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Genetic Algorithm-based PID Controller for Load-Frequency Control in Two Area Interconnected Power System

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Abstract

This paper presents an analysis on the dynamic performance of Load Frequency Control (LFC) of two areas interconnected multi-source power system by the use of a Genetic Algorithm (GA) based PID controller. In this paper, area-1 consists of the Micro Hydropower system (MHPS), Battery Energy Storage System (BESS), and PV System and area-2 consists of MHPS, Super Capacitor Energy Storage System (SCESS) and Wind Power Plant (WPP). The fluctuating output power of Renewable Energy Sources (REs) and therefore the perturbation of the load demand will cause power imbalance and frequency deviation within the system. The control scheme guarantees that steady-state error of frequencies and inadvertent interchange of tie-lines are maintained during a given tolerance limitation. The performances of the controllers are simulated using MATLAB SIMULINK. The ESS is connected as auxiliary regulation. To research the effectiveness of the proposed approach, time-domain simulations are administered considering different contracted scenarios and therefore the comparative results are presented. Further, sensitivity analysis is performed by varying the system parameters and operating load conditions. it's observed from the simulation results that the designed controllers are robust, and therefore the optimum gains of the proposed controller needn't be reset albeit the system is subjected to a large variation in loading conditions and system parameters. Finally, the effectiveness of the proposed control scheme is evaluated under random step load disturbance.

Keywords

Load Frequency Control (LFC), PID controller, Area Control Error (ACE), Tie-line, MATLAB / SIMULINK

1. Introduction

TThe main aim of power systems is to provide the required amount of power supply to customers with a given voltage and frequency. The frequency and voltage levels will be varying with the change of the load. The active power and reactive power have a combined effect on the frequency and voltage, the control problem of frequency and voltage can be separated. The frequency is majorly dependent on active power while voltage is majorly dependent on reactive power. Thus, the control issue in the power system can be separated into two independent problems. One is frequency control i.e., active power control while the other is voltage control i.e., reactive power control. The active power balance between generation and load so that frequency control occurs in the system is known as load frequency control.

In the recent focus on renewable sources of energy such as Photovoltaic In the recent focus on renewable sources of energy such as Photovoltaic and wind power plant mostly penetration in the power system, the uncertainties of active power production are highly increased due to the output of the PV and Wind power plants depends on the different parameters such as weather conditions, geographical location, placement direction, etc. The PV output power depends on the irradiance, temperature, and placement of the PV panel and the output power of the wind power plant depends on geographical location, wind speed, air density, blade radius, and direction of wind flow. The loads are never constant so that the variation of the generation, as well as load, occur the fluctuation of active power causes the variation of load frequency of the power system so that the load frequency is very important for an interconnected power system. The problem of Load Frequency Control (LFC) in power systems has to do with an attempt to control:

a) Sudden disturbances that disrupt normal conditions of system operation.

b) Sudden disturbances that occur due to outages and connections of loads on different hours in the power system.

At the occurrence of a new change on requesting for active power at any part of the generating system under consideration, this change spreads throughout the generating system as a frequency problem. For effective active power output to be maintained in a system, the power frequency of the network should be kept at a constant state[1]. The load–frequency control is a part of the AGC system. AGC of the power system is to maintain frequency and power change over the tie-lines at their scheduled values. Therefore, it's a simultaneous load frequency control. The load frequency control takes consideration of the management of disturbances on the frequency of power system up to the production of active power output by generators and management of power from the tie-line connection in the power system. The LFC ensures it keeps the frequency throughout the system line nearly to zero state. It also tries to remain the active power output within the power system under consideration on the value specified for the line. The main requirement of any power generating system is to keep the power on zero steady states, so the active and reactive powers should also be effectively controlled. The LFC technique ensures that active and stable power is produced and then supplied to an interconnected system such that the cost of power production and supply will be cheap and reliable while making sure that the voltage and frequency are controlled over an acceptable range[2]. The LFC technique has the following main aims

- To keep the power frequency of the network on the required range of value
- To make sure that the load between the generating systems is evenly distributed
- To achieve total control of the load or power interchange across the tie lines

The moment there is a unit step increase in the load of the system power output, there is a corresponding system fluctuation in the frequency of the whole system. The controllers also ensure that those minute changes in p.u load demand are controlled to keep control of the magnitude of the voltage and frequency throughout the specified ranges. With the increasing scale and capacity of the renewable energy power plant, uncertainty in system increases. Just relying on predictive control would make it easy to bring frequency fluctuations in the system and add weight to the adjustment. Under such circumstance, the control effect of traditional LFC controller is not ideal and operational requirements cannot be met. It would be hard to satisfy the ever-expanding scale of renewable energy generations. Therefore, the LFC controller design is required.

