A new design for PID controller by considering the operating points changes in Hydro-Turbine Connected to the equivalent network by using Invasive Weed Optimization (IWO) Algorithm

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ABSTRACT

This paper presents a new optimization algorithm to design an optimal proportional, integral, derivative (PID) controller in hydro-turbine generator governor for damping output frequency oscillations. In this research, we utilize a stochastic and optimal based PID controller to control frequency-response of the hydro turbine. The proposed algorithm is employed to design an optimal PID controller by adjusting the PID parameters. Here, the parameters of the PID controller are optimized by IWO Algorithm. For analyzing the proposed technique, the final results of IWO algorithm is compared with ABC algorithm. Simulation results showed that the proposed method has better performance in different load condition of power system.

Keywords

Optimal Control, Invasive Weed Optimization Algorithm (IWO), Hydro Turbine, Governor, Operating points, ABC algorithm.

1. Introduction

In the original power system units, governors are employing for speed tuning of turbine generators. Different studies have been applied to analyze the effect of governor parameter changes on the hydro-turbine system efficiency [1].

When increasing the number of superior transmission voltages, interconnections, parallel proceeds of the turbine generators in a power generation unit and improvement of large power generating units have endorsed, that design of the governors stands an important and challenging subject [2].

In 1995, Jiang, J proposed a robust and optimal method to analysis and design of a hydraulic turbine governor [3].

In this approach, the designed governor will secure the stabile and the performance of the speed control for the turbine operating range showed better results compared with the traditional PID controller during major load disturbances.

Lately, researchers study on the implementing gain scheduling [4], robust optimal control theory [5], adaptive control [6] and neural networks [7] for control- design of hydro turbines.

This paper describes a new robust PID (RPID) controller to control the governing system of hydro turbine in the disturbance condition.

Here, Invasive Weed Optimization (IWO) algorithm is used to design robust controllers in hydro-turbine governing system. The final results by IWO algorithm will then compare with the ABC based approach. Simulation results show the superiority of the presented technique toward ABC based method. The main idea in this study is to design a controller by considering the network and turbine operating points changes simultaneously; for performing this purpose, we need a powerful PID to adjust the hydro turbine. Invasive weed optimization algorithm (IWO) as a new optimization algorithm which has good performances in different purposes is employed in this research.

2. Designing the Optimal RPID Controller

Coefficient points of the Turbine are achieved from [8] and are given in the table below.

The block diagram of the utilized turbine can be considered as the figure below [9]:

Table1. Turbine Coefficients for analyzing system

Operating point	$\frac{\partial m}{\partial z}$	$\frac{\partial m}{\partial h}$	$\frac{\partial m}{\partial b}$	$\frac{\partial m}{\partial w}$	$\frac{\partial b}{\partial z}$	$\frac{\partial q}{\partial z}$	$\frac{\partial q}{\partial h}$	$\frac{\partial q}{\partial b}$	$\frac{\partial q}{\partial w}$
T_1= 22.5MW	0.88	0.40	0.00	-0.39	0.00	0.80	0.06	0.00	0.13
T_2= 84.3MW	0.90	1.20	0.50	-0.86	2.30	0.40	0.20	0.30	0.38
T_3 =113.0MW	0.34	1.50	0.52	-0.75	1.00	0.38	0.24	0.69	0.62

