Designing a Robust Controller for Power System Stabilizer by Using Quantum Invasive Weed Optimization Algorithm

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ABSTRACT

In this paper, we propose a new optimized PID control-ler to stabilize the synchronous machine connected to an infinite bus. The model for the synchronous machine is 4-ordered linear Philips-Heffron synchronous machine. In this research, the parameters of the PID controller are optimally achieved by minimizing a definite fitness func-tion to removes the unstable Eigen-value to the left side of imaginary axis. The considered parameters for the con-troller are achieved by employing a new defined, quantum invasive weed optimization algorithm.After applying the proposed controller, it is compared by the

particle swarm optimization as a popular and high perfor-mance algorithm. Here, controller is obtained for all op-erating points. Final results show that the using quantum invasive weed optimization algorithm has a better perfor-mance toward the compared particle swarm optimization.

Keywords

Quantum Invasive Weed Optimization Algorithm, Philips-Heffron Model, Power System Stabilizer, Single Machine Connected to an Infinite Bus

1. INTRODUCTION

In the last decades, synchronousmachine stability has re-ceived a great deal of attention and it will receive additive attention in thefuture [1].

Once a disorder happens in the steady state,it is depended on the synchronous machine dealing after implementing. Stability problem can be analyzed from two directions: steady state stability and transient state stability [2, 3].

Steady-state stability analysis is to study the power system and its generators in strictly steady state conditions and try to find the maximum possible generator load which can be transmitted with no loss of synchronism of any other generator [4, 5]. In this case, steady-state stability limit includes the maximum power [6]. Transient stability is the ability of the power system to guarantee synchro-nism when subjected to a sudden and large disturbance

in a limited time such as a fault on transmission facilities, loss of a large load or loss of generation [7].

In this paper, a new population based,(QIWO) technique for optimizing the parameters of PID controller in a pow-er system stabilizer is introduced. The final resultsfor the proposed algorithm have been compared and analyzed and their advantages and disadvantages are characterized. Quantum Invasive Weed Optimization (QIWO) algorithm is a new quantum based optimization algorithm which is employed to solve optimization problems of different var-ies [8]. Like most of optimization algorithms in the area of evolutionary computation, QIWO has no need to the gradient of the function in its optimization process. From a special point of view, QIWO can be thought of as the so-cial as standard IWO algorithm. QIWO is a mathematical inspiration and the computer simulation of human culture evolution by considering a quantum society.

Quantum Invasive Weed Optimization algorithm begins by a population of candidate solutions (called weeds). These weeds are moved around in the search space due to a few simple formulae.

In the cycle, the weeds will be survived which have more strength. Finally when developed positions are being de-tected, these will then come to guide the movements of the weed [8].

1.SINGLE MACHINE INFINITE BUS (SMIB) MODEL

In this research, the studied system is the one machine connected to infinite bus system through a transmission line having resistance re and inductance xe shown in Fig-ure 1.
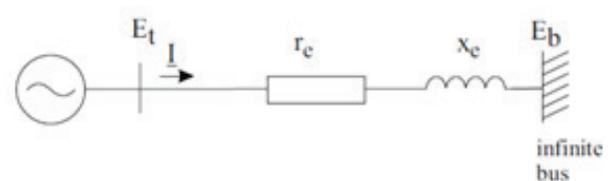

Fig.1: Single machine infinite bus mode

The synchronous machine is substantial for power system operation. The general form of the synchronous machine connected to infinite bus through transmission network can be achieved by the Thevenin's equivalent circuit.

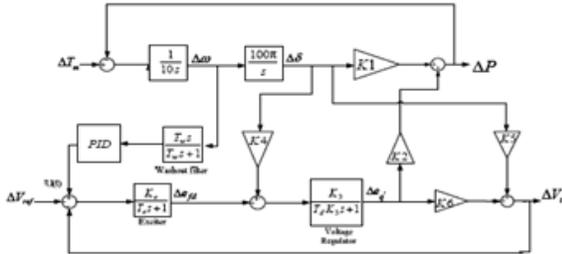In this research, we analyzed 4-ordered linear Philips-Heffron synchronous machine.