Although some advanced controllers have been developed for the load frequency control of interconnected power systems such as fuzzy logic, artificial neural network, and distributed model predictive controller, the proportional-integral (PI) and proportional integral derivative (PID) controllers are still the most popular for LFC because of their simple structure and high robustness.For micro grid networks with photovoltaic (PV) systems, battery units, micro wind turbines (MWT), and fuel cells, the most suitable control method is a self-adjusting control method. Daneshfar and Bevrani actualized a FLC process with a GA that was applied to a grid network which had two or three areas, in a classic or hybrid power system [3]. Moreover, optimization methods embedding flexible alternative current transmission systems (FACTS) were executed on multi areainterconnected power systems, in some studies. In the systems, the effects of the FACTSs on the frequency of the line were monitored.

2. Methodology

2.1 LFC Model

The dynamic model of LFC in two-area interconnected power system is as shown in Fig. 1 is presented in this section. In area-1 of the power system consists of speed governing system, turbine, generator, battery as an energy storage system, PV as renewable energy and load. In area-2 of power system consists of speed governing system, turbine,generator, supercapacitor as an energy storage system, Wind power as renewable energy and load. To simplify the analyses of the frequency domain, transfer functions are used to model each component in the system.
Governor is represented by the transfer function[4].

$$G_G = \frac{\Delta X}{\Delta P_V} = \frac{K_g}{1+sT_g} \tag{1}$$

Turbine is represented by the transfer function[4].

$$G_T = \frac{\Delta P_T}{\Delta X} = \frac{1+sK_t}{1+sT_t} \tag{2}$$

Generator is represented by the transfer function[4].

$$G_{Ge} = \frac{\Delta P_{g11}}{\Delta X} = \frac{1+sK_{ge}}{1+sT_{ge}} \tag{3}$$

The transfer function of Battery energy storage system is represented by[4].

$$G_B = \frac{\Delta P_b}{\Delta P_{ref}} = \frac{K_{ba}}{1+sT_{ba}} \tag{4}$$

Bidirectional Converter can be started from following formula[4].

$$G_{Bi} = \frac{\Delta P_{g12}}{\Delta P_b} or \frac{\Delta P_{g22}}{\Delta P_c} = \frac{K_{bi}}{1+sT_{bi}} \tag{5}$$

The transfer function of SuperCapacitor energy storage system is represented by[4].

$$G_C = \frac{\Delta P_c}{\Delta P_{ref}} = \frac{K_c}{1+sT_c} \tag{6}$$

Inverter is represented by the transfer function[4].

$$G_{Bi} = \frac{\Delta P_{g12}}{\Delta P_b} or \frac{\Delta P_{g22}}{\Delta P_c} = \frac{K_{bi}}{1+sT_{bi}} \tag{7}$$

The transfer function of PV system is represented by[4].

$$G_{PV} = \frac{K_{PV}}{1+sT_{PV}} \tag{8}$$

Wind power System is represented by the transfer function[4].

$$G_W = \frac{K_W}{1+sT_W} \tag{9}$$

The transfer function of generator and load is represented by[4].

$$G_{GL} = \frac{K_P}{1+sT_P} \tag{10}$$

Where $K_P = \frac{1}{D}$ and $T_P = \frac{2H}{fD}$ .D is load frequency dependent parameter,$D = \frac{P_{L1}}{f}$. P_{L1} is nominal load.H is inertia constant.f is nominal frequency.

