Dynamic Modelling and Performance Assessment of a Wind-Diesel Hybrid Power System

Karunakar Kathari[1], Vinod Arun Kumar Errampalli[2] and Lokanadham Kathari[3]

Abstract— **This paper describes the modelling, control and dynamic analysis of a small isolated electric power system consisting of a wind turbine generator (WTG) and a diesel generator. The dynamic analysis of electric power system is performed in time domain considering simplified models of the system components by taking into account the pitch controller of the wind turbine and the speed governor of the diesel engine. Wind disturbance model consists of gusting of the wind, rapid ramp changes, and random noise components. The wind turbine generator is always operated with its rated power and the additional power required by the load which is supplied by the diesel generator. In this work, two control schemes, namely, proportional- integral (PI) and proportional-integral-derivative (PID) controllers are used for better dynamic performances of the wind-diesel power system under the conditions of wind and load disturbances. The gain parameters of PI and PID controllers are optimized using optimization techniques such as genetic algorithm (GA) and particle swarm optimization (PSO). The simulation results are presented and compared the dynamic performance of wind-diesel power system for different optimum gain parameters of PI and PID controllers obtained using GA and PSO.**

I. INTRODUCTION

A constantly growing power demand has to be met through an adequately planned electrical power generation system. Electrical energy is environmentally the most good-natured form of energy, with production routed through conventional fossil fuel burning or through nuclear energy and wherever possible through hydro resources. In addition to other disadvantages, all of these give rise to environmental issues of a diverse nature. Therefore it is necessary to consider the problems of generation of electrical power and environment jointly so that the increasing demand of electrical power for industrialization will be met with minimal environmental degradation. Utilization of wind energy is one of the solutions in favourable sites which are remote from centralized electrical energy supply systems. Since wind power varies randomly there should be a stand-by power source to meet the demand required by the load. The diesel and wind power generation system is one of the hybrid systems utilizing more than one energy source. A wind and diesel power system is very reliable because the diesel system acts as a cushion to take care of variation in wind speed, and would always provide power equal to load minus the wind power [1].

A number of conventional methods are available to control the output power of WTG systems such as state space method, robust control, and optimal control. The dynamic behaviour of an autonomous system consisting of diesel and wind turbine generators was studied by Scott et al. [2]. Their analysis reveals that the change in control parameter settings can improve the damping of the power system. In [3], the authors studied the dynamic modelling and analysis of wind-diesel power system by applying a programmable smoothing load and using a standard proportional-integral-derivative (PID) controller installed on the diesel system. The PID controller is generally used in power systems for the design of power system stabilizers to improve the dynamics of the power system. Tripathy et al. have used magnetic energy storage unit in the isolated wind-diesel power system to minimize the power and frequency deviations under load disturbance conditions [4]. In [5], [6], the authors have studied the autonomous wind-diesel power system under different scenarios. They have presented both the mathematical model as well as an implementation of their algorithm. Das et al. have studied the dynamic analysis of an isolated wind-diesel hybrid power system [1]. In [7], the authors have used a fuzzy logic controller for an isolated wind-diesel hybrid power system. However using a fuzzy logic controller in isolated wind-diesel power system depends extensively on heuristic knowledge. In [8], the authors have studied the dynamic characteristics of autonomous wind-diesel systems by integrating the analysis of main modes of the wind-diesel system and the controller parameters.

The literature review shows that the dynamic performance analysis of wind-diesel power system has been an interesting topic of many researchers [2], [4], [8], [1]. Most of the literature focused on the study of wind-diesel system dealing with small autonomous installation without considering the modelling details of wind speed and wind power. Further, optimization of controller gain parameters to improve the dynamic behaviour of the wind-diesel system to withstand wind disturbance has neither been addressed nor studied in the literature. In addition to these, the effect of power injection into a distribution network by wind-diesel system has also not been addressed in the literature.

