Optimum Control of Hydro-Turbine Connected to the equivalent network for Damping Frequency Oscillation Using Invasive Weed Optimization (IWO) Algorithm

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ABSTRACT: In this paper, an artificial-based optimizes and analysis of an optimal proportional, integral, derivative (PID) controller is introduced for a hydro-turbine generator governor. The main purpose, optimization PID controller parameters of hydro-turbine connected to the network for damping output frequency oscillation. In the proposed approach, an optimal and evolutionary based proportional, integral, derivative (PID) is utilized to control frequency-response of hydro turbine. The evolutionary algorithm is used to make an optimal proportional-integral-derivative (PID) controller tuning parameters. The parameters of PID controller are optimized by IWO Algorithm. The achieved result of IWO method is compared with PSO algorithm. The results of simulations show the excellence of the proposed approach for solve Hydro-turbine governor control problem in different load condition of power system.

Keywords: Invasive Weed Optimization Algorithm (IWO), PSO, Governor, Hydro Turbine, Optimal Control, Stability Analysis.

INTRODUCTION

Governors are utilized to adjust the speed of turbine generators in power system primary units. There are different researches has been conducted to consider the effect of governor parameter settings on the overall hydro-turbine system efficiency (Natarajan, 2005). Incrementing the number of interconnections, superior transmission voltages, parallel proceeds of the turbine generators in a power generation unit and development of large power generating units have certified that design of the governors stands a challenging and important subject (Chaudhry, 1970). A robust and optimal approach the analysis and design of a hydraulic turbine governor is introduced by (Jiang, 1995). The profits of this method are that the designed governor will secure the stability and performance of the speed control for the whole turbine operating range. The efficiency of the presented controller is shown to be better to that of the conventional PID controller during major load disturbances. Recently, researchers work on the applying gain scheduling (Orelind et al., 1989): adaptive control (Ichtev and Puleva, 2008), robust optimal control theory (Ilyas Eker, 2004), and neural networks for control- design of hydro turbines. In this article a new robust PID (RPID) controller is introduced to control the hydro turbine governing system in the disturbance condition (Venayagamoorthy and Harley, 2001). In this paper Invasive Weed Optimization (IWO) algorithm is utilized to design a robust PID controllers for hydro-turbine governing system. The results achieved from IWO algorithm are finally compared with the PSO-based method. Experimental results show the high efficiency of the presented approach into PSO-based method. The main purpose on this research is to design a controller with considering the network and turbine operating points changes simultaneously; for doing this, we need a powerful PID for adjusting the hydro turbine. Invasive weed optimization algorithm (IWO) is introduced as a new optimization approach for this purpose. The final results from the proposed method are then compared by a PID tuning based on PSO optimization and showed the excellence of the new algorithm toward PSO based tuning of hydro turbine PID.
**Optimal PID Controller Design**

Turbine three coefficients points are given in table 1. The presented points are extracted from (Orelind et al., 1989).

<table>
<thead>
<tr>
<th>Operating point</th>
<th>$\frac{\partial m}{\partial z}$</th>
<th>$\frac{\partial m}{\partial h}$</th>
<th>$\frac{\partial m}{\partial b}$</th>
<th>$\frac{\partial q}{\partial z}$</th>
<th>$\frac{\partial q}{\partial h}$</th>
<th>$\frac{\partial q}{\partial b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1 = 22.5$MW</td>
<td>0.88</td>
<td>0.40</td>
<td>0.00</td>
<td>-0.39</td>
<td>0.00</td>
<td>0.86</td>
</tr>
<tr>
<td>$T_2 = 84.3$MW</td>
<td>0.90</td>
<td>1.20</td>
<td>0.50</td>
<td>-0.86</td>
<td>2.30</td>
<td>0.40</td>
</tr>
<tr>
<td>$T_3=113.0$MW</td>
<td>0.34</td>
<td>1.50</td>
<td>0.52</td>
<td>-0.75</td>
<td>1.00</td>
<td>0.38</td>
</tr>
</tbody>
</table>

The block diagram of the utilized turbine is shown in Fig. 1 (Paynter, 1955).

with combination three working points of turbine (T1, T2 and T3), and three network points (N1, N2 and N3), a 9 working points robust controller has been designed that could be secure the turbine even with inappropriate positions where: $N_1=\{ B=0.2, T_s=19.2 \}$, $N_2=\{ B=0.0167, T_s=230 \}$ and $N_3=\{ B=0.131, T_s=84.46 \}$.

Nowadays, proportional-integral-derivative (PID) controller is a more appliance approach used control theory in industry. This PID controller assigns a convenient design for both steady-state and transient responses, along with beneficial and popular resources to the real world control subjects. Zero Adding in a closed loop transfer function using differential controller modifies the transient response, and pole adding to a closed loop transfer function with integrator controller, lessons the steady state error (Chew et al., 1992).