In Fig.1, B_1 and B_2 are the frequency bias parameters. ACE_1 and ACE_2 are area control errors. U_1 and U_2 are the outputs from PID controller. R_1 and R_2 are governor speed regulation parameters($Hz/p.u.$). T_g, T_t, T_{ba}, T_{bi}, T_{PV}, T_i, T_p, T_C and T_W are time constant in second of governor, turbine, battery energy storage system, bidirectional converter, PV system, inverter, generator and load, supercapacitor energy storage system and wind power plant respectively. K_g, K_t, K_{ba}, K_{bi}, K_{PV}, K_i, K_p, K_C and K_W are the gains of governor, turbine, battery energy storage system, bidirectional converter, PV system, inverter, generator and load, supercapacitor energy storage system and wind power plant respectively. ΔP_{tie} is the incremental change in tie line power($p.u.$). T_{1-2} is synchronizing cofficient. ΔP_{d1} and ΔP_{d2} are the load demand changes. Δf_1 and Δf_2 system frequency deviation in Hz.The parameters are illustrated in Appendix.

The standard state space form of the system can be expressed as

$$\dot{X} = Ax(t) + Bu(t) + Ld(t) \tag{11}$$

Where $x(t), u(t)$ and $d(t)$ are the state, control and load disturbance vector respectively whereas A, B and L are state matrix, control matrix and disturbance matrix of appropriate dimensions respectively. The vectors $x(t), u(t)$ and $d(t)$ are given by

$$x(t) = [\Delta f_1 \Delta P_{g11} \Delta X_1 \Delta P_{g12} \Delta P_b \Delta P_{g13} \Delta P_{tie} \Delta f_2 \Delta P_{g21} \Delta X_2 \\ \Delta P_{g22} \Delta P_c \Delta P_{g23}]^T$$

$$u(t) = [U_1 U_2]^T$$
$$d(t) = [\Delta P_{d1} \Delta P_{pv} \Delta P_{d2} \Delta P_W]$$

The system output depends on the area control error(ACE).

$$y(t) = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} \tag{12}$$

2.2 Controller Structure

To maintain the scheduled system frequency and scheduled tie-line power. PID controllers are provided in both areas of two area systems under study. The ACE is represented by the equation below:

$$ACE_i = B_i \Delta f_i + \Delta P_{tiei} \tag{13}$$

Where B_i is the frequency bias constant, Δfi is the frequency deviation, $\Delta P_{tiei}$is the change in the tie-line power, B_i is the expression of the frequency change in the power unit. The input signal U is given to corresponding control area.

$$U = K_p ACE + K_i \frac{ACE}{s} + K_d ACEs \tag{14}$$

Where K_p,K_i and K_d are PID controller parameters. These parameters are optimized by GA in this paper.