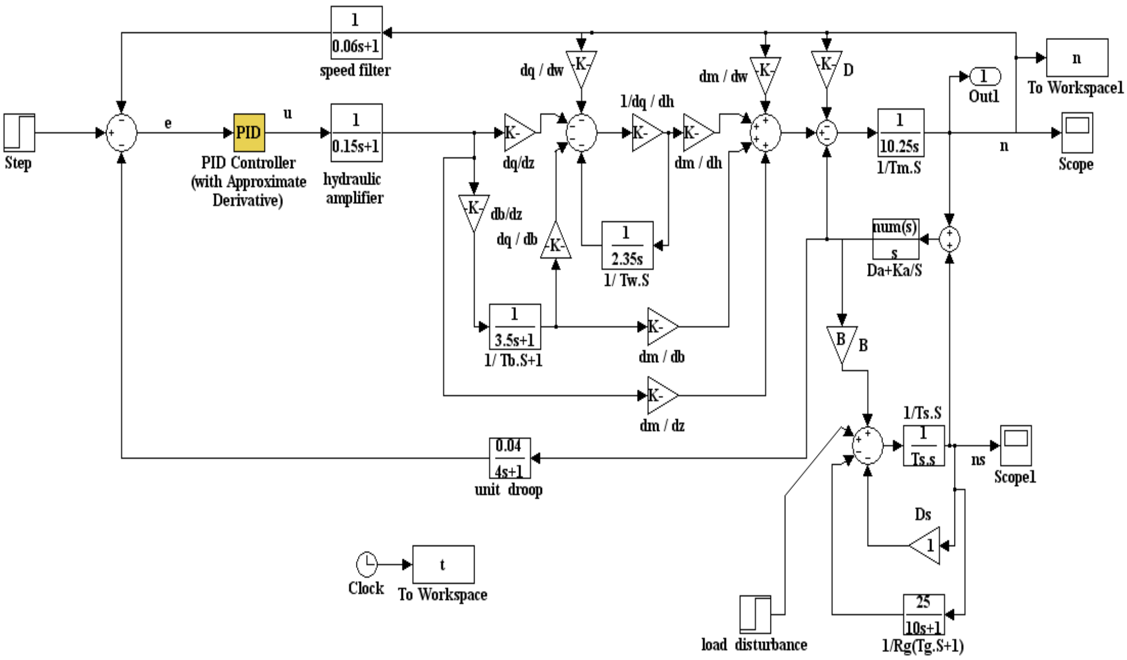


Fig.1. water turbine model- jointed generator to the equivalent network.

Blending these 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 untoward positions where: N_1= {B=0.25, T_s=20}, N_2={ B=0.0283 , T_s=226} and N_3={B=0.147, T_s=75.36}.

Recently, proportional-integral-derivative (PID) controller is turned into a more popular technique in control industries. PID controller can be considered as a suitable design not only for steady-state but also for transient responses, along with useful and popular resources to the real world control purposes.

By adding the zeros and poles using differential and integrator controllers into the closed loop transfer function respectively, we can modify the transient response and reduces the steady state error [10].

We can adjust the PID controllers by different techniques like: hand tuning, Ziegler Nichols, Cohen-coon tuning and Z-N step response, etc. but these techniques have some restrictions [11].

Practically, PID tuning requires *trial and error* and some practical rules for using in the industry; this problem turns the control process into a high cost and difficult activity. Optimization Algorithms like GA, PSO, ABC and IWO have illustrated their capability in giving better results by reclaim the efficiency indices and the steady states details.

In this study we utilized invasive weed optimization (IWO) algorithm to optimal design of PID controller of the hydro turbine. The main reasons for selecting the PID control is because they have simple structure, they can implement and operate easily into most other utilized controllers. Transfer function for a conventional PID controller can be achieved as the equation below:

$$\frac{U(s)}{E(s)} = K_P\left(1+\frac{1}{T_I(s)}\right) \quad (1)$$

$$\frac{U(s)}{E(s)} = K_P\left(1+\frac{1}{T_I(s)}+T_D(s)\right) \quad (2)$$

Here, *U(s)* represents the control signal, K_P illustrates the proportional gain, *E(s)* is the error signal, T_I represents the integral time constant, K_I is integral gain, T_D is derivative time constant and K_D describes the derivative gain.

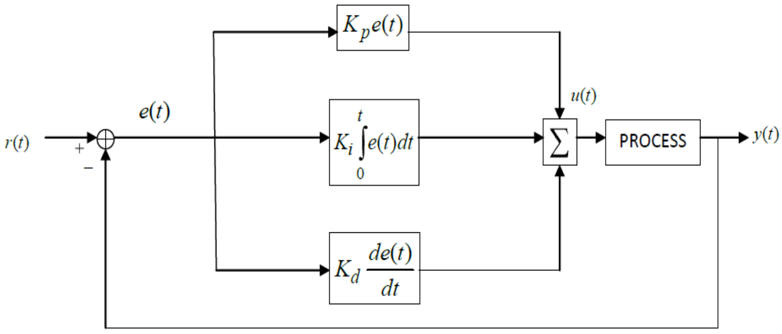


Fig.2 PID logic control

The main idea in here is to use IWO algorithm as an optimization algorithm to design a robust control on the load disturbances of hydro turbine. Afterwards, a comparison between the proposed IWO based technique toward the ABC based one will show the priority of the proposed method.

3. Artificial Bee Colony (ABC) Algorithm

Artificial Bee Colony (ABC) Algorithm is a stochastic algorithm which is mimicked form the behavior of honeybee swarms. An improved model of the ABC algorithm was then introduced to implement constrained optimization problems. ABC algorithm has been presented to perform well for a great deal of static problems. Artificial bee's colony consists of three principal steps: employed, onlookers and scout bees. Here, employed bees randomly seek for food-source locations which are in fact solutions. After discovering the location, employed bees relegate their location information and the nectar contents (solutions qualities) of the food sources with the onlooker bees on the dance area [12].