The objective of this work is to study the dynamic modelling and performance analysis of isolated wind-diesel power system by optimizing the controller gain parameters using two optimization techniques such as genetic algorithm (GA) and particle swarm optimization (PSO). The specific

[1]M.Tech Student in the Department of Electrical and Electronics Engineering, NBKR Institute of Science & Technology (Autonomous), Vidyangar, Andhra Pradesh, karunakathari@gmail.com

[2]Associate Professor in the Department of Electrical and Electronics Engineering, NBKR Institute of Science & Technology (Autonomous), Vidyangar, Andhra Pradesh, arunkev74@gmail.com

[3]Associate Professor in the Department of Electrical and Electronics Engineering, Sri Venkateswara College of Engineering & Technology (Autonomous), Chittoor, Andhra Pradesh, klokanadh@gmail.com

points of interest are:

1) To model an isolated power system consisting of a wind turbine generator (WTG) and a diesel generator.
2) To study the dynamic performances of an isolated wind-diesel power system using proportional-integral (PI) and proportional-integral-derivative control (PID) schemes.
3) To compare the dynamic responses of the wind-diesel power system for PI and PID control schemes.

The work focuses on improving the dynamic performance of the wind-diesel power system under the conditions of wind and load disturbances. For this purpose, we use two control schemes. First, the proportional integral (PI) controller is used to study the dynamic responses of the wind-diesel power system. Second, the dynamic responses of wind-diesel power system are carried out using proportional integral derivative controller (PID). The gain parameters of controllers are optimized using GA and PSO techniques. Finally, we compare the dynamic performance of wind-diesel system for optimized gain parameters of PI and PID controllers obtained using GA and PSO techniques.

The paper is organized as follows. The mathematical modelling of wind speed, wind power, and wind-diesel power system are presented in Section II. Section III provides the concepts of genetic algorithm and particle swarm optimization techniques. The simulation results of the dynamic performance analysis of wind-diesel power system Section IV. The paper ends with few concluding remarks in Section V.

II. Modelling of wind-diesel system

This section provides the mathematical modelling details of different wind speed components, wind power and wind-diesel power system. The main objective is to provide a state-space model of wind-diesel system.

A. Wind speed

In order to study the dynamic responses of wind-diesel power system a wind disturbance model is considered, which is modelled by considering the sum of base wind, gust, ramp wind, and random noise. The output power of the wind turbine generator depends on wind speed (V_W). The mathematical model for different wind speed components are presented below in detail [9].

The mathematical model for wind is described by using the equation

$$V_W = V_{WB} + V_{WG} + V_{WR} + V_{WN} \tag{1}$$

The base wind mathematical model is

$$V_{WB} = K_B \tag{2}$$

where K_B is a constant and this component of wind is constant component present in the model of wind speed.

The mathematical model for gust wind is expressed by

$$V_{WG} = \begin{cases} 0, & \text{for } \; t < T_{gust_1} \\ V_{cos}, & \text{for } \; T_{gust_1} < t < T_{gust_1} + T_{gust} \\ 0, & \text{for } \; t > T_{gust_1} + T_{gust} \end{cases} \tag{3}$$

where t is time in seconds and,

$$V_{cos} = (MGWS/2)(1 - \cos(2\pi[(t/T_{gust}) - (T_{gust1}/T_{gust})])) \tag{4}$$

The mathematical model for ramp wind is expressed by

$$V_{WR} = \begin{cases} 0, & \text{for } \; t < T_{ramp_1} \\ V_{ramp}, & \text{for } \; T_{ramp_1} < t < T_{ramp_2} \\ 0, & \text{for } \; t > T_{ramp_2} \end{cases} \tag{5}$$

where

$$V_{ramp} = MRWS(1 - (t - T_{ramp2})/(T_{ramp1} - T_{ramp2})) \tag{6}$$

Where $T_{ramp2} > T_{ramp1}$. This expression can be approximated to a step change by minimizing the difference between T_{ramp2} and T_{ramp1}.

The mathematical model for noise wind is expressed as

$$V_{WN} = 2\sum_{i=1}^{N}[S_v(\Omega_i)\Delta\Omega]^{1/2}\cos(\Omega_i t + \phi_i) \tag{7}$$

where

$$\Omega_i = (i - 1/2)\Delta\Omega \tag{8}$$

and ϕ_i a random variable with uniform probability density on the interval $0 - 2\pi$ and $S_v(\Omega_i)$ is the spectral density function which is defined as

$$S_v(\Omega_i) = \frac{2K_N F^2|\Omega_i|}{\pi^2[1 + (F\Omega_i/\mu\pi)^2]^{4/3}} \tag{9}$$

where $K_N =$ surface drag coefficient = 0.004, $F =$ turbulence scale = 2000 m, $\Omega_i =$ is i^{th} frequency component of random noise, $\mu =$ mean speed of wind = 7.5 m/s and N is considered as 50.