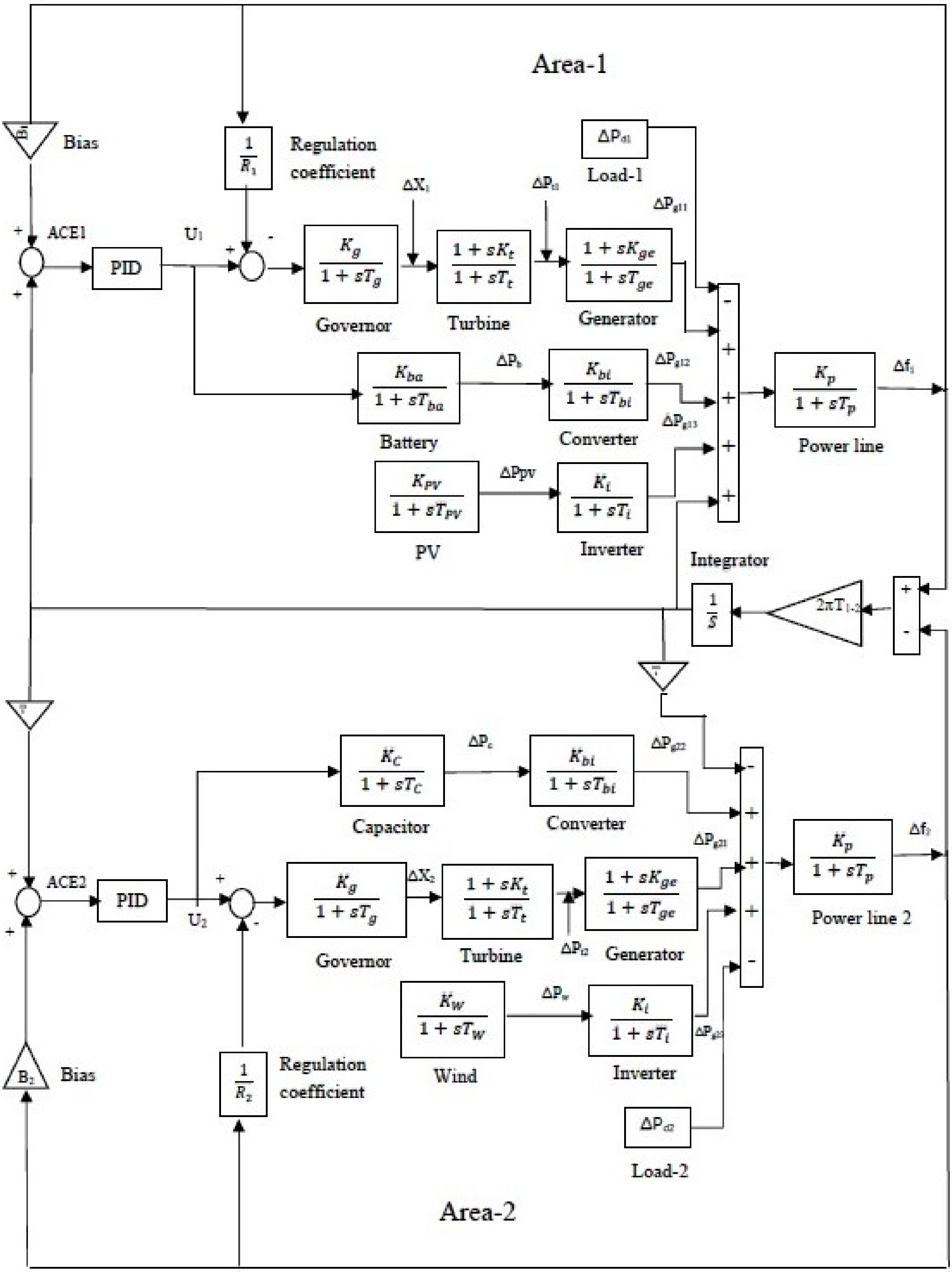

Figure 1: : State Space model of two area interconnected power system

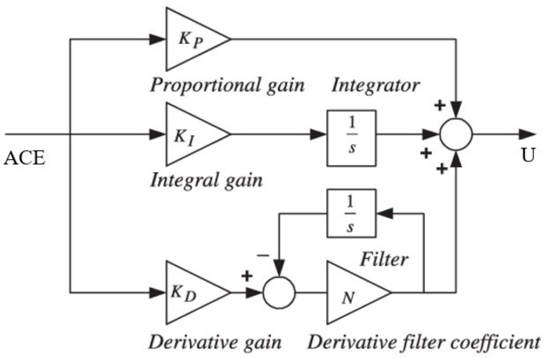

Figure 2: : Structure of the PID controler

2.3 Obective Function

A system is considered as an optimum control system when the controller parameters are adjusted so that the objective function reaches a minimum value. In the design of a modern genetic algorithm optimized PID controller. The design of objective function to tune PID controller parameters is generally based on performance indices that considers the entire closed loop response. Some of specifications for LFC are as follows:

1) Frequency deviations and tie-line power deviation recover to zero as soon as possible under a step load change.
2) The integral of frequency deviations and tie-line power deviation should be minimum.

To satisfy these specifications, four conventional performance indices are designed such as the Integral of Time multiplied Absolute Error (ITAE), Integral of Time multiplied Squared Error (ITSE), Integral of Squared Error (ISE) and Integral of Absolute Error (IAE) as follows[5].

$$ITAE = \int_0^t \left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|\right).tdt \quad (15)$$

$$IAE = \int_0^t \left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}|\right) dt \quad (16)$$

$$ISE = \int_0^t \left(\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2\right) dx \quad (17)$$

