine
T_G	Is used for Time constant of Governor
ΔV_t	Change in Terminal Voltage
Δf	Small Change in Frequency
ΔP_t	Small Change in interlink line power

Table-6 Parameters of Hybrid power system

Name	Transfer Function	Parameters
Speed Governor	$\frac{1}{1+sT_g}$	$T_g = 0.08$
Turbine	$\frac{1}{1+sT_t}$	$T_t = 0.03$
Reheater	$\frac{1+csT_r}{1+sT_r}$	$T_r = 10, \quad c = 0.5$
Gas Turbine	$\frac{K_g}{C_g + sb_g} \frac{1+sX_c}{1+\ sY_c} \frac{1+sT_{cr}}{1+\ sT_{fc}} \frac{1}{1+\ sT_{cd}}$	$K_g = 1, C_g = 1, b_g = 0.5,$ $X_c = 0.06, Y_c = 1, T_{cr} = 0.01,$ $T_{fc} = 0.23, \quad T_{cd} = 0.2,$
Electric Hydraulic Governor	$\frac{K_d s^2 + K_p S + K_i}{K_d s^2 + (K_p + \frac{f}{R_2})S + K_i}$	$K_d = 1.4, K_p = 1.7,$ $K_i = 1.9, R_2 = 2.4$
Hydro Turbine	$\frac{1+sT_w}{1+0.5sT_w}$	$T_w = 1$
Diesel	$K_{diesel}\frac{1+s}{s+0.025s^2}$	$K_{diesel} = 16.5$
Nuclear	$\frac{K_{H1}}{1+sT_{H1}} + \frac{K_{R1}}{(1+sT_{H1})(1+sT_{RH1})}$ $+ \frac{(1+sT_{RH2})}{(1+sT_{RH2})(1+sT_{H2})}$	$K_{H1} = 0.2, \quad T_{H1} = 0.5,$ $K_{R1} = 0.3, \quad T_{RH1} = 7,$ $T_{RH2} = 5, \quad T_{H2} = 9$
Power System	$\frac{K_p}{1+sT_p}$	$K_p = 120, \quad T_p = 10$

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