The four components together are considered for analyzing the dynamics of the wind-diesel hybrid system.

B. Wind power

The wind turbine generator is characterized by the power coefficient C_p and wind velocity. The power coefficient C_p is again characterized by tip speed ratio and blade pitch angle. The wind blade dynamics are approximated by the following non linear functions.

Mathematically, tip speed ratio is expressed as

$$\gamma = \frac{V_W}{\omega_B} \tag{10}$$

The power coefficient C_p can be approximated as

$$C_p = \frac{1}{2}(\gamma - 0.0228\beta^2 - 5.6)e^{-0.17\gamma} \tag{11}$$

The wind power is expressed by

$$P_W = \frac{1}{2}\rho A_B C_p V_W^3 \tag{12}$$

where,C_p is the power coefficient, ρ is the air density of the wind, A_B is the area swept by the wind blade, V_W is the wind speed, air density of the wind is $\rho = 1.25$ kg/m^3 and the area swept by the wind blade is $A_B = 1735$ m^2.

The characteristic curve of wind speed versus WTG power is shown in Fig. 1. The cut in velocity is the wind speed at which the wind turbine starts delivering wind power.

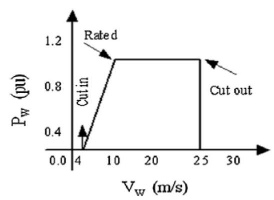


Fig. 1: Characteristic curve of wind speed vs wind power

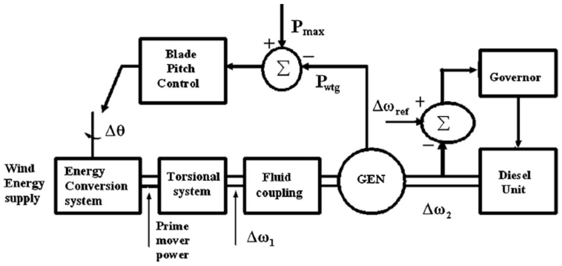


Fig. 2: Conceptual model of wind-diesel isolated power system

C. Model of wind-diesel system

The wind-diesel hybrid model consists of the wind speed model, diesel generator model, blade pitch control of wind turbine and wind turbine generator model as sub systems [2], [4], [1]. A minimum wind speed is required during the start up and synchronization. The diesel generator dynamics are controlled by speed control governor of diesel.

The conceptual model of the wind diesel isolated power system is shown in Fig. 2. The uncertainty in the wind speed is modelled by taking gust, ramp wind and random noise as discussed in the previous section. The diesel generator drives the synchronous generator and develops the reference grid for the induction generator which is coupled to the wind turbine. The output power of wind turbine generator can be controlled by changing the pitch angle of the blades of the wind turbine generator using a hydraulic pitch actuator. When the wind power exceeds the reference value the pitch angle of the blade is controlled to bring the output power produced by WTG is equal to the set point.

D. State-space model of wind-diesel system

A linearized mathematical model of wind turbine generator and diesel generator is considered to study the dynamic responses under wind speed and load disturbances. The state space model of the wind-diesel hybrid power system (Fig. 3) can be written as follows

$$\dot{X} = AX + \Gamma P \tag{13}$$

Where X and P are state and disturbance vectors, respectively. A and Γ are constant matrices associated with wind-diesel power system.

$$X' = [\Delta H_1 \ \Delta H \ \Delta D \ \Delta\omega_1 \ \Delta\omega_2 \ \Delta P_{f_1} \ \Delta P_{f_2} \ \Delta U_1] \tag{14}$$

$$P' = [P_W \ P_{load} \ P_{max}] \tag{15}$$

where X' and P' are the transpose of X and P, respectively. ΔH_1,ΔH, ΔD ,$\Delta\omega_1$,$\Delta\omega_2$, ΔP_{f_1},ΔP_{f_2} and ΔU_1 are