ISE is formed by integrating the square error in fixed time interval. *ISE* will penalize larger error than minor error, which exhibits a small overshoot but has a large settling time. In addition, *IAE* is the absolute error that increases over time, which produces slow dynamic response. *ITAE* criterion can use the time multiplication term to penalize the error more in the later stage and therefore effectively reduce the settling time, which cannot be achieved with *IAE* or *ISE* based tuning. Hence, the objective function *J* used in genetic algorithm is defined as:

$$mimimizeJ(K_p, T_i, T_d) = w_1(ISE) + w_2(IAE) + w_3(ITAE) \quad (18)$$

Whrere w_1,w_2 and w_3 are weight indices

3. Result and Discussion

The LFC of interconnected power system is done by MATLAB code, Simulink and control block. Among them control block is best. In the control block require the transfer function of each block then connected as the series and parallel as the system, tie line is connected between them for interchange the required power. After knowing the transfer function of each block determines the step response and impulse response. The step response gives the overshoot time, rise time and settling time. Impulse response of dynamic system is its output when presented with a brief input signal. Normally impulse response is reaction is the reaction of dynamic system in response to some external change. Since the impulse function contains all frequencies the impulse response defines the response of linear time invariant system for all frequency. Normally when the step response of each area was plotted then the system was unstable then used of the Zieglor Nichols method for PID tuning and determined the PID parameter and made the system stable shown in Table 1.

Table 1: PID parameters of each control area

Control areas	K_P	K_i	K_d
Area-1	0.7785	3.370	0.07361
Area-2	10.35	8.27	0.0286

Case-1: Fixed power output from PV and Wind
The output power of the PV power system and wind power system are 0.3 p.u. and 0.5 p.u. which is the full rated output power of respective power system.

a) Load disturbance 0.1 p.u. at Area-1 and 0.05 p.u. at Area-2.

The output power of the renewable energy resources is dynamic but the output power of renewable energy

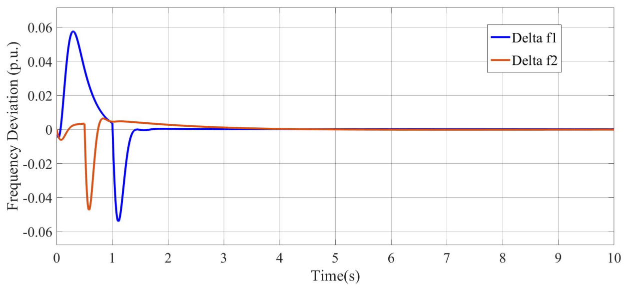

Figure 3: : Frequency deviation for 0.1 p.u. step load change in area-1 and for 0.05 p.u. step load change in area-2 with fixed generation

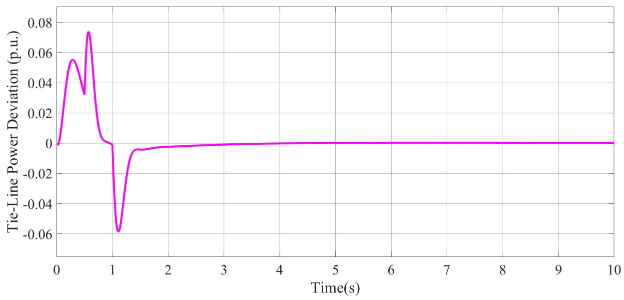

Figure 4: :Tie line power deviation for 0.1 p.u. step load change in area-1 and for 0.05 p.u. step load change at area-2 with fixed generation

resources is kept constant.A 0.1p.u. step load increase in area-1 and a 0.05 p.u. step load increase in area -2 is considered simultaneously at t=0 sec. The dynamic response achieved by GA based PID controller are shown in Figure 3 and Figure 4.The settling time of frequency and tie line power deviation are Δf_1 =1.46s, Δf_2=2.58s and ΔP_{tie}=2.31s.The overshoot of frequency and tie line power deviation are 0.0572 p.u.Hz, -0.0486p.u.Hz and 0.0768 p.u.MW. The settling time and overshoot is decrease due to the fast response of BESS and SCESS.

b) Load disturbance 0.1 p.u. at Area-1 and 0.15 p.u. at Area -2.

