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PSO Based Frequency Control of Wind-Diesel Integrated to Two Area Power System

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ABSTRACT: In recent year the renewable power generation systems integrated to power system is more complex to control frequency. In this paper, PID controller gains are tuned by using PSO technique is used for control the load frequency of two area power system with inter connection of wind-diesel system. The performance is shown in a two area system for the sudden changes in generation or load or both. The tuning process of PID controller is difficult for non linear system. PSO technique is used for better optimum values with respect to frequency deviation. Simulation results for combination of PSO and PID control technique is improved when compared to classical PID controller in terms of rising time and settling time.

KEYWORDS: Diesel engine generator, frequency deviation, non linear system, PID controller, PSO technique, wind generator.

I.INTRODUCTION

In recent scenario, the demand for clean power is high due to environmental pollution concern. So, we have to minimize the usage of fossil fuels for generating the power. According to non conventional resources, we have wind, solar and fuel cell sources for generating the on board electricity. Among these wind energy conversion system is very effective for power generation and for the optimal performance of integrated wind energy system, the controller gains are tuned by using PSO [3].When we interconnect to the grid system, there is a problem with constant voltage with wind system. So, we have to hybridize the wind with diesel engine system to maintain constant voltage [6] at load end. The interconnected system is divided into control areas with each consisting of one or more power utility companies. At the time of interconnection there is another problem of frequency deviation then LFC is used to maintain frequency deviation constant against continuous variations of loads [10] and PID controller is used to minimize oscillations in frequency by tuning process. According to case study of northern grid failure, deviation in the frequency was main responsible for failure of grid. In PID controller operation, gains of the controller are used to tune the rise time, settling time and damping oscillations. Manually tuning of PID controller is very difficult and that are valid for particular error value. So, to modify the classical PID controller for automatic gains adjustment according to variations in error with respect to time, the automatic gains are controlled by new optimum techniques i.e., Particle Swarm Optimization technique, artificial neural network, fuzzy controller, genetic algorithm etc. PSO technique is best suitable [9] for tuning PID controller to minimize the rising time, settling time and oscillations.

II. HYBRID TOPOLOGY

According to the block diagram of hybrid topology is shown in Fig 1. According to the Fig 1 the block diagram of hybrid topology consists wind energy system and diesel engine system. The total power supplied to the load side by wind energy system and diesel system. The transfer functions with first order of wind and diesel energy systems are shown in below.

III. WIND TURBINE MATHEMATICAL MODEL

In this, wind turbine is the heart of wind energy conversion system. The mechanical power which is produced by the turbine is depends on power coefficient C_P is product of the both tip speed ratio λ and the pitch angle of turbine blades

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θ_{blade}. The tip speed is defined as ratio of increasing of linear speed by the tip of blade and the wind generated speed. At particular instant of time the output of the turbine generator is varied with respect to speed of the wind.

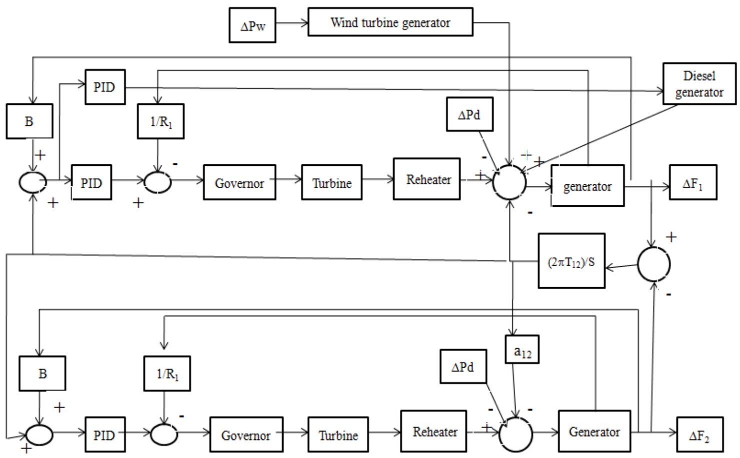

Fig. 1 Block Diagram of Hybrid System

The wind turbine generator is controlled by pitch angle of blades due to frequency oscillations and output variation. We have to fix the set point for pitch angle and the pitch system is changing the pitch angle according to wind speed and direction. The mathematical model of wind turbine is the total power generated by wind speed is expressed as

$$P_{turbine} = 0.5\rho A v^3 C_P(\lambda, \theta_{blade}) \tag{1}$$

Where,

ρ = Air density (Kg/m^3)