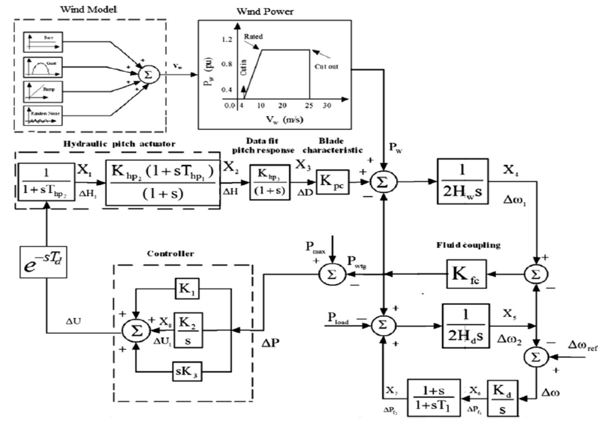


Fig. 3: Functional block diagram of wind-diesel isolated power system

state variables of X_1, X_2, X_3, X_4, X_5, X_6, X_7 and X_8, respectively.

$$\Delta P = P_{max} - P_{wtg} \tag{16}$$

$$P_{wtg} = K_{fc}(\Delta\omega_1 - \Delta\omega_2) \tag{17}$$

where $\Delta\omega_1$ and $\Delta\omega_2$ are angular frequency deviations in wind turbine generator and diesel generator, respectively and K_{fc} is the fluid coupling coefficient. Fig. 3 shows the block diagram representation of wind diesel isolated power system. In this work, two control schemes, namely, PI and PID are used to actuate the hydraulic pitch actuator to control the blade pitch angle of wind turbine to adjust the power of wind turbine according to the set point. The additional power required by the load is supplied by the diesel generator. The hydraulic pitch actuator generates the necessary control signal to adjust the blade pitch angle of the wind turbine to control the ouput power of wind-turbine generator.

The transfer function of hydraulic pitch actuator is given as

$$\frac{\Delta H(s)}{\Delta U(s)} = \frac{K_{hp_2}(1 + sT_{hp_1})}{(1 + sT_{hp_2})(1 + s)} \tag{18}$$

First, only proportional-integral control scheme is used by setting $K_3 = 0$ in Fig. 3. Secondly, the proportional-integral-derivative control scheme is used. In both the cases the controller gains are optimized by using genetic algorithm and particle swarm optimization techniques. The transfer function given in (18) can be split into two blocks by considering ΔH_1 as state variable X_1, i.e.,

$$\frac{\Delta H_1(s)}{\Delta U(s)} = \frac{1}{(1 + sT_{hp_2})} \tag{19}$$

$$\frac{\Delta H(s)}{\Delta H_1(s)} = \frac{K_{hp_2}(1 + sT_{hp_1})}{(1 + s)} \tag{20}$$

$$\frac{\Delta D(s)}{\Delta H(s)} = \frac{K_{hp_3}}{(1 + s)} \tag{21}$$

Mathematically, the transfer function of the diesel generator governor can be represented as

$$\frac{\Delta P_{f_2}(s)}{\Delta\omega(s)} = \frac{K_d(1+s)}{s(1+sT_1)} \tag{22}$$

The transfer function given in Equation (22) can be split into two blocks by considering ΔP_{f_1} as another state variable.

$$\frac{\Delta P_{f_1}(s)}{\Delta\omega(s)} = \frac{K_d}{s} \tag{23}$$

$$\frac{\Delta P_{f_2}(s)}{\Delta P_{f_1}(s)} = \frac{(1+s)}{(1+sT_1)} \tag{24}$$

The required system data is given in Appendix.

III. Controller gain parameters optimization

This section provides complete algorithm for obtaining optimum controller gain parameters based on GA and PSO optimization techniques.

A. Optimization of PI and PID controller gain parameters using GA

Genetic algorithm (GA) is quite popular to solve the optimization problems mainly because of its robustness in finding optimal solution and ability to provide near optimal solution. In this optimization technique, the performance of each binary string in the population is determined by calculating its fitness value, which is to be maximized to get the optimal solution. The GA is associated with the objective function to be minimized in the optimization procedure [10], [11], [12].