Onlooker bees peruse some deal dances to achieve a nectar amount by using the information given by the employed bee; this operation is performed based on their nectar amount probability.

In this position, it develops the position in her memory and tests the nectar amount of the candidate source. If the generated nectar has a better position rather than the previous one, the bee retains the new position and passes the old one up. The probability (p_i) of the selected food source (by onlooker bees) can be described as below:

$$p_i = \frac{fitness_i}{\sum_{i=1}^{Eb} fitness_i} \tag{3}$$

Here, $fitness_i$ defines the fitness function of the solution *i*, and E_b defines the number of nectar source positions and is equal to the half of *CS*. In order to determine a neighboring nectar source position, the ABC algorithm modifies a random parameter and keeps the other parameters fixed as below:

$$x_{ij}^{new} = x_{ij}^{old} + u\left(x_{ij}^{old} - x_{kj}\right) \tag{4}$$

where, $k \neq i$ and both are in between [1, 2, …, *Eb*]. *u* is a random number in the interval [-1,1] and *j* can be chosen randomly in the interval [1, 2, …, *D*]. x_{ij} illustrates the j^{th} parameter of the x^i as the solution. After the nectar source position has been single, the employed bee joined with it adjusts to a scout. The scout generates a quiet new nectar source position as:

$$x_i^{j(new)} = \min x_i^j + u\left(\max x_i^j - \min x_i^j\right)$$

Onlooker and Employed bees choose new nectar sources about the prior one belonging on visual information based on the comparison of nectar source positions [13]. Table 2 shows the pseudo-code of the ABC algorithm.

4. Invasive Weed Optimization

Nowadays, natural based evolutionary algorithms which are utilized for solving the optimization problems Are getting popular. GA, PSO, ACO and ABC algorithms are some examples for these techniques. Mehrabian and Lucas presented a new algorithm based on weeds colonizing which is traditional as invasive weed optimization algorithm (IWO) [14].

IWO has some prominent characteristics in comparison with other optimization algorithms which includes the way of reproduction, spatial dispersal, and competitive exclusion [15].

In 2011, Alireza Akbarzadeh and Mohammad Sadeghi analyze IWO and compared it with genetic algorithms (GAs), mimetic algorithms (MAs), and particle swarm optimization (PSO). The experimented results showed the superiority of the IWO rather than the other methods. The pseudo code of invasive weed optimization algorithm is summarized as below:

1) Initializing: A determinate number of seeds are being distributed over the search area.
2) Reproduction: Every seed grows to a flowering plant and generates seeds based on its fitness.
3) Spatial dispersal: The generated seeds get randomly pervaded over the search area by mean value equal to zero, varying variance and normally distributed random numbers. Although, standard deviation (SD), δ, of the random function will be reduced from a predecessor described value, $\delta_{initial}$ to a final value δ_{final}in every generation.
4) Here, δ_{iter} defines the SD at the present time step, Iter is the maximum number of iterations and n represents

the nonlinear modulation index.

5) Competitive exclusion: This step will be following until the maximum number of plants gets reached; in this situation, the plants with lower fitness can survive and generate seeds and the others are being omitted. The process resumes until maximum number of iteration get reached and the plant with the best fitness is closest to the optimal solution.

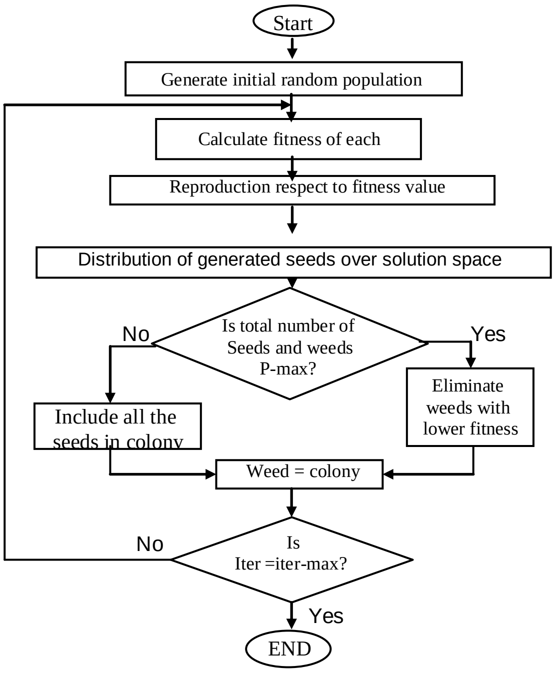


Fig.3. Flowchart of IWO Algorithm

5. Simulations Results and Discussion

After modeling the system in the Matlab software, the results are analyzed. Here, we used invasive weed optimization (IWO) algorithm for making an optimized PID controller in the hydro turbine on the input of hydraulic amplifier. The required parameters for turbine simulation are achieved from [1].