A = Swept area (m^2) and A = πr^2 (m^2)

v = wind velocity (m/s)

C_P = Wind turbine power coefficient

λ = Tip speed ratio

θ = Pitch angle of blade

Here, Tip Speed Ratio (TSR) is defined as ratio of product of turbine angular velocity and rotor radius of turbine and speed of the wind. Note that, TSR and pitch angle of turbine blades are decides the efficiency of the system. The above two parameters are used to calculate the power coefficient C_P of the rotor. Continuing this, the turbine efficiency is also calculated by using power coefficient of rotor.

Where, $C_P = P_{Rotor}$ or $P_{Tyrbine} / P_{Wind}$

$$\text{Tip Speed Ratio, TSR} = \frac{\omega_{Rotor} R_{Rotor}}{v_{Speed}} \tag{2}$$

Where, ω_{Rotor} = Turbine rotor Speed (rad/s)

R_{Rotor} = radius of rotor (m)

v_{Speed} = wind speed (m/s))

The power extracted from wind turbine is more complex, its mathematical analysis is more popular to express aero-dynamic torque and aero-dynamic power equations are given below,

Aerodynamic Torque,

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$$T_{aero} = \frac{P_{turbine}}{\omega_{rotor}} = \frac{0.5\rho A v^3 C_P(\lambda,\theta_{blade})}{\frac{v\lambda}{R}} \quad (3)$$

The mathematical model with first order transfer function of wind energy system is represented as

$$G_{WTG}(S) = \frac{K_{WTG}}{sT_{WTG}+1} \quad (4)$$

IV. DIESEL GENERATOR

Electrical machines are categorized as generator and motor based on their principle of action. According to 3-phase induction generator have 3 windings in stator and rotor frames. The equivalent circuit for generator is shown below, the voltage, flux, current and torque equations are expressed from two phase dq- axis model.

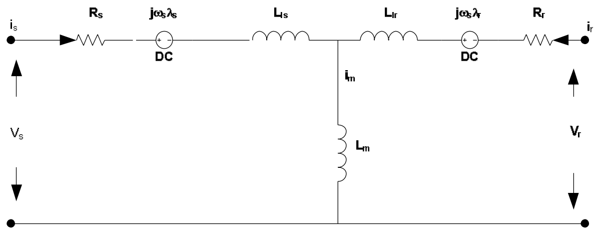

Fig. 2 Generator equivalent circuit

Hence voltages, flux and currents equations are written as

$V_s = V_{ds} + jV_{qs}$ (5)

$V_r = V_{dr} + jV_q$ (6)

$i_s = i_{ds} + ji_{qs}$ (7)

$i_r = i_{dr} + ji_{qr}$ (8)

$\lambda_s = \lambda_{ds} + j\,\lambda_{qs}$ (9)

$\lambda_r = \lambda_{dr} + j\,\lambda_{qr}$ (10)

The voltages, currents and flux linkages of the rotor and stator are written

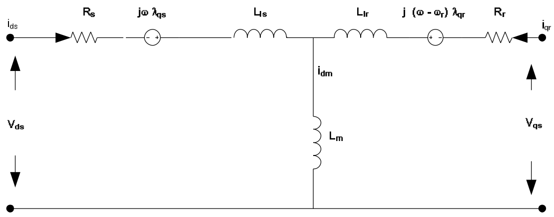

Fig. 3 Equivalent circuit of d- axis

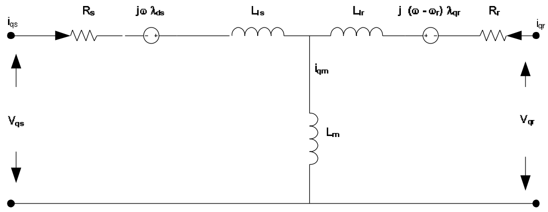

Fig. 4 Equivalent circuit of q- axis

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The induction generator voltage equations in terms of dq – axis are given by