1) Fitness functions and constraints: The roots of the characteristic equation are the eigenvalues of wind-diesel isolated system matrix $\mathbf{A}$, i.e.,

$$|\mathbf{A} - \lambda I| = 0 \tag{25}$$

Where the values of the λ are the eigenvalues of the matrix $\mathbf{A}$ and I is the identity matrix which has the same order as that of $\mathbf{A}$. If all the eigenvalues lie on the left half of the s-plane then the system is stable otherwise the system is unstable. When all the eigenvalues lie on the left half of the s-plane, the stability of the system mainly depends on the eigenvalue nearer to the origin. It must be forced to move the eigenvalue away from the origin on the left half of the s-plane for better dynamic performances. When all the eigenvalues lie on the left half of the s-plane, the eigenvalue whose real part is close to the origin, we can define mathematically as,

$$\zeta = max(real(\lambda_i)), \qquad i = 1,2,3,\ldots,n \tag{26}$$

Where λ is known as degree of stability. In this case the objective function is defined as

$$J_1 = |\zeta| \tag{27}$$

and J_1 has to be maximized. As mentioned earlier fitness need to be maximized in GA therefore, fitness function F_1 based on eigenvalues is given as:

$$F_1 = J_1 \tag{28}$$

Fitness function based on quadratic objective function: In this case an objective function is

$$J_2 = \int_0^t (P_{max} - P_{wtg})^2 dt \tag{29}$$

is minimized for computing the optimum gain parameters of PI and PID controllers using GA and the fitness function is defined as:

$$F_2 = \frac{K}{1+J_2} \tag{30}$$

where K is considered as 100.

Constraints on gain parameters: The limits are imposed on proportional, integral and derivative gain parameters for the system shown in Fig.3 , i.e.,

$$K_i^{min} \le K_i \le K_i^{max}, \quad i = 1,2,3 \tag{31}$$

K_1, K_2 and K_3 will always lie in between their specified minimum and maximum values and can be obtained as:

$$K_i = K_i^{min} + \frac{(K_i^{max} - K_i^{min})}{(2^{l_i} - 1)} I_i \tag{32}$$

where l_i = bit size of K_i and I_i is decimal value of K_i after converting each binary string. Same bit size is chosen for K_1, K_2 and K_3 but K_3 is not considered while optimizing PI gain parameters.

2) Algorithm for GA based optimization: The complete algorithm for GA based optimization is given below:

1) Generate binary strings and initialize population
   (a) $[K_1, K_2]$ for PI controller
   (b) $[K_1, K_2, K_3]$ for PID controller
   where $K_1, K_2, \text{and} K_3$ represent the binary sub strings.
2) (a) Compute the decimal value of each binary sub string in a string to get the values of K_1 and K_2 for PI controller and $K_1, K_2, \text{and} K_3$ for PID controller using $K_i = K_i^{min} + \frac{(K_i^{max} - K_i^{min})}{(2^{l_i}-1)} I_i$.
   (b) Solve $\dot{X} = AX + \Gamma P$ for obtaining the fitness value considering PI and PID controllers using $F_2 = K/1 + J_2$, where $J_2 = \int_0^t (P_{max} - P_{wtg})^2 dt$ and $K = 100$.
3) Set $pqr = 1$
4) For $j = 1$ to $j =$ "populaiton size $\times$ cross over rate", Do;
   (a) Using Roulette wheel selection method, select two parents from population.
   (b) Generate two off springs by performing cross over
   (c) Based on mutation probability mutate these two offspring.
   (d) Generate new population combining newly generated strings and strings having best fitness from old population.
5) Calculate fitness of each offspring (as in Step-2)
   $pqr = pqr + 1$; If $(pqr \le pqr_{max})$ go to Step-4.

B. Optimization of PI and PID controller gain parameters using PSO

Particle swarm optimization (PSO) is a optimization technique which starts with a randomly generated population called swarm. The swarm consists of individuals called particles and each particle in the swarm represents a potential solution of the optimization problem. Each particle moves in a multidimensional search space with a velocity guided by the information of the objective function. The position and velocity of each particle are updated according to the following mathematical expressions:

$$v_i^{k+1} = W^k v_i^k + c_1 r_1 \left(pbest_i^k - x_i^k\right) + c_2 r_2 \left(gbest^k - x_i^k\right) \tag{33}$$