Adjusting the PID controllers can be utilized with different ways include: hand tuning, Cohen-coon tuning, Ziegler Nichols and Z-N step response; but these methods have some limitations (Zarringhalami et al., 2010). Recently in practice, PID tuning needs to test personnel using a trial and error way and some practical rules; this makes the process to have high cost and difficult activity. Evolutionary Algorithms (EAs) like GA, ICA, PSO, and IWO have demonstrated their reliefs in giving better results by reclaim the steady states details and efficiency indices.
In this paper, invasive weed optimization (IWO) algorithm is selected as the optimal design of PID controller with hydro turbine. The main reasons make us to use PID are: simple structure, easy to implement, easiness of operation in understanding rather than most other advanced controllers and premier of all, robust performance in a wide range of operating conditions. The transfer functions of a PID controller can be represented as:

\[
\frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i(s)}\right) \quad (1)
\]

\[
\frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i(s)} + T_d(s)\right) \quad (2)
\]

where \(U(s)\) is the control signal, \(K_p\) is proportional gain, \(E(s)\) is error signal, \(T_i\) is integral time constant, \(K_i\) is integral gain, \(T_d\) is derivative time constant and \(K_d\) is derivative gain.

The main purpose on this research is to use IWO algorithm as an optimized approach to design a robust control on the load disturbances of hydro turbine. After that, a comparison between IWO design of PID controller and a PSO based approach of the PID controller illustrates the priority of the proposed method.

**Particle Swarm Optimization (PSO) Algorithm**

Particle Swarm Optimization (PSO) algorithm is a population based stochastic optimization approach expanded in 1995 by Kennedy and Eberhart, inspired by the social behavior of particles flocking and fish schooling (Zarringhalami et al., 2010). Formal PSO algorithm operates by owning a population of candidate solution (called a swarm) solution (called particles). These particles are moved around in the search-space in order to some specified formulae. The motion of the particles is followed by their own best known position in the search-space as well as the entire swarm’s best known position. After discovering the modified positions, these will then come to guide the motions of the swarm. The process is iterated and by performing so it is hoped, but not guaranteed, that a satisfactory solution will finally be figured out (Kim et al., 2008; Panda, and Padhy,); the swarm regulates according to the following two equations:

\[
v_{i}^{t+1} = w v_{i}^{t} + c_1 r_1 (P_{i}^{t} - x_{i}^{t}) + c_2 r_2 (g_{i}^{t} - x_{i}^{t}) \quad (3)
\]

\[
x_{i}^{t+1} = x_{i}^{t} + v_{i}^{t+1} \quad (4)
\]

where \(n\) is the number of particles, \(w\) is the weighted inertia, \(C_1\) and \(C_2\) are the positive constants, \(r_1\) and \(r_2\) are two random numbers distributed within the range \([0,1]\), \(t\) is the iteration number, \(P_{i}\) is the best position of the \(i^{th}\) particle and \(g_{i}\) is the best particle among the group members. By using (3), the particle updates its velocity based on its previous velocity and the distances to its current position from its own best historical position and the best positions of the neighbors in every iteration step, and then it flies towards a new position specified by (4).

The step of particle swarm optimization method is presented below:

- **Stage 1:** Input the primal data and maximum number of iteration \((t_{\text{max}})\).
- **Stage 2:** Initialize particles in the population.
- **Stage 3:** Calculate fitness extent of the each particle.
- **Stage 4:** Compare and update fitness value with \(p_i\), \(g\).
- **Stage 5:** If the \(t = t_{\text{max}}\), go to stage 7. Otherwise, go to the next stage.
- **Stage 6:** Update velocity and position by Equations (3), (4).
- **Stage 7:** Print the global best solution.

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**Figure 2. PID logic control**

**Figure 2. PID logic control**
Invasive Weed Optimization

Recently, evolutionary algorithms inspired from natural processes which are attended paid for solving the optimization problems. GA, PSO, ACO and ABC algorithms are some examples of such algorithms. Mehrabian and Lucas introduced another algorithm which is inspired from weeds colonizing which is well-known as invasive weed optimization algorithm (IWO) (Suresh et al., 2009).

Some of the prominent characteristics of IWO in comparison with other evolutionary algorithms is the way of reproduction, spatial dispersal, and competitive exclusion (Akbarzadeh and Sadeghi, 2011). Alireza Akbarzadeh and Mohammad Sadeghi (2011) compared the IWO with genetic algorithms (GAs), mimetic algorithms (MAs), and particle swarm optimization (PSO). The experimented showed that the results from IWO are as good as (in some cases are better than) the results from other methods.