$V_{ds} = R_s i_{ds} + p\,\lambda_{ds} - \omega\,\lambda_{qs}$ (11)

$V_{qs} = R_s i_{qs} + p\,\lambda_{qs} + \omega\,\lambda_{ds}$ (12)

$V_{dr} = R_r i_{dr} + p\,\lambda_{dr} - (\omega - \omega_r)\,\lambda_{qs}$ (13)

$V_{qr} = R_r i_{qr} + p\,\lambda_{qr} + (\omega - \omega_r)\,\lambda_{qs}$ (14)

And flux linkages in dq – axis are obtained as

$\lambda_{ds} = (L_{ls}+L_m)\,i_{ds} + L_m i_{dr}$ (15)
$\quad = L_s\,i_{ds} + L_m i_{dr}$

$\lambda_{qs} = (L_{ls}+L_m)\,i_{qs} + L_m i_{qr}$ (16)
$\quad = L_s\,i_{qs} + L_m i_{qr}$

$\lambda_{dr} = (L_{lr}+L_m)\,i_{dr} + L_m i_{ds}$ (17)
$\quad = L_r\,i_{dr} + L_m i_{ds}$

$\lambda_{qr} = (L_{lr}+L_m)\,i_{qr} + L_m i_{qs}$ (18)
$\quad = L_r\,i_{qr} + L_m i_{qs}$

The given electromagnetic torque T_e

$T_e = 3/2\,P\,(i_{qs}\,\lambda_{ds} - i_{ds}\,\lambda_{qs})$ (19)

All the above equations are developed from the dq – axis model of the induction generator in most of the reference frame is arbitrary and its corresponding dq – axis equivalent circuits are (mostly all the asynchronous generators mathematical equations developed by above and below relations only) and fluxes shown single equation

$p\,\lambda_{ds} = V_{ds} - R_s i_{ds} + \omega\,\lambda_{qs}$ (20)

$p\,\lambda_{qs} = V_{qs} - R_s i_{qs} - \omega\,\lambda_{ds}$ (21)

$p\,\lambda_{dr} = V_{dr} - R_r i_{dr} + (\omega - \omega_r)\,\lambda_{qr}$ (22)

$p\,\lambda_{qr} = V_{qr} - R_r i_{qr} - (\omega - \omega_r)\,\lambda_{dr}$ (23)

Where in the p is always derivative operator located in equivalent circuit.

The matrix form of flux linkages equations can be written as

$$\begin{bmatrix}\lambda_{ds}\\ \lambda_{qs}\\ \lambda_{dr}\\ \lambda_{qr}\end{bmatrix} = \begin{bmatrix} L_s & 0 & L_m & 0\\ 0 & L_s & 0 & L_m\\ L_m & 0 & L_r & 0\\ 0 & L_m & 0 & L_r\end{bmatrix}\begin{bmatrix} i_{ds}\\ i_{qs}\\ i_{dr}\\ i_{qr}\end{bmatrix} \quad (24)$$

$$T_e = \left[\frac{3}{2}\right]\left[\frac{P}{2}\right]\frac{1}{\omega_b}\left(\lambda_{ds} i_{qs} - \lambda_{qs} i_{ds}\right)$$

(25)

$$\frac{d\omega_r}{dt} = \frac{P}{2J}\left(T_e - T_L\right)$$

For synchronous reference frame and the stationary reference frame the speed of the arbitrary reference frame can be set to w_s is zero. In diesel generator, the nonlinear problem is creates lot of disturbance and there is a dead time between the injection and production of mechanical torque. The transfer function of diesel engine is represented as

$$G_{DEG}(S) = \frac{K_{DEG}}{sT_{DEG} + 1} \quad (26)$$

V. POWER, FREQUENCY DEVIATIONS AND CONTROL STRATEGY

To supply quality power to the consumer side, it is compulsory to maintain online frequency control for demand and power constraints. By maintaining or regulating the active power for scheduling the frequency for certain level. In hybrid system, wind and diesel generating units are interconnected to improve power quality we have to arrange some special control techniques. According to control strategies the mismatch problem between supply and demand can be alleviating and other way to control the fluctuations by controlling fuel input to diesel generating unit. There will be a classical approach to control the oscillations PI or PID technique. Adjusting or tuning of PID controller is very difficult by manually. The researchers are going to be provided a new path for tuning PID controller with optimization techniques. In the optimization technique we have particle swarm optimization technique is best suitable for tuning PID

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controller. In this paper tuning PID controller with PSO technique for controlling frequency deviations in two area systems is discussed below.

