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# An Isolated Power System Stabilizer Using PSO Controller

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## ABSTRACT:

This paper describes the dynamic analysis of a small isolated power system comprising a wind turbine generator and a diesel generator. The analysis is carried out in time domain considering simplified models of the system components by taking into account the wind turbine pitch controller and the diesel engine speed governor. Wind disturbance model consisting components of gusting of wind, rapid ramp changes and random noise. The wind generator is always operated with its rated power and the additional power required by the load is supplied by the diesel generator. For better dynamic performances of wind–diesel system under wind and load disturbance conditions, two control schemes are used.

In the first case, a proportional–integral (P–I) controller and in the second case a proportional–integral–derivative (P–I–D) controller are used. Gain parameters of these controllers are optimized using genetic algorithm (GA) and Particle swarm optimization (PSO) considering two different objective functions and the results are compared. The sensitivity analysis of the wind diesel system is carried out for parameter uncertainties and the stability of the system is analyzed using D-stability criterion. Analysis is also carried out to examine the effect of power injection to a 69 bus radial distribution network by wind–diesel isolated system.

## KEYWORDS:

Wind turbine generator, Diesel generator, P–I controller, P–I–D controller, Genetic algorithm, Particle swarm optimization.

## INTRODUCTION:

With the rapid depletion of fossil fuels the role of renewable energy resources is increasing in the current world energy scenario. Wind power generation is most economical compared to other nonconventional energy resources. Wind turbine generators (WTG's) are mainly suitable for isolated loads where the power transmission is a major problem. In remote areas generally electrical energy has been supplied by diesel generators. The wind–diesel isolated power system is most popular for remote areas. Diesel generator functions as a backup source to compensate the power supply variations due to wind speed fluctuations. High power fluctuations results at the output of wind turbines due to sudden changes in load and abnormal wind speed variations and they should be minimized. A number of conventional methods such as state space method, optimal control and robust control are found in the literature to control WTG output power.

The objective is to achieve good dynamic performance of WTG output power under wind and load disturbance conditions. Scott et al. [1] have studied the dynamic behavior of an autonomous system comprising of die-sel generator and wind turbine generators. Their analysis reveals that the change in control system settings can improve the damping. Kamwa[2] studied the dynamic modeling and performance of wind–diesel systems by applying a programmable smoothing-load and using a standard PID regulator installed on the diesel unit. Tripathy et al. [3] have used magnetic energy storage unit to minimize the power and frequency deviations under load disturbance conditions in the isolated wind–diesel power system.

Kariniotakis and Stavrakakis [4,5] have studied the autonomous wind–diesel system under various scenarios. They have presented the mathematical model as well as implementation of their algorithm. Das et al. [6]have studied the dynamic performance of an isolated wind–diesel hybrid power system. Chedid et al. [7] have used fuzzy logic controller for an isolated wind–diesel hybrid power system. However fuzzy logic controller for such system depends extensively on heuristic knowledge. Papathanassiou and Papadopoulos [8] have integrated the analysis of main modes of the wind–diesel hybrid system and the parameters of the controllers. Above literature review shows that the dynamic behavior of wind–diesel power system has been the subject of many researchers [1–8] dealing with small autonomous installation but most of the literatures mentioned above did not consider the details of modeling of wind speed and power [2,3,6–8].Previous researchers have also not made any attempt to optimize the gain parameters of the controller to improve the dynamic performances of the wind–diesel system to withstand wind disturbance. In addition to that they have not studied the effect of power injection by wind–diesel system into a distribution network.

In power systems P–I–D controller is generally used in the design of power system stabilizers and load frequency control applications to improve the dynamic responses of the system [9–12]. In this paper, two control schemes are used to controlthe blade pitch angle of the wind turbine generator for obtaining the better dynamic performances of wind–diesel hybrid system under wind disturbance conditions. The first controller is a propor-tional–integral (P–I) controller and second one is proportional– integral–derivative (P–I–D) controller. Gain parameters of these two controllers are optimized using genetic algorithm (GA) and Particle swarm optimization (PSO) considering the two different objective functions. The sensitivity analysis and stability analysis of wind diesel system are studied to test the robustness of the closed loop system for parameter variations.