$$v_i^{min} \leq v_i^k \leq v_i^{max} \tag{34}$$

$$W^k = W_{max} - \frac{(W_{max} - W_{min})}{iter_{max}} iter_k \tag{35}$$

$$x_i^{k=1} = x_i^k + v_i^{k=1} \tag{36}$$

where c_1 and c_2 are positive acceleration constants and their values are set to 1.5. The r_1 and r_2 values are randomly generated numbers between 0 and 1. The second term in (33) represents the cognitive part of PSO where the particle changes its velocity based on its own experience and memory, and the third term represents the social part of the algorithm where the particle changes its velocity based on the knowledge adapted by the social behaviour of the neighbourhood particles in the swarm. In the PSO algorithm, the parameter v_i^{max} determines the fitness between the present position and target position regions are searched. The particles may fly past good solutions when the v_i^{max} is too high and the particles may not explore beyond local solutions when it is too low. Therefore the value of v_i^{max} is often chosen within 10-20% of the dynamic range of the variable. The inertia weight (W) provides a balance between global and local explorations. Whereas, W often decreases linearly. The values of W_{min} and W_{max} are set to 0.4 and 0.9 respectively [13], [14].

1) Objective and fitness functions: The same objective functions described by (27) and (29) are considered for finding the optimized gain parameters of PI and PID controllers for the wind-diesel power system using PSO . The optimized gain parameters are obtained by maximizing the fitness functions given in (28) using PSO.

2) Algorithm for PSO based optimization: The complete algorithm for PSO based optimization is given below:

1) Initialize the population swarm particles with random positions and set initial velocity positions to zero,
   (a) $[K_1, K_2]$ for PI controller
   (b) $[K_1, K_2, K_3]$ for PID controller
   where $K_1, K_2, \text{and} K_3$ represent individual particles in the swarm.
2) Set pqr $= 1$.
3) (a) Calculate the fitness value of each particle using $F_1 = J_1$ for PI controller and using $F_2 = K/1 +$

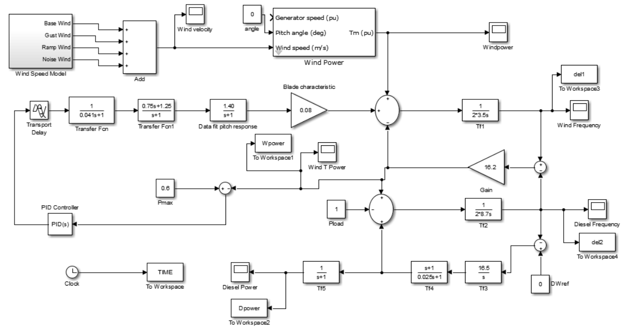


Fig. 4: MATLAB simulink model for an isolated wind-diesel power system

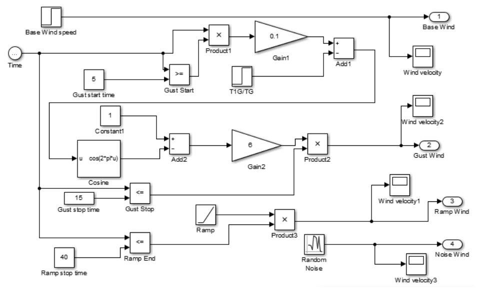


Fig. 5: MATLAB simulink model for wind speed (subsystem)

   J_2 for PID controller, where $J_2 = \int_0^t (P_{max} - P_{wtg})^2 dt$ and $K = 100$.
   (b) Set the current value as pbest if the fitness value of particle is better than pbest,
   (c) The best fitness value of pbest is identified as gbest.
4) (a) Calculate the velocities of the particles using (33), (34) and (35).
   (b) Update the positions of the particles using (36).
5) pqr $=$ pqr $+ 1$;
   if(pqr $\Longleftarrow$ pqr$_{max}$) go to Step-3.

IV. Results and discussions

This section presents the simulation results of wind-diesel power system for two control schemes, PI and PID controllers. The main objective is the comparison of dynamic performance for optimized control gains obtained using GA and PSO techniques. The parameters of PI and PID controllers are optimized for wind-diesel power system using GA and PSO techniques and the algorithms are executed in MATLAB. The simulink model for an isolated wind-diesel power system is developed using MATLAB simulink for analysing the dynamic performance. The developed MATLAB simulink model is shown in Fig. 4. The simulink model for wind speed which is subsystem of Fig. 4 is shown in Fig. 5.

A. Performance of power system for GA based PI and PID controllers

The optimum gain parameters of PI and PID controllers obtained using GA for objective function in (27) are given in Table I.