The pseudo code of invasive weed optimization algorithm is summarized as below:

**Initialization**: A finite number of seeds are being distributed over the search area.

**Reproduction**: Every seed grows to a flowering plant and produces seeds depending on its fitness.

**Spatial dispersal**: The generated seeds get randomly dispersed over the search area by normally distributed random numbers with mean equal to zero, but varying variance; in other words, seeds will be randomly distributed such that they abide near to the source plant. However, standard deviation (SD), $\delta$, of the random function will be decreased from a formerly previously described value, $\delta_{\text{initial}}$, to a final value $\delta_{\text{final}}$ in every step (generation).

Where $\delta_{\text{iter}}$ is the SD at the present time step, $\text{Iter}$ maximum number of iterations and $n$ is the nonlinear modulation index.

**Competitive exclusion**: This step pursuing until maximum number of plants is reached; now only the plants with lower fitness can survive and generate seeds, others are being eliminated. The process continues until maximum number of iteration is reached and hopefully the plant with the best fitness is closest to the optimal solution.

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**SIMULATIONS RESULTS AND DISCUSSION**

The system is modeled and optimized in matlab software respectively. Invasive weed optimization (IWO) algorithm is used for optimize PID controller of the hydro turbine on the input of hydraulic amplifier.

Turbine parameters are achieved from (Natarajan, 2005);

For analyzing the system response, 5 analysis metrics are utilized as below:
\[ IAE = 100 \times \int |e(t)|dt \]  
\[ ISE = 10^4 \times \int e^2(t)dt \]  
\[ ITSE = 1000 \times \int t e^2(t)dt \]  
\[ ISTSE = 100 \times \int t_{sim}^2 e^2 dt \]  
\[ FD = (10^4 \times OS^2) + (10^4 \times US^2) + (0.0001 \times t_i^2) \]

Transfer function of PID controller is:

\[ PID = K_p + \frac{K_i}{s} + K_d s \]

purpose of the proposed system is designed as below:

\[ ISTSE + C = 10 \times \int t_{sim}^2 e^2 dt + (100 \times US)^2 \]

\[ O \leq K_p, K_i, K_d \leq 2 \]

At this case, there is another design which is used for comparison:

\[ FD = (10^4 \times OS^2) + (10^4 \times US^2) + (0.0001 \times t_i^2) \]

where OS is the overshoot, US is undershoot and \( t_i \) is the output setting time of the system.

And the final values of PID controller for optimizing the hydro turbine by using IWO and PSO algorithms are presented in table 2 and the values of parameters of the utilized algorithms are presented in table 3.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Table 2. IWO and PSO PID Controller Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( K_p )</td>
</tr>
<tr>
<td>IWO-PID</td>
<td>0.3779</td>
</tr>
<tr>
<td>PSO-PID</td>
<td>0.6548</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3. IWO and PSO Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>IWO</td>
</tr>
<tr>
<td>-----</td>
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<td></td>
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</table>

As it can be seen from figure 4, the desirable value for IWO algorithm has higher efficiency than the PSO-Based approach. The desirable system is a hydro turbine connected to synchronous generator and equivalent system; in the presented system, parameters include: Base Changer (B) and Mechanical Start Time of equivalent system (\( T_s \)) for network and \( T_1, T_2, T_3 \) (operating point for hydro turbine) are utilized as operating points for designing the PID controller. Control section is applied by IWO algorithm and PSO algorithm; system output frequency deviation in operating point with considering the load disturbances (0.2 PU) are shown below:
In this paper, a new robust governor design using an artificial based approach control approach was presented for hydro-turbine controls to enhance the system efficiency. The results were showed that the proposed method can developed a mechanism to deal with the varying system dynamics. The employed cost function for system optimization is a robust function; designing of robust system is performed by discussing the system operation point changes that is shown in system parameters indefinitely. In this article, after simulating the hydro turbine system and analyzing of turnover in the control system during disturbance occurs, the controllers rule is considered in system stabilization. By comparison with a PSO-based PID controller, it shows that this method can improve the dynamic performance of the system in a better way as indicated in tables 2, 4, 5 and figure 4. Final results demonstrated that performance of the system was significantly enhanced by the proposed optimal design approach.
**Nomenclatures**

- \( n \): Incremental machine speed.
- \( n_s \): Incremental system speed.
- \( q \): Incremental flow.
- \( m \): Incremental mechanical torque.
- \( z \): Incremental gate position.
- \( b \): Incremental blade angle.
- \( h \): Incremental head.
- \( T_B \): Time constant between gate and corresponding blade movement (3.5Sec).
- \( T_W \): Water start time (2.35Sec).
- \( T_B \): Time constant of hydraulic amplifier (0.15Sec).
- \( D \): Machine electrical damping factor (0.8).
- \( T_M \): Mechanical start time (10.25Sec).
- \( K_A \): Equivalent synchronizing factor (655.98).
- \( D_A \): Equivalent damping factor (17.4).
- \( T_N \): Time constant of speed filter (0.06Sec).

**REFERENCES**