Finally, the power injection by the wind diesel system into 69 node distribution network is also examined. Main Objective of thesis Gain parameters of P–I and P–I–D controllers have been optimized by using genetic algorithm and particle swarm optimization considering Eigen value based objective function and quadratic objective function for different values of wind speed model rather than two objective functions and entire wind axis act as a variable and also for different P-I and P-I-D values of controller. Analysis reveals that the gain parameters optimized using particle swarm optimization and genetic algorithm give more or less similar dynamic responses by reducing the number of iterations by using the both PSO and GA . However, it was found that particle swarm optimization is computationally more efficient than genetic algorithm. It was also observed that the effect of wind noise on dynamic performances is negligible and may be neglected from the mathematical model. The sensitivity analysis has also been carried out to demonstrate the robustness of the closed loop system to parameter variations. The closed loop system is shown robustly stable according to D-stability criterion.

## Modeling of wind speed and power:

### Model of wind speed:

A wind disturbance model is considered to study the dynamic performance of wind–diesel system. The wind disturbance is modeled considering the sum of base wind, gusting, ramp, and random noise. The generated power of the wind turbine generator depends on wind speed ($V_W$).

$$V_W = V_{WB} + V_{WG} + V_{WR} + V_{WN} \qquad (1)$$

The base wind mathematical model is expressed by

$$V_{WB} = K_B \qquad (2)$$

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 different wind speed components are discussed below in detail [13].

The four component wind model is described by using the following equation:
The gust wind mathematical model is expressed by

VWG=

$$\begin{cases} 0 & for \quad t < Tgust1 \\ Vcos & for \quad Tgust1 < t < Tgust1 + Tgust \\ 0 & for \quad t > Tgust1 + Tgust \end{cases}$$

Where t is time in seconds and

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

$$Vwr = \begin{cases} 0 & for\ t < Tramp1 \\ Vramp & for\ Tramp1 < t < Tramp2 \\ 0 & for\ t < Tramp2 \end{cases}$$

Where

$$Vramp = MRWS(1 - (t - Tramp_2)/(Tramp_1 - Tramp_2)) \quad (6)$$

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

Wind generator output power

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

Tip speed ratio is expressed by

$$\gamma = Vw/w_B$$

The power coefficient $C_p$ can be approximated by

$$C_P = 1/2(\gamma - 0.0228\beta^2 - 5.6)e^{-0.17\gamma}$$

The wind power is expressed by

$$Pw = 1/2\ PA_BC_PV^3_W$$

The air density of the wind is q (= 1.25 kg/$m^3$) and the area swept by the wind blade is $A_B$ (= 1735 $m^2$).
Fig. 1 represents the characteristic curve of wind speed versus WTG power. The cut in velocity is the wind speed at which the wind turbine starts delivering wind power

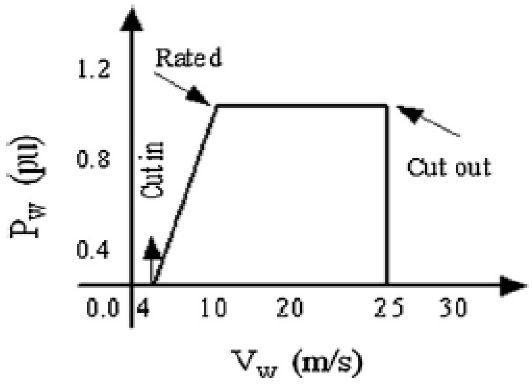

**Fig. 1. Wind speed versus wind power.**

Model of wind–diesel system

The wind–diesel hybrid model consists of the following sub sys-tems [1,3,6].

1. Wind speed model
2. Diesel generator model
3. Control scheme for WTG power
4. Wind turbine generator model

During the start up and synchronization, a minimum wind speed is required. The diesel generator dynamics are controlled by diesel speed control governor. Fig. 2 represents the conceptual model of the wind–diesel iso-lated power system. The uncertainty in the wind speed is modeled considering gust, ramp and random noise. The mathematical model of wind speed has been discussed in the previous section. The diesel generator drives the synchronous generator and devel-ops the reference grid for the induction generator which is coupled to the wind turbine.

The wind turbine generator output power 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 of the blade is con-trolled to bring the power generated by WTG is equal to the set point.

## State space model of wind–diesel system

A linearized model of WTG and diesel generator is considered to analyze the dynamic performances under wind speed and load fluctuations. The state space model of the wind–diesel hybrid system (Fig. 3) can be written as follows

$$X^1=AX+\neg V$$

Where X and P are sate and disturbance vectors respectively. A and ¬ are constant matrices associated with wind-diesel hybrid systems.