A. PID Controller

There are many types of controller such like proportional, integral, derivative and combinational of these (PI, PID). The block diagram of Proportional Integrative Derivative (PID) controller is shown in Fig.1

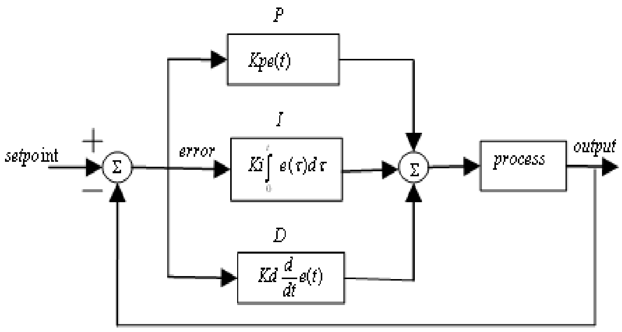

Fig. 5 Block diagram of a PID controller.

The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value. Better margin of stability is ensured with PID controllers. The mathematical equation for the PID controller is given as

$$y(t) = K_p e(t) + K_i \int_0^t e(t)\,dt + K_d \frac{d}{dt} e(t) \qquad (27)$$

Where y (t) is the controller output and u (t) is the error signal. K*p*, K*i* and K*d* are proportional, integral and derivative gains of the controller. The limitation conventional PI and PID controllers are slow and lack of efficiency in handling system non-linearity. Generally these gains are tuned with help of different optimizing methods such as Ziegler Nicholas method, Genetic algorithm, etc., The optimum gain values once obtained is fixed for the controller. But in the case deregulated environment large uncertainties in load and change in system parameters is often occurred. The optimum controller gains calculated previously may not be suitable for new conditions, which results in improper working of controller. So to avoid such situations the gains must be tuned continuously.

B. Advantages of PID Controller

They can perform poorly in some applications. PID controllers, when used alone, can give poor performance when the PID loop gains must be reduced so that the control system does not overshoot, oscillate or hunt about the control set point value. A problem with the Derivative term is that small amounts of measurement or process noise can cause large amounts of change in the output.

C. Particle Swarm Optimization

PSO is a global optimization algorithm for dealing with problems in which a best solution can be represented as a point or surface in an n-dimensional space.

PSO algorithm:

Step 1: Initialize randomly the individual at the population. The objective is to be evaluated for each individual.

Step 2: Compare each individuals evaluation value with its P_{best}. The best evaluation value among the P_{best} is denoted as G_{best}.

Step 3: New velocities are calculated using equation

$$V_{id}^{t+1} = W \times V_{id}^{t} + C_1 \times rand0 \times P_{best} \times X_{id}^{t} + C_2 \times rand0 \times G_{best} \times X_{id}^{t} \qquad (28)$$

Step 4: If $V_{id}^{t+1} < V_{d\,\min}$ then $V_{id}^{t+1} = V_{d\,\min}$ and if $V_{id}^{t+1} > V_{d\,\max}$ then $V_{id}^{t+1} = V_{d\,\max}$

Step 5: New searching points are calculated using the equation

$X_{id}^{t+1} = X_{id}^{t} + V_{id}^{t+1}$ Where i =1,2,3,...........,n and

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d= 1,2,3,..........,m.
Step 6: Check the voltage limits if

$V_{id}{}^{t+1} < V_{d\,\min}$, then $V_{id}{}^{t+1} = V_{d\,\min}$

Step 7: Evaluate the fitness values for new searching point. If evaluated values of each particle are better than previous I_{best} then set I_{best} to I_{best}. If I_{best} is better than G_{best} then set G_{best} with I_{best}.