We used 5 analysis metrics to analyze the system response as below:

$$IAE = 100 \times \int |e(t)| dt \quad (6)$$

$$ISE = 10^4 \times \int e^2(t) dt \quad (7)$$

$$ITSE = 1000 \times \int t.e^2(t) dt \quad (8)$$

$$ISTSE = 100 * \int t_{sim}^{\ 2} \cdot e^2 dt \quad (9)$$

$$FD = (10^4 \times OS^2) + (10^4 \times US^2) + (0.0001 \times t_s^{\ 2}) \quad (10)$$

A traditional PID controller includes three parts of proportional, integrator and derivator which can be modeled as below:

$$PID = K_p + \frac{K_i}{s} + K_d s \quad (11)$$

The main objective of the system control can be illustrated as an index performance:

$$ITSE + C = 100 * \int t_{sim} \cdot e^2 dt + (1000 * US)^\wedge 2 \quad (12)$$

$$0 \le K_p, K_i, K_d \le 2 \quad (13)$$

Furthermore, we used another design which for analyzing as below:

$$FD = (10^4 \times OS^2) + (10^4 \times US^2) + (0.0001 \times t_s^{\ 2}) \quad (14)$$

In this case, OS describes the overshoot, US is undershoot and t_s illustrates the output setting time of the system. After applying the control strategy, the final values for PID controller and its parameters are achieved as table 2 and table 3.

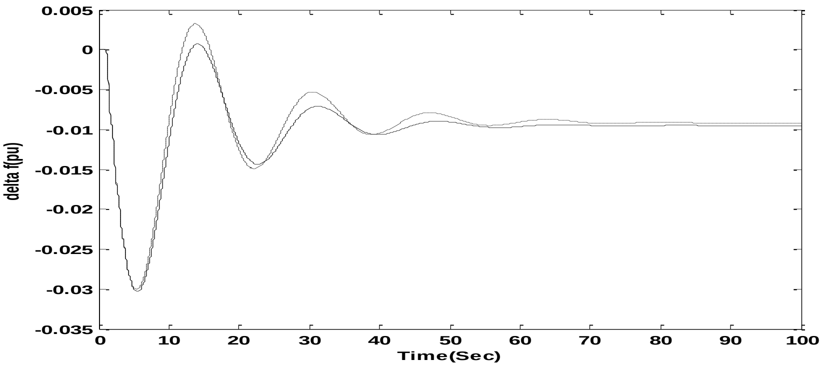
Table2. IWO and PSO PID Controller Parameters

Characteristic	K_P	K_I	K_D
IWO-PID	0.4926	1.5618	0.3852
ABC-PID	0.3779	1.3736	0.3670

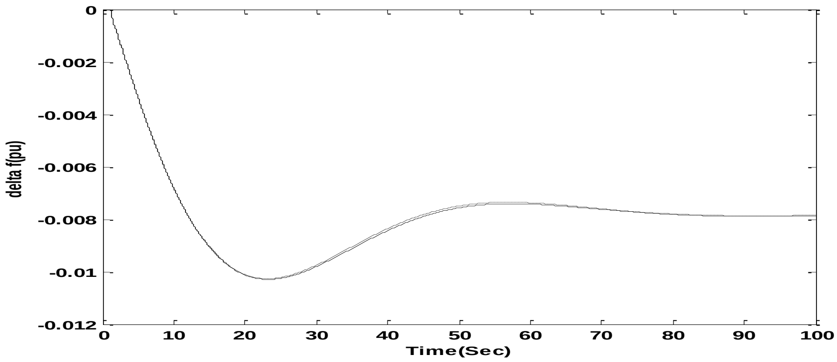
Table3. IWO and ABC Parameters

IWO			**ABC**		
Initial Pop. Size	Nonlinear modulation index(n)	Iteration	Colony. size	limit	Iteration
20	10	20	40	100	20