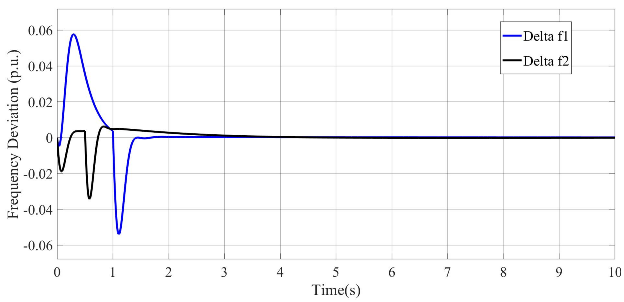

Figure 5: : Frequency deviation for 0.1 p.u. step load change in area-1 and for 0.15 p.u. step load change in area-2 with fixed generation

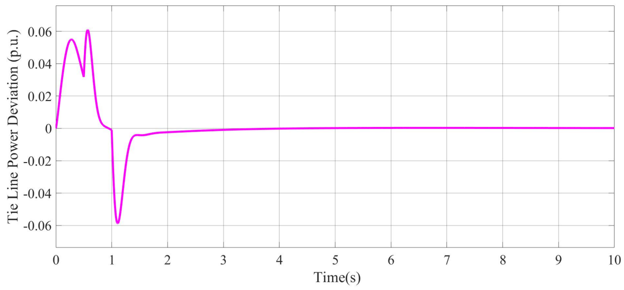

Figure 6: : Tie line power deviation for 0.1 p.u. step load change in area-1 and for 0.15 p.u. step load change in area-2 with fixed generation

The dynamic response of two areas interconnected power system, the frequency deviation and tie line power deviation occurs in both areas according to the load disturbance 0.1 p.u. in area-1 and 0.15 p.u. in area 2 is shown in Figure 5 and Figure 6 respectively. When the frequency of the system decreases, the energy storage system such as BESS and SCESS gives e fast response to make the system stable as fast as possible.The settling time of frequency and tie line power deviation are Δf_1 =1.48s, Δf_2=2.62s and ΔP_{tie}=2.71s. The overshoot of frequency and tie line power deviation are 0.0582 p.u.Hz, -0.0386p.u.Hz and 0.0608 p.u.MW.

c) Load disturbance 0.2 p.u. at Area-1 and 0.25 p.u. at Area -2.

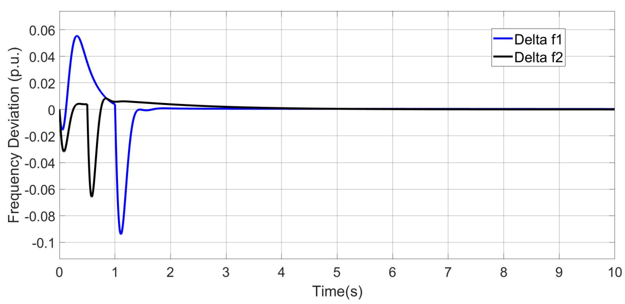

Figure 7: : Frequency deviation for 0.2 p.u. step load change in area-1 and for 0.25 p.u. step load change in area-2 with fixed generation.

In order to prove the dynamic performance of the system with the purposed GA based PID controller, a step load change in demand of 0.2 p.u. in area -1 and 0.25 p.u. in area-2 at t=0sec and the system dynamic responses are shown in Figure 7 and Figure 8. The settling time of frequency and tie line power deviation are Δf_1 =1.48s, Δf_2=2.62s and ΔP_{tie}=2.74s. The overshoot of frequency and tie line power deviation are -0.0945p.u.Hz, -0.0625p.u.Hz and -0.1p.u.MW.

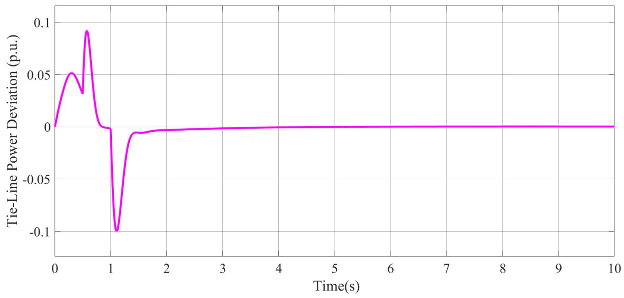

Figure 8: : Tie line power deviation for 0.2 p.u. step load change in area-1 and for 0.25 p.u. step load change in area-2 with fixed generation.