D. PSO Flow Chart

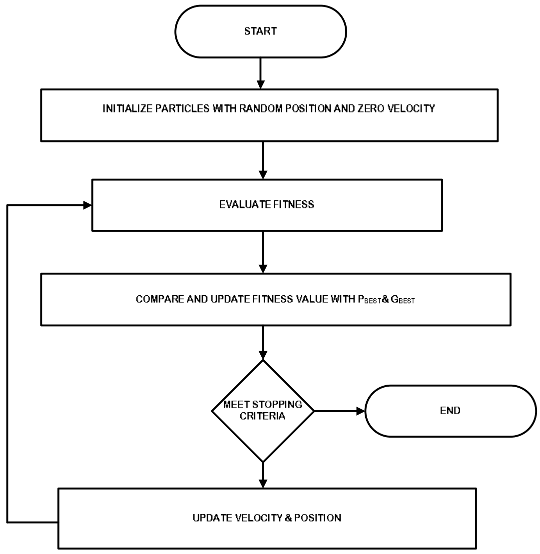

Fig. 6 PSO flow chart

VI. MODEL OF TWO AREA POWER SYSTEM

Each area is assumed to have only one equivalent generator and is equipped with governor- turbine system. They are the control signals from the controllers A two area model is adapted in the work is shown in Fig.7 [2] & [11].

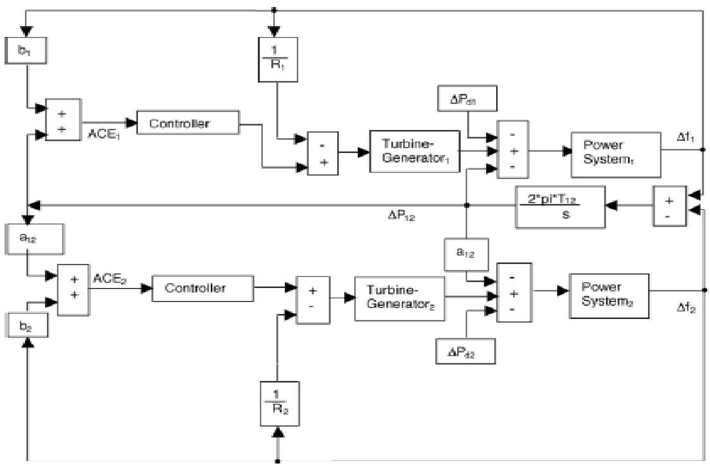

Fig. 7 Block diagram of two area power system.

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The terms showed in the Fig.7are termed given below:

f_i :Nominal system frequency of i^{th} area. [HZ]
Δf_i: Incremental frequency deviation of i^{th} area. [HZ pu]
T_{si} : Speed governor time constant of i^{th} area [sec.]
K_{gi} : Gain of speed governor of i^{th} area
R_i: Governor Speed regulation of the of i^{th} area [*Z H*/pu.MW]
T_{ti} : Governor Speed regulation of the of i^{th} area [*Z H*/pu.MW]
K_{ti} : Gain of turbine of i^{th} area
K_{pi} :Gain of power system (generator load) of i^{th} area.[*Z H* /pu.MW]
K_{pi} = 1/D
T_{pi} Gain of power system (generator load) of i^{th} area. [*ZH* /pu.MW]
$T_{pi} = 2H_i$ /Difi
H_i : Inertia constant of i th area . [MW-sec/MVA]
ΔP_{Gi} : Incremental generator power output change of i^{th} area .[pu MW]
ΔP_{ti} : Incremental turbine power output change of i tharea. [pu MW]
K_i : Gain of controller of i^{th} area.

TABLE I
TUNING GAIN PARAMETERS FOR PID CONTROLLERS

K_{P1}	1.874220497947366
K_{I1}	0.000000000002352
K_{D1}	0.000000000386733
K_{P2}	0.000000000016361
K_{I2}	-0.034026437557874
K_{D2}	-0.000000000171431
K_{P3}	0.000000000002372
K_{I3}	-0.00229954573170
K_{D3}	0.000000000024019

VII. SIMULATION RESULTS

When the load demand increases, then the load frequency is going to deviate from the normal condition. If we integrate the wind and diesel system to one of the two area system, then the error in load frequency is minimized with PID controller.