Fig.2. Philips-Heffron model of synchronous machine

The related equations for this model are described in the below:

$$\Delta \dot{\delta} = \omega_0 \Delta \omega$$

$$\Delta \dot{\omega} = \frac{1}{M}\left(-K_1\Delta\delta - D\Delta\omega - K_2\Delta e'_q\right)$$

$$\Delta \dot{e}'_q = \frac{1}{T'_d}\left(-K_4\Delta\delta - \frac{\Delta e'_q}{K_3} + \Delta e_{fd}\right)$$

$$\Delta \dot{e}_{fd} = \frac{1}{T_e}\left(-K_e K_5\Delta\delta - K_e K_6\Delta e'_q - \Delta e_{fd} + K_e u\right)$$

2. PARTICLE SWARM OPTIMIZATION ALGORITHM

Particle Swarm Optimization (PSO) algorithm is an optimizationapproach developed in 1995 by Kennedy and Eberhart, imitating by the social behavior of birds flocking and fish schooling [9]. In this algorithm optimal solution to a mathematical optimization problem is inspiredfrom birds behave during the food follow, the escape from hunters and the search for mates. Recently, PSO algorithm has been employed in wide variety of problems ranging from classical mathematical programming problems to scientific optimization problems and highly specialized engineering [10, 11].

A standard PSO algorithm starts by an initial population (called a swarm) of candidate solution (called particles).

These particles are moved around in the search-space in order to a few slick formulae. The movements of the particles are pursued by their own best known position in the search-space as well as the whole swarm's best known position [9]. After finding the proper positions, these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be detected [9-11]. The pseudo code of PSO Algorithm is presented below:

Step 1: Input the basic data and maximum number of iteration (Imax).
Step 2: Initialize particles in the population.
Step 3: Calculate fitness value of the each particle.
Step 4: Compare and update fitness value with pi, gi..
Step 5: If the I=Imax, go to step 7. Otherwise, go to the next step.
Step 6: Update velocity and position by Equations (12), (13).
Step 7: Print the global best solution

3. QUANTUM INVASIVE WEED OPTIMIZATION (Q-IWO)

Quantum Invasive Weed Optimization (QIWO) is a new optimization algorithm which is proposed by Razmjooy and Ramezani in 2014 [12]. This algorithm is based on extending the invasive weed optimization algorithm by the quantum theory computing. It is described by a consideration about quantum seeds and their competition to survive. The main advantage of QIWO is the reaching to the global minimum in less iteration. Since, we decided to utilize this algorithm to optimize the proposed classifier. The pseudo code of the QIWO is presented in below [8]:

1. Start
2. Initialize population
3. Classical state conversion
4. Evaluate objective values
5. Quantum state conversion
6. Fast non-dominated sorting
7. Generate child population via tournament selection and IWO operators
8. Evaluate objective values of child population
9. Combine parent and child population
10. Fast non-dominated sorting
11. Create next generation based on rank and crowding distance
12. Go to 7
13. Classical state conversion
14. end

4. POWER SYSTEM STABILIZERS BODYCONTROL WITH PID

Power system stabilizers (PSS) are one of the most widely used systems to deal with low frequency oscillations. PSS is used to improve the damping of synchronous machine [13, 14].

After briefly describing two algorithms in the prior section, it is time to design the proposed PID controller for power system stabilizer. The fitness function and the parameter constraints are considered as below:

$$J = \max \ \text{Re} \left(\lambda_{k,l} \right)$$ (5)
$$0 \le K_p, K_i \le 50$$
$$0 \le K_d \le 10$$

The power system stabilizer (PSS) block diagram of the analyzed system is shown in the follow:
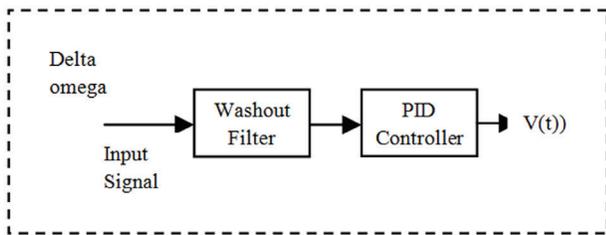
Fig.3. Power system stabilizer block diagram.