$X^1=[\Delta H1\ \Delta H\ \Delta D\ \Delta w_1\ \Delta w_2\ \Delta P_{f1}\ \Delta P_{f2}\ \ \Delta U_1]$

$P^1 =[P_w\ P_{load}P_{max}]$

Where $X^1$ ,$P^1$= transposes of X and P

$\Delta H1\ \Delta H\ \Delta D\ \Delta w_1\ \Delta w_2\ \Delta P_{f1}\ \Delta P_{f2}\ \ \Delta U_1$= state variablesof $X_1$ to $X_8$ respectively

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

$P_{wtg}=K_{fc}(\Delta w_1 - \Delta w_2)$

Where $\Delta w_1$ ,$\Delta w_2$= angular frequency

generator and diesel generator and $K_{fc}$ is the fluid coupling coefficient. Block diagram representation of wind diesel isolated power system is shown in Fig. 3. In this paper P–I and P–I–D control schemes are used to actuate the hydraulic pitch actuator to control the wind turbine blade pitch angle to adjust the wind turbine power according to the set point. The diesel generator supplies the addi-tional power required by the load. The hydraulic pitch actuator gen-erates the necessary control signal to adjust the wind turbine blade pitch angle to control the power of WTG.

## Gain parameters optimization of P–I and P–I–D controllers 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. Genetic algorithms employ search procedures based on the mechanics of natural selection and survival of the fittest. It has been applied to several power system problems. In GA, the performance of each binary string in the population is measured by calculating its fit-ness value, which is to be maximized to get the optimal solution. It is associated with the objective function to be minimized in the optimization procedure [14,15].

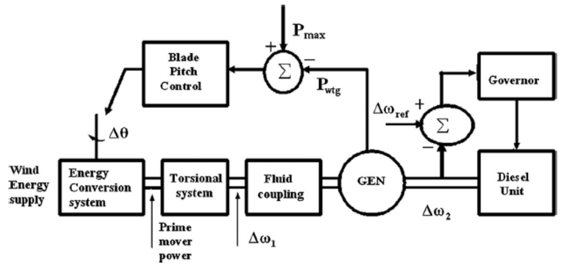

Fig. 2. Conceptual block diagram of wind–diesel isolated power system.

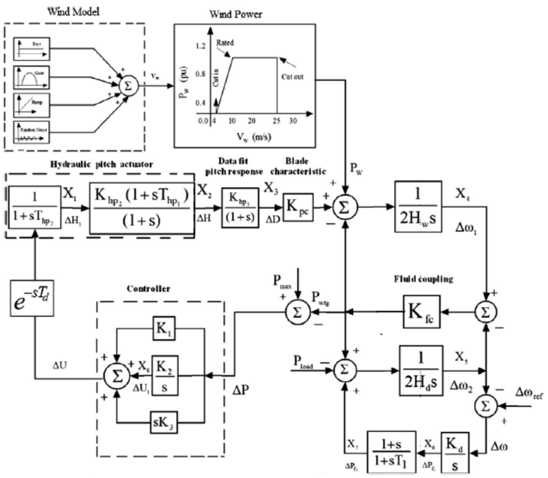

Fig. 3.Wind–diesel small isolated power system.

Fitness function based on eigenvalues

The eigenvalues of wind–diesel isolated system matrix A are the roots of the characteristic equation, i.e.,

$$[A-yI]=0$$

where the values of the k are the eigenvalues of the matrix A and I is the identity matrix of the same order as that of A. The system will be stable if all the eigenvalues lie on the left half of the s-plane. When all the eigenvalues lie on the left half of the s-plane, the system stability mainly depends on the eigenvalue nearer to the origin. For better dynamic performances it must be forced to move away from the origin on the left half of the s-plane. Mathematically, when all the eigenvalues lie on the left half of the s-plane, the eigenvalue whose real part is close to the origin

Algorithm for GA based optimization

Complete algorithm is given below:

Step-1

Generate binary strings and initialize population

(a) [$K_1$, $K_2$] for P–I controller.

(b) [$K_1$, $K_2$, $K_3$] for P–I–D controller.
Where $K_1$, $K_2$ and $K_3$ represent the binary substrings

Step-2

(a) Calculate the decimal value of each binary substring in a string to obtain the values of $K_1$ and $K_2$ for P–I controller and $K_1$, $K_2$ and $K_3$ for P–I–D controller using Eq. (32).