Case-2:Variable output power of PV and Wind
The output power of the PV power system is 0-0.3p.u. and wind power system is 0.1-0.5 p.u. respectively. For the variable power generation of REs used of ramp function.

a)Load Disturbance 0.05 p.u. in Area-1 and 0.1 p.u. in Area-2.

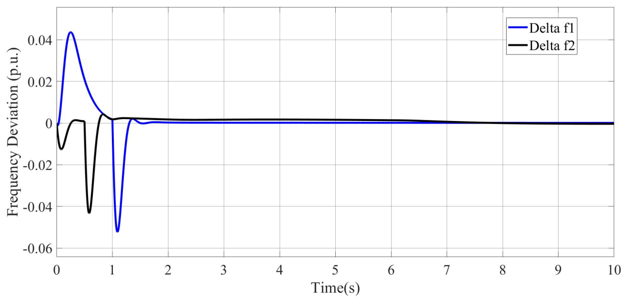

Figure 9: : Frequency deviation for 0.05 p.u. step load change in area-1 and 0.1 p.u. step load change in area-2 with variable generation.

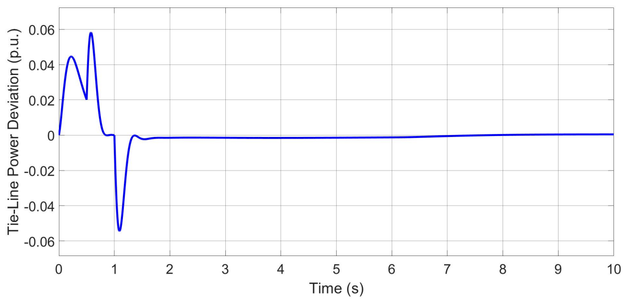

Figure 10: : Tie line power deviation for 0.05 p.u. step load change in area-1 and for 0.1 p.u. step load change in area-2 with variable generation.

The dynamic response of two areas interconnected power system, the frequency deviation and tie line power deviation occurs in both areas according to the load disturbance 0.05 p.u. in area-1 and 0.1 p.u. in area 2 is shown in Figure 9 and Figure 10 respectively. When the frequency of the system decreases, the energy storage system such as BESS and SCESS gives e fast response to make the system stable as fast as possible. The settling time of frequency and tie line power deviation are Δf_1 =1.2s, Δf_2=4.76s and ΔP_{tie}=4.9s. The overshoot of frequency and tie line power deviation are -0.0524 p.u.Hz, -0.0428p.u.Hz and 0.058 p.u.MW..

b)Load Disturbance 0.1 p.u. in Area-1 and 0.2 p.u. in Area-2.

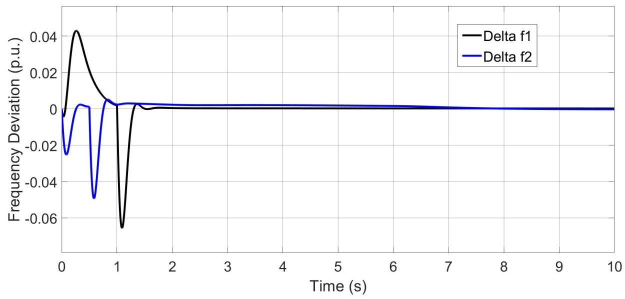

Figure 11: : Frequency deviation for 0.1 p.u. step load change in area-1 and for 0.2 p.u. step load change in area-2 with variable generation.

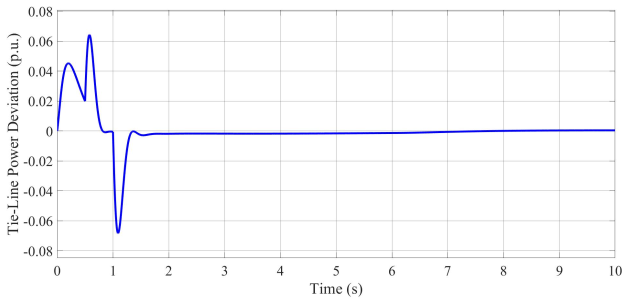

Figure 12: : Tie line power deviation for 0.1 p.u. step load change in area-1 and for 0.2 p.u. step load change in area-2 with variable generation.