From the above, in theproposed technique, a PID controller is employed instead of lead-lag controller in the prior models. In this research, the rotor speed variation is selected as the input signal of the PSS. Washout mechanism is employed to eliminate the controller effects in the steady state. Indeed, the system oscillations are damped due to PSS. Itproduces a control signal to the AVR loop after the disturbance occurs. The system coefficients matrix can be presented as below:

$$A = \begin{bmatrix} 0 & \omega_0 & 0 & 0 & 0 \\ \frac{-k_1}{M} & 0 & \frac{-k_2}{M} & 0 & 0 \\ \frac{-k_4}{Td0'} & 0 & \frac{-1}{k_3 Td0'} & \frac{1}{Td0'} & 0 \\ \frac{Mk_e\left(-k_5 + Mk_i/\omega_0 - k_d k_1\right)}{MTe} & \frac{k_e k_p}{Te} & \frac{-Mk_6 k_e - k_2 k_e k_d}{MTe} & \frac{-1}{Te} & \frac{k_e}{Te} \\ \frac{Mk_i/\omega_0 - k_d k_1}{MTw} & \frac{k_p}{Tw} & \frac{-k_2 k_d}{MTw} & 0 & \frac{-1}{Tw} \end{bmatrix}$$

The system data is given in the appendix.

5. SIMULATIONS AND RESULTS

In this case, we have considered the variations P= (0.1, 0.2…1) and Q=(-0.3, -0.2…1) to analyze the system robustness in different conditions. The operating points can be achieved from the table below:

Table 1. Operating Points

Case No	P	Q
1	1	0.5
2	0.5	0.2
3	0.7	-0.1
4	0.8	0
5	0.8	0.4
6	1	1

The optimized values for parameters of the PID controller by the described algorithms aregiven in the table 2.

It is apparently from fig.4 to fig.10 that the desirable value for QIWO algorithm has a high performance than the PSO-Based approach.

Table 2. Controller Coefficients for the PID

Algorithm	k_P	k_I	k_D
QIWO	48.4463	42.5382	7.4325
PSO	47.2587	3.8344	9.3210

Notice that the considered system is a synchronous generator connected to infinite bus and power system stabilizer; in the described system, parameters are: Electrical Active power (P) and Electrical reactive power)Q) for the system (operating points for synchronous generator) are utilized as the operating points to design the PID controller. Control part of the system is optimized by employing QIWO and PSO algorithms; system output speed deviations for the operating points are shown in the below:
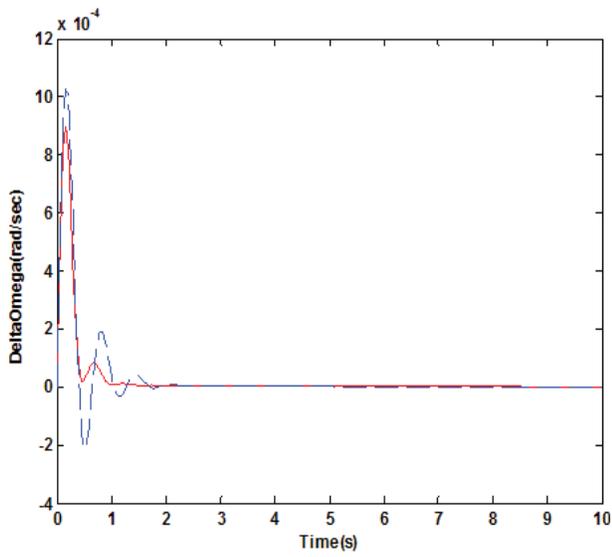
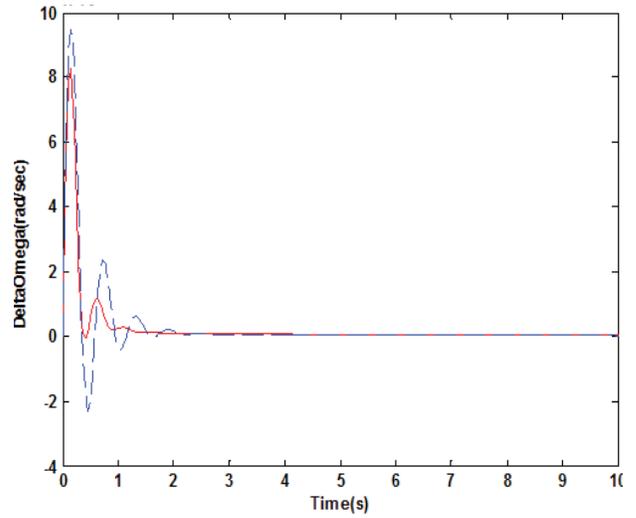**Fig.4. Operation points: P=1,Q=0.5 (Solid (QIWO), Dashed (PSO))**

