ABSTRACT
In this paper, we propose a new optimized PID controller 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 function to removes the unstable Eigen-value to the left side of imaginary axis. The considered parameters for the controller 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 performance algorithm. Here, controller is obtained for all operating points. Final results show that the using quantum invasive weed optimization algorithm has a better performance 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, synchronous machine stability has received a great deal of attention and it will receive additive attention in the future [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 synchronism 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 power system stabilizer is introduced. The final results for 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 varies [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 social 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 detected, 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 Figure 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.

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 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
5. SIMULATIONS AND RESULTS

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

<table>
<thead>
<tr>
<th>Case No</th>
<th>P</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>3</td>
<td>0.7</td>
<td>-0.1</td>
</tr>
<tr>
<td>4</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>5</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

The optimized values for parameters of the PID controller by the described algorithms are given 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>
<thead>
<tr>
<th>Algorithm</th>
<th>( k_p )</th>
<th>( k_i )</th>
<th>( k_d )</th>
</tr>
</thead>
<tbody>
<tr>
<td>QIWO</td>
<td>48.4463</td>
<td>42.5382</td>
<td>7.4325</td>
</tr>
<tr>
<td>PSO</td>
<td>47.2587</td>
<td>3.8344</td>
<td>9.3210</td>
</tr>
</tbody>
</table>

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

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

Fig. 7. Operation points: $P=0.8, Q=0$ (Solid (QIWO), Dashed (PSO))
Table 3. Results of the response analysis in the considered operating points

<table>
<thead>
<tr>
<th>Case No.</th>
<th>QIWO</th>
<th>PSO</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over Shoot</td>
<td>Under Shoot</td>
</tr>
<tr>
<td>1</td>
<td>0.000861</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0.001</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>0.000815</td>
<td>-0.000041</td>
</tr>
<tr>
<td>4</td>
<td>0.0007953</td>
<td>-0.000035</td>
</tr>
<tr>
<td>5</td>
<td>0.0009057</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 4. Achieved results of the algorithms for the PSS

<table>
<thead>
<tr>
<th></th>
<th>QIWO</th>
<th>PSO</th>
</tr>
</thead>
<tbody>
<tr>
<td>number of seeds</td>
<td>Pmax</td>
<td>Iteration</td>
</tr>
<tr>
<td>20</td>
<td>15</td>
<td>50</td>
</tr>
</tbody>
</table>

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.
REFERENCES


13) Anurag, Sharma, Jha Manoj, and M. F. Qureshi, “Power System Transient Stability Analysis Based on Evolutionary Interval Type-2 Fuzzy Logic Controller and GA System,” Power, 3(6), 2014.


APPENDIXES
System data:
Machine (pu):
\( \begin{align*}
& x_d = 1.6, x_d' = 0.32, x_q = 1.55 \\
& v_t0 = 1.05, w_0 = 314 \text{ (rad/sec)}, T_{d0}' = 6.0 \text{ (sec)} \\
& D = 0; M = 10 \\
& P,Q = \text{ Electrical active and reactive power of output machine (pu)}
\end{align*} \)

Transmission Line (pu):
\( \begin{align*}
& r_e = 0; x_e = 0.4 \\
& \text{Transmission Line (pu)}:
\end{align*} \)

Exciter:
\( \begin{align*}
& K_e = 50; T_e = 0.05 \text{ (sec)}
\end{align*} \)

Washout Filter:
\( \begin{align*}
& T_w = 5 \text{ (sec)}
\end{align*} \)
The function of k-parameters and other data are presented below:
\( \begin{align*}
& i_q0 = (P \cdot v_{t0}) / sqrt((P \cdot x_q) + (v_{t0}^2 + Q \cdot x_q)) \\
& v_d0 = i_q0 \cdot x_q \\
& v_q0 = (v_{t0} - v_{d0}) / 0.5 \\
& i_d0 = (Q + x_q \cdot i_q0) / v_q0 \\
& E_q0 = v_q0 + i_d0 \cdot x_q \\
& E_0 = sqrt((v_d0 + i_q0 \cdot x_e)^2 + (v_q0 - i_d0 \cdot x_e)^2) \\
& \text{delta} = \text{tan}^{-1}\left(\frac{v_d0 + i_q0 \cdot x_e}{v_q0 - i_d0 \cdot x_e}\right) \\
& K_0 = \text{fo}((x_q - x_d')(x_e + x_d') \cdot (E_0 \cdot E_0 \cdot \text{cos}(\text{delta}))) + ((E_0 \cdot E_0 \cdot \text{cos}(\text{delta}))) \\
& K_2 = (E_0 \cdot \text{sin}(\text{delta})) / (x_e + x_d) \\
& K_3 = (x_e + x_d') / (x_e + x_d) \\
& K_4 = ((x_d - x_d') \cdot (x_e + x_d')) \cdot (E_0 \cdot \text{sin}(\text{delta})) \\
& K_5 = (x_q \cdot v_d0 \cdot E_0 \cdot \text{cos}(\text{delta})) / ((x_e + x_d') \cdot v_{t0}) - ((x_d - x_d') \cdot v_d0 \cdot E_0 \cdot \text{sin}(\text{delta})) / ((x_e + x_d') \cdot v_{t0})
\end{align*} \)
K6 = \frac{(xe \cdot vq0)}{(xe + xd') \cdot vt0);

**List of figures and table captions**

Fig. 1: Single machine infinite bus model
Fig. 2. Philips-Heffron model of synchronous machine
Fig. 3. Power system stabilizer block diagram.
Fig. 4. Operation points: \( P=1, Q=0.5 \) (Solid (QIWO), Dashed (PSO))
Fig. 5. Operation points: \( P=0.5, Q=0.2 \) (Solid (QIWO), Dashed (PSO))
Fig. 6. Operation points: \( P=0.7, Q=-0.1 \) (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 1. Operating Points
Table 2. Controller Coefficients for the PID
Table 3. Results of the response analysis in the considered operating points
Table 4. Achieved results of the