(b) Obtain the eigenvalues of the system given by Eq. (25) and determine the fitness for P–I and P–I–D controllers using Eq. (28).

(c) Solve Eq. (13) for obtaining the fitness value considering P– I and P–I–D controllers using Eq. (30).

Step-3

Set IT = 1.

Step-4

For j = 1 to j = ‘‘population size _ 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.

Step-5:

Calculate fitness of each offspring (as in Step-2)

IT = IT + 1

If (IT $\leq$ ITMAX) go to Step-4.

## Gain parameters optimization of P–I and P–I–D controllers using PSO

Particle swarm optimization (PSO) is a metaheuristic 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 velocity and position of each particle are updated according to the following equations:

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

$$v_i^{\min} \leqslant v_i^k \leqslant v_i^{\max}$$

$$w^k = w_{\max} - \frac{(w_{\max} - w_{\min})}{iter_{\max}}\, iter_k$$

$$x_i^{k+1} = x_i^k + v_i^{k+1}$$

Where $c_1$ and $c_2$ are positive acceleration constants and both the values are set to 1.5. The values of $r_1$ and $r_2$ are randomly generated numbers in between 0 and 1. In the Eq. (33) the second term 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 PSO where the particle changes its velocity based on the knowledge adapted by the social behavior of the neighborhood particles in the swarm. In the PSO algorithm the parameter $v^{\max}{}_i$ determines the resolution or fitness between which regions the present position and target position are searched. If $v^{\max}{}_i$ is too high the particles may fly past good solu-tions and if it is too low the particles may not explore beyond local solutions and hence the value of $v^{\max}{}_i$ 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. As originally developed, w often decreases linearly from about 0.9 to 0.4 the values of $w_{\max}$ and $w_{\min}$ are set to 0.9 and 0.4 respectively [9,16].

Optimization of P–I and P–I–D controller gains using PSO For finding the optimum gain parameters of P–I and P–I–D con-troller for the wind diesel system using PSO the same objective functions described by Eqs. (27) and (29) developed based on eigenvalue and quadratic objective function in the previous section are considered. The optimum gains are obtained by maximizing the fitness functions described by Eqs. (28) and (30) using PSO.

Algorithm for PSO based optimization

The complete algorithm for PSO is given below:

Step-1

Initialize the population of particles of the swarm with random positions and set initial velocity positions to zero,

(a)[$K_1$, $K_2$] for P–I controller.
(b)[$K_1$, $K_2$, $K_3$] for P–I–D controller.
Where $K_1$, $K_2$ and $K_3$ represent individual particles in the swarm.

Step-2

Set iter = 1.

Step-3

(a) Calculate the fitness value of each particle using Eq. (28) for P–I controller and using Eq. (30) for P–I–D controller.
(b) If the fitness value of particle is better than pbest, set the current value as pbest.

(c) The best fitness value of pbest is identified as gbest.

Step-4

(a) Calculate the velocities of the particles using Eqs. (33)–(35).

(b) Update the positions of the particles using Eq. (36).