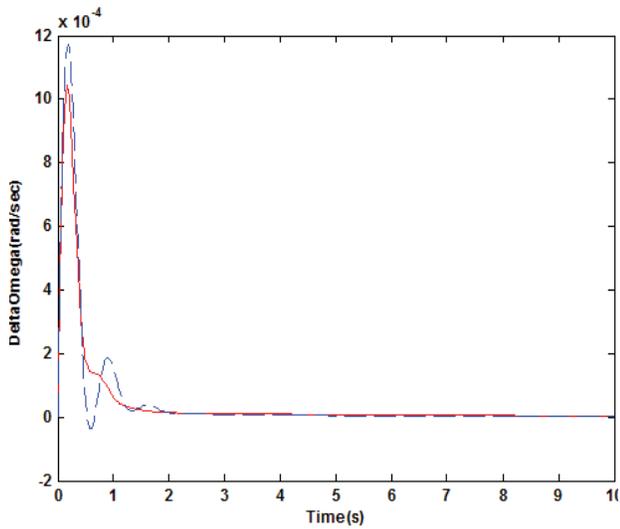**Fig.6. Operation points: P=0.7,Q=-0.1(Solid (QIWO), Dashed (PSO))**

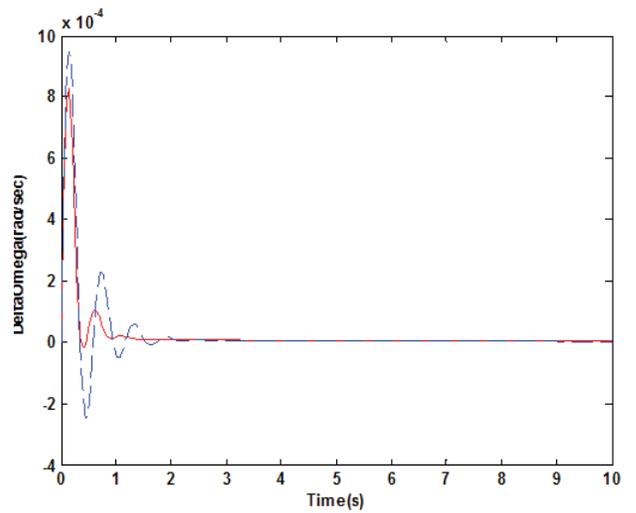**Fig.5. Operation points: P=0.5,Q=0.2 (Solid (QIWO), Dashed (PSO))**

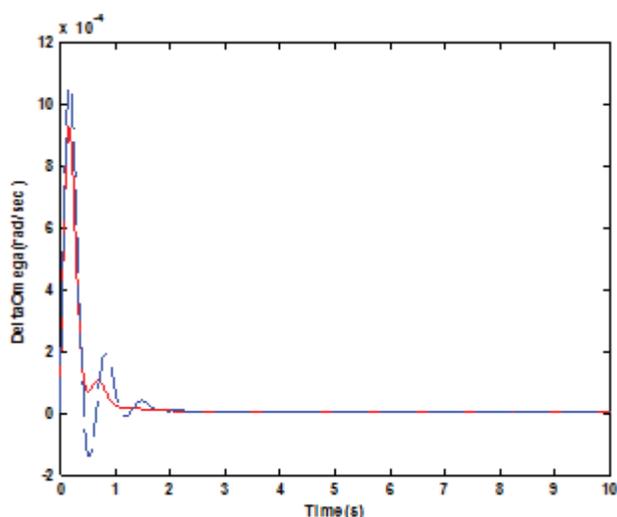**Fig.7. Operation points: P=0.8,Q=0 (Solid (QIWO), Dashed (PSO))**