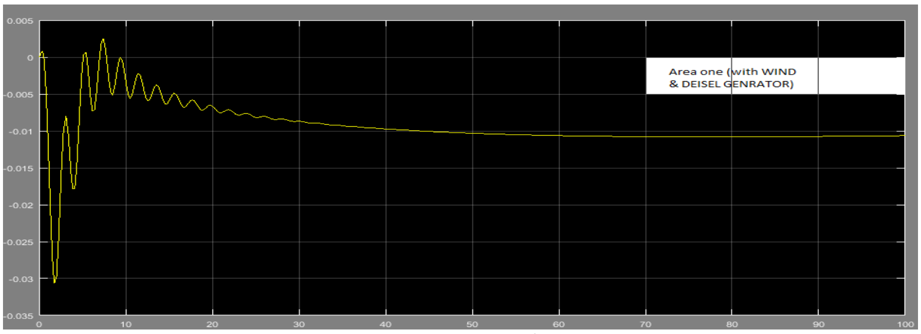

Fig. 8 Area one output frequency

According to the area one result, the peak overshoot occurred at 7 seconds with magnitude of 0.004 Hz. The steady state is occurred at 50 seconds with magnitude of 0.011Hz. But the tuning process is more complexity, so we implement PSO based PID controller for getting optimum results.

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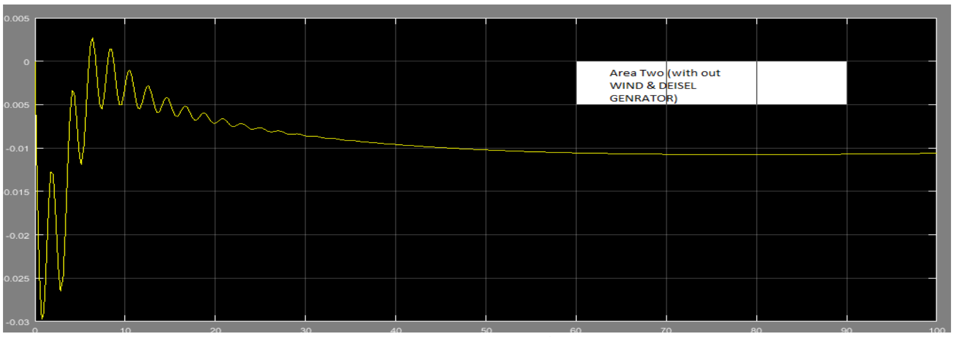

Fig. 9 Area two output frequency

But coming to area two, the peak over shoot occurred at 6.5 seconds with the magnitude of 0.003 Hz. The steady state is occurred at 50 seconds. By considering both at a time, the lag in frequency deviation in area two system compared to area one system is more, so the steady state is reached quickly in area one system with PSO based PID controller.

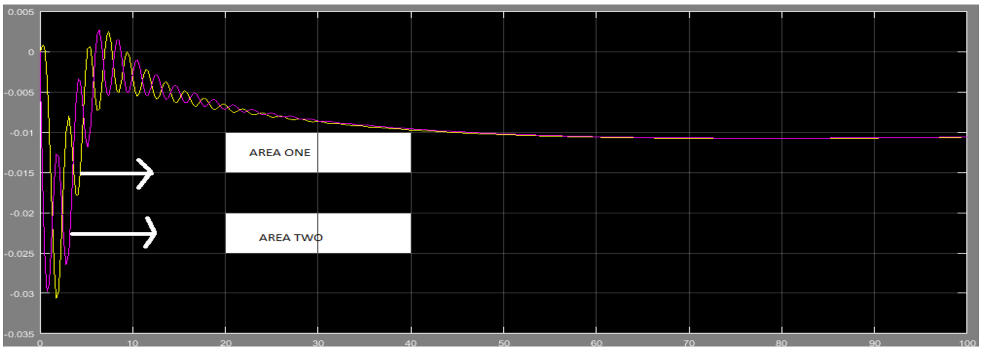

Fig. 10 Area one and two output frequency

VIII. CONCLUSION

In this paper, the renewable power generation systems are integrated to power systems is very difficult to control the frequency. PID controller with PSO technique is used to tune the gain parameters for controlling the load frequency of two area system. From the simulation analysis, PSO based PID controller technique is provides better optimum values compared to classical PID controller. Therefore, this topology is better to tuning the gain parameters for control the non linear loads.

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