Step-5

Iter = Iter + 1;
If (iteriter$_{\max}$) go to Step-3

## RESULTS AND DISCUSSIONS

### Performance of GA based PID Controller Compared with Conventional PID

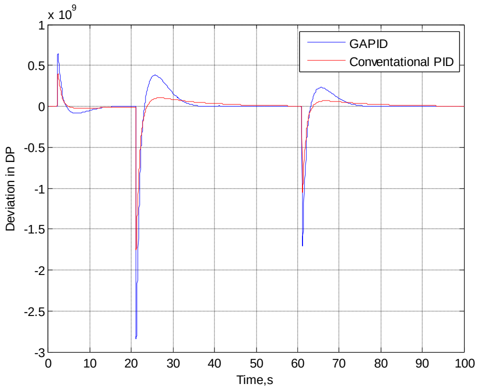

Fig .4.dynamic responses for WTG power output and diesel generator power output

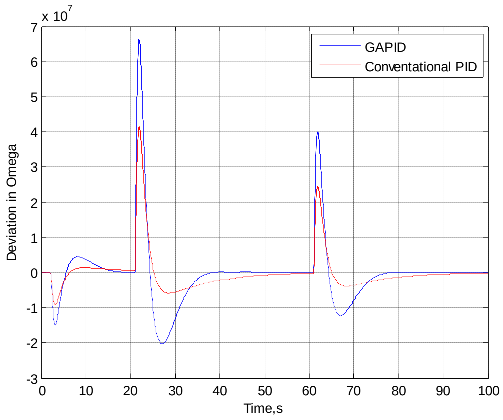

Fig .5.the dynamic responses for WTG frequency deviation

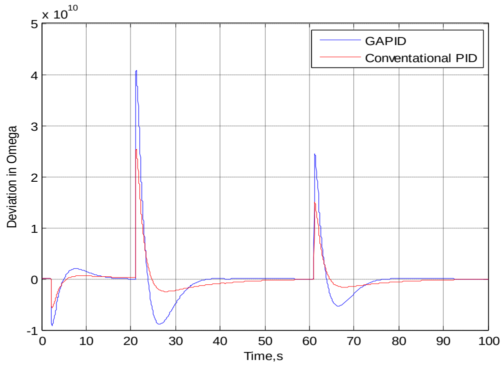

Fig.6. the dynamic responses for WTG frequency deviation

## Performance of PSO based PID Controller Compared with Conventional PID

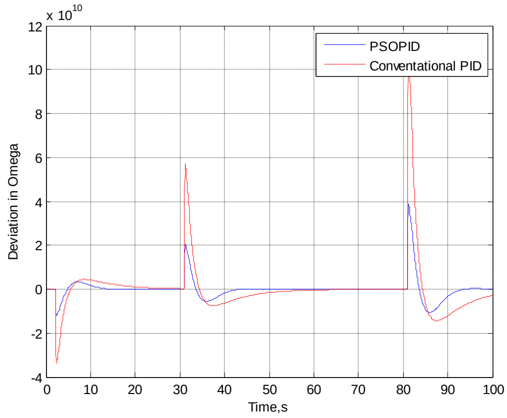

Fig.7. Dynamic responses for WTG frequency deviation

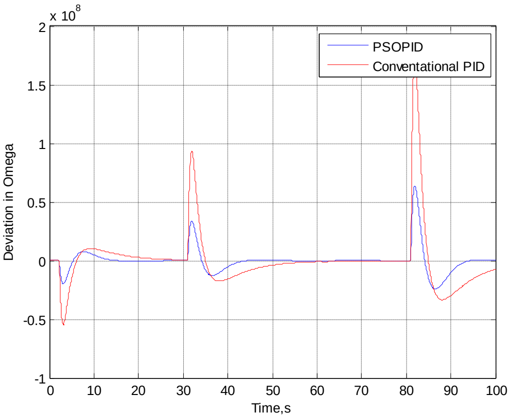

Fig.8. the dynamic responses for WTG frequency deviation

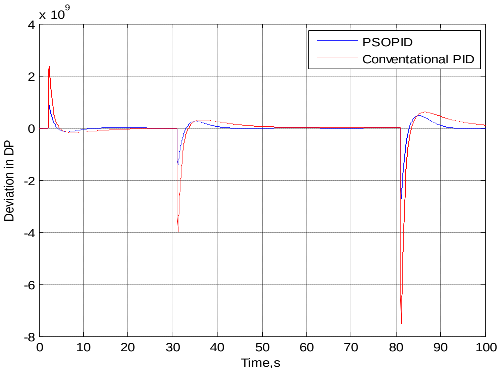

Fig.9. Dynamic responses for WTG power output and diesel generator power output

## CONCLUSIONS:

In this paper dynamic performances of an isolated wind–diesel hybrid power system has been studied considering P–I and P–I–D controllers. Complete wind model has also been incorporated in this study. Gain parameters of P–I and P–I–D controllers have been optimized by using genetic algorithm and particle swarm optimization considering eigenvalue based objective function and quadratic objective function. Analysis reveals that the gain parameters optimized using particle swarm optimization and genetic algorithm give more or less similar dynamic responses. However, it was found that particle swarm optimization is computationally more efficient than genetic algorithm. It was also observed that the effect of wind noise on dynamic performances is negligible and may be neglected from the mathematical model. The sensitivity analysis has also been carried out to demonstrate the robustness of the closed loop system to parameter variations. The closed loop system is shown robustly stable according to D-stability criterion. Finally the effect of power injection by wind–diesel hybrid system on a distribution network was examined and its performance was found to be satisfactory.

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