The dynamic responses for frequency of WTG, diesel frequency, output power of WTG and output power of diesel generator considering the optimum PI and PID gain parameters given in Table I are shown in Fig. 6. These dynamic responses are obtained for $P_{max} = 0.6\ pu, P_{load} = 1.0\ pu$ and it is assumed that the base wind speed is present throughout the study period, i.e., for $0 \leq t \leq 80\ s$; whereas gust wind speed is present for $5s \leq t \leq 15s$ and ramp wind speed is present for $30\ s \leq t \leq 40\ s$. The noise wind component was present throughout, i.e., for $0 \leq t \leq 80\ s$. It is observed from Fig. 6(a), Fig. 6(b) and Fig. 6(d) that the peak value of deviation in WTG frequency, diesel frequency and diesel power with PID control scheme is more than that obtained with PI control scheme. The deviation in peak value of wind power as shown in Fig. 6(c) is slightly less with PID controller than that obtained with PI controller. However, when ramp wind period is over , there is a sudden drop in WTG frequency deviation, wind turbine output power and increase in diesel generator power output during transient imbalance. But when the ramp wind speed period is over, the dynamic responses (Fig. 6) with PID controller is much superior than that obtained with PI controller in terms of peak deviation.

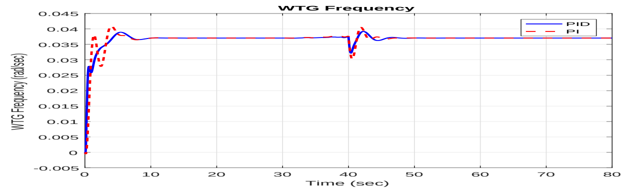
TABLE I: Optimized PI and PID gain parameters considering fitness function given in (28) using GA

Control scheme	Optimum controller gains	Objective function
PI	$K_1 = 47.08$	J_1
	$K_2 = 73.20$	
PID	$K_1 = 99.16$	
	$K_2 = 126.10$	
	$K_3 = 72.22$	

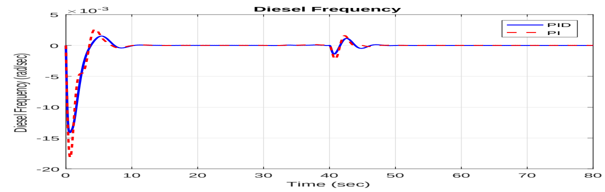
B. *Performance of power system for PSO based PI and PID controllers*

The optimum gain parameters PI and PID controllers obtained using PSO technique are given in Table II for objective function in (27). The optimum values of controller gain parameters using PSO are more or less same for $0 \leq P_{max} \leq 0.6$.

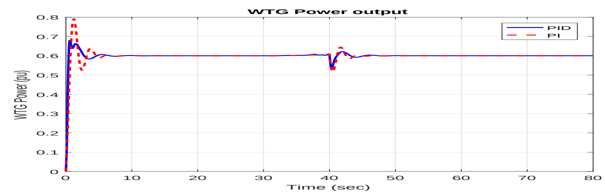
The dynamic responses for frequency of WTG, diesel frequency, output power of WTG, and diesel generator power considering the optimum PI and PID gain parameters given in Table II are shown in Fig. 7. These dynamic responses are obtained for $P_{max} = 0.6\ pu, P_{load} = 1.0\ pu$ and it is assumed that the base wind speed was present throughout the study period, i.e., for $0 \leq t \leq 80\ s$; whereas gust wind speed is present for $5s \leq t \leq 15s$ and ramp wind speed is present for $30\ s \leq t \leq 40\ s$. Further, it also assumed that the noise wind component is present throughout, i.e., for $0 \leq t \leq 80\ s$. It is observed from Fig. 7(a), Fig. 7(b) and 7(d) that the deviation in peak value of WTG frequency, diesel frequency and diesel power with PID controller is more than that obtained with PI control scheme. The deviation in peak value of wind power as shown in Fig. 7(c) is slightly less



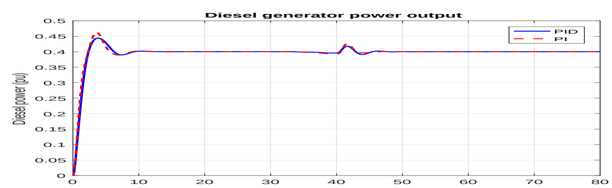
(a) WTG frequency



(b) Diesel frequency



(c) WTG power output



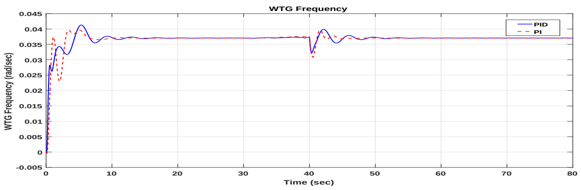
(d) Diesel generatot power output

Fig. 6: Comparison of dynamic responses for wind-diesel power system considering optimum value of PI and PID gain parameters for fitness function given in (28) obtained using GA.