In order to prove the dynamic performance of the system with the purposed GA based PID controller, a step load change in demand of 0.1 p.u. in area-1 and 0.2 p.u. in area-2 at t=0sec and the system dynamic responses are shown in Figure 11 and Figure 12. The settling time of frequency and tie line power deviation are Δf_1 =1.6s, Δf_2 =6s and ΔP_{tie} =5.12s. The overshoot of frequency and tie line power deviation are -0.063 p.u.Hz, -0.0465p.u.Hz and -0.0647 p.u.MW.

c)Load Disturbance 0.15 p.u. in Area-1 and 0.35 p.u. in Area-2

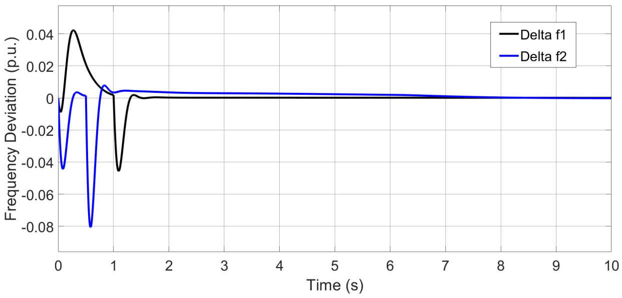

Figure 13: : Frequency deviation for 0.15 p.u. step load change in area-1 and for 0.35 p.u. step load change in area-2 with variable generation.

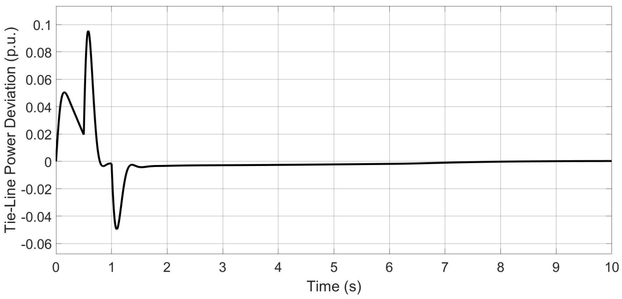

Figure 14: : Tie line power deviation for 0.15 p.u. step load change in area-1 and for 0.35 p.u. step load change in area-2 with variable generation.

A 0.15p.u. step load increase in area-1 and a 0.35 p.u. step load increase in area-2 is considered simultaneously at t=0 sec. The dynamic response achieved by GA based PID controller are shown in Figure 13 and Figure 14. The settling time of frequency and tie line power deviation are Δf_1 =2s, Δf_2 =6s and ΔP_{tie} =5.2s. The overshoot of frequency and tie line power deviation are -0.0435p.u.Hz, -0.081p.u.Hz and 0.0972p.u.MW. The settling time and overshoot is decrease due to the fast response of BESS and SCESS.

4. Conclusion

In this paper, a GA based PID controller was proposed for frequency stability problems in a two area multi source interconnected power system. The power system to be controlled was consisted of a hydropower Solar power, Wind power and energy storage devices. All systems and controller was designed and simulated with the MATLAB-Simulink program. In the simulations, a change in the frequencies and the tie-line power were observed by load disturbance in each area with fixed and dynamic generation. Since there was a two-area power system and they were connected by a tie-line, the outputs of Δf_1, Δf_2, and ΔP_{tie} of the system were plotted. The ability of the system to adapt to sudden power fluctuations at the operation point was also improved. In each control area had the energy storage device so that the deviation frequency was damped very short time due to fast response of energy storage device. In the meantime, the optimum values of the Kp, Ki, and Kd parameters for the PID controller were determined by the Zigler-Nichols method.

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Appendix A

Parameters of two area interconnected power system

K_{pv}	= 0.0075	K_g	= 1
T_{pv}	= 0.03	T_g	= 0.05
K_i	= 1	K_{ge}	= -1
T_i	= 0.4	T_{ge}	= 0.5
K_W	= 1	K_t	= 5
K_W	= 1.5	T_t	= 28.75
K_{ba}	= 1	T_{1-2}	= 0.086
T_{ba}	= 0.1	R_1	$= R_2 = 2.43$
K_c	= 68.78	K_P	= 60
K_{bi}	= 1	T_P	= 18
T_{bi}	= 0.2	w_1	$= w_2 = w_3 = \frac{1}{3}$