Fig.8. Operation points: P=0.8,Q=0.4 (Solid (QIWO), Dashed (PSO))
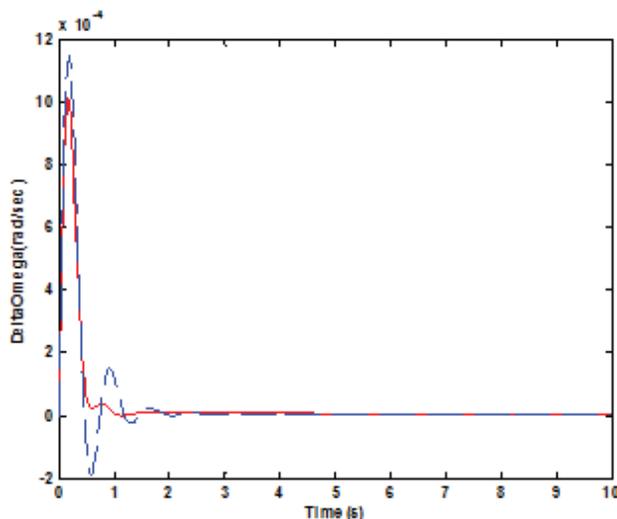

Fig.9. Operation points: P=1,Q=1 (Solid (QIWO), Dashed (PSO))

Table 3. Results of the response analysis in the considered operating points

Case No.	QIWO		PSO	
	Over Shoot	Under Shoot	Over Shoot	Under Shoot
1	0.000861	0	0.000926	-0.0000124
2	0.001	0	0.0015	0
3	0.000815	-0.000041	0.000864	-0.0000397
4	0.0007953	-0.000035	0.0008349	-0.0000473
5	0.0009057	0	0.0009627	0

Table 4. Achieved results of the algorithms for the PSS

QIWO			PSO		
number of seeds	Pmax	Iteration	Pop size	C1,C2	Iteration
20	15	50	50	2	20

6. CONCLUSION

In this paper a new developed optimization algorithm (quantum invasive weed optimization algorithm (QIWO)) method is presented to determine optimal PID controller parameters using is presented. The Applications of the QIWO algorithm for optimizing the PID controller gains in a power stabilizer system are analyzed. In this paper, the system stabilization is considered as a basic application of the algorithm. The results for quantum invasive weed optimization algorithm is compared by the particle swarm optimization and the simulation results show that the proposed algorithm has a high convergence with less iterations rather than the particle swarm optimization which is one of the best algorithms in the control applications. The simulation results have been analyzed on a single-machine power system.

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APPENDIXES
System data:

Machine (pu):
xd=1.6, xd'=0.32, xq=1.55
vt0=1.05, w0=314(rad/sec), Td0'=6.0 (sec)
D=0; M=10
P,Q= Electrical active and reactive power of output machine (pu)

Transmission Line (pu):
re=0; xe=0.4

Exciter:
Ke=50; Te=0.05 (sec)

Washout Filter:
Tw=5 (sec)
The function of k-parameters and other data are presented below:
iq0=(P*vt0)/sqrt((P*xq) 2+(vt02+Q*xq) 2);
vd0=iq0*xq;
vq0= ((vt02)-(vd02)) 0.5;
id0=(Q+xq*(iq02))/vq0;
Eq0=vq0+id0*xq;
E0= sqrt((vd0+iq0*xe)2+(vq0-id0*xe)2);
delta = tan-1((vd0+iq0*xe)/(vq0-id0*xe));
K1= (((xq-xd')/(xe+xd'))*(iq0*E0*sin(delta)))+((Eq0*E0*cos(delta))/(xe+xq));
K2= (E0*sin(delta))/(xe+xd);
K3= (xe+xd')/(xe+xd);
K4= ((xd- xd')/(xe+ xd'))*(E0*sin(delta));
K5= ((xq*vd0*E0*cos(delta))/((xe+xq)*vt0))-((xd'*vd0*E0*sin(delta))/((xe+ xd')*vt0));

K6= (xe*vq0)/((xe+ xd')*vt0);

List of figures and table captions