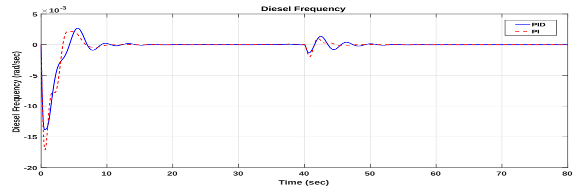
with PID controller than that obtained with PI controller. But the dynamic responses as shown in Fig. 7 in the case of ramp wind disturbance with PID controller is much superior than that obtained with PI control scheme in terms of peak deviation.

V. CONCLUSIONS

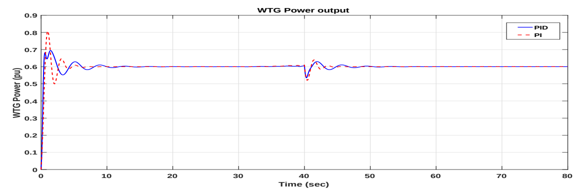
In this work, an isolated wind-diesel power system has been modelled and studied the dynamic performance of power system considering proportional-integral and proportional-integral-derivative controllers. Controller gain parameters are optimized using two optimization techniques such as genetic algorithm and particle swarm optimization. From the performance analysis it is observed that the controller gain parameters optimized using particle swarm optimization and genetic algorithm give more or less similar dynamic responses. However, it is found that particle swarm optimization technique is computationally more efficient than genetic algorithm. Further, it is also observed that the effect of wind noise on dynamic responses is negligible and may



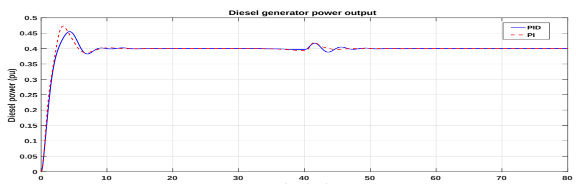
(a) WTG frequency



(b) Diesel frequency



(c) WTG power output



(d) Diesel generator power output

Fig. 7: Comparison of dynamic responses for wind-diesel power system considering optimum value of PI and PID gain parameters for objective function given in (28) obtained using PSO.

be neglected from the mathematical model.

Future directions include the study of sensitivity analysis of wind-diesel power system to demonstrate the robustness of the closed loop system to parameter variations.

APPENDIX

System data is mentioned below [2], [4], [6]:
Base value $= 250\ kVA$
Wind system inertia constant $(H_w) = 3.52\ s$
Diesel system inertia constant $(H_d) = 8.7\ s$
MGWS $= 12\ m/s$, MRWS $= 10\ m/s$
$V_{WB} = 7\ m/s$, $K_{fc} = 16.2\ pu\ kW/Hz$
$K_{hp2} = 1.25$, $K_d = 16.2\ pu\ kW/Hz$
$K_{hp3} = 1.40$, $T_{hp1} = 0.60\ s$, $T_{hp2} = 0.041\ s$, $K_{pc} = 0.080$
$P_{max} = 0.6$, $P_{load} = 1.0\ pu$, $T_1 = 0.025\ s$
$\Delta\omega_{ref} = 0.0$, $\Delta\Omega = 0.5 - 2.0\ rad/s$
Surface drag coefficient $(K_N) = 0.004$
Turbulance scale $(F) = 2000\ m$
Mean speed of wind $= 7.5\ m/s$

TABLE II: Optimized PI and PID gain parameters considering fitness function given in (28) using PSO

Control scheme	Optimum controller gains	Objective function
PI	$K_1 = 48.28$	J_1
	$K_2 = 75.20$	
PID	$K_1 = 90.12$	
	$K_2 = 89.10$	
	$K_3 = 70.45$	

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