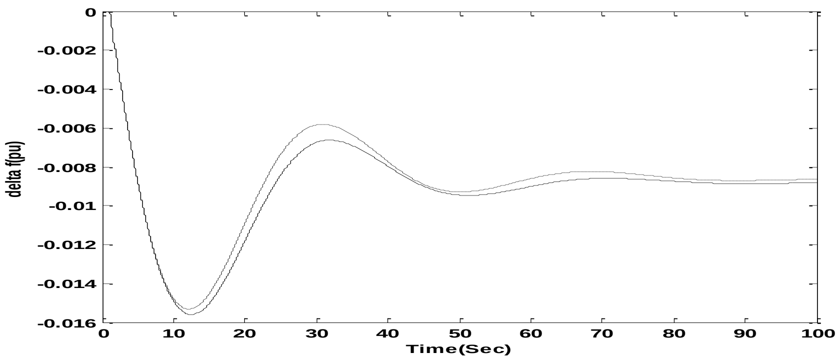
As it can shown in figure 4, the desirable obtained parameter for IWO algorithm has higher efficiency than the ABC-Based method. The simulated system is a hydro turbine connected to synchronous generator and network; in the presented system, parameters of system include: *Base Changer* (B) and *Mechanical Start* Time of equivalent system (T_s) for network and T_1, T_2, T_3 (operating point for hydro turbine) are used as operating points for optimization the parameter of PID controller in load frequency loop . Control section is applied by IWO algorithm and ABC approach; system output frequency deviation in operating point with considering the load disturbances (0.3 PU) are shown below:


delta f(pu)
Time(Sec)

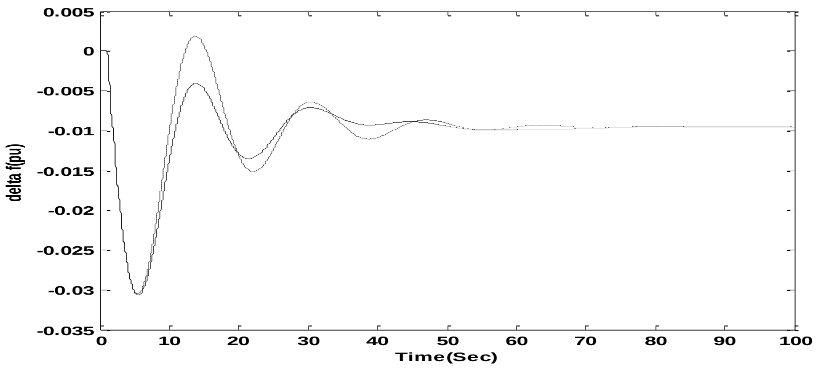
(a)


delta f(pu)
Time(Sec)

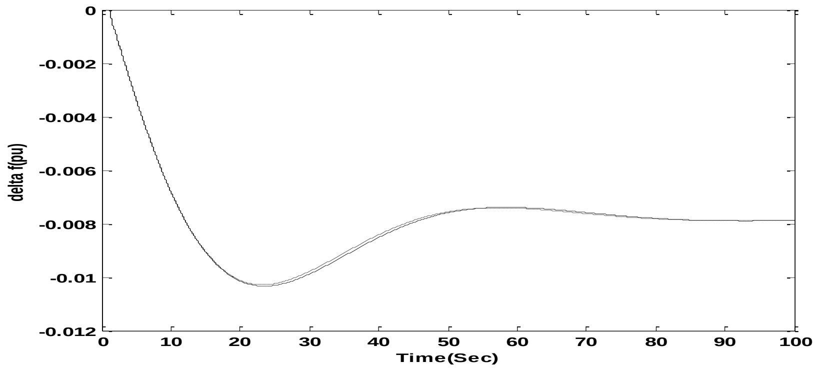
(b)


delta f(pu)
Time(Sec)

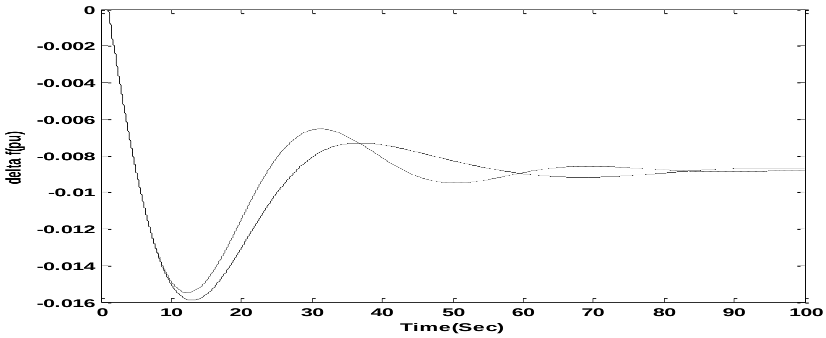
(c)


delta f(pu)
Time(Sec)

(d)


0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
delta f(pu)
0
10
20
30
40
50
60
70
80
90
100
Time(Sec)

(e)


0
-0.002
-0.004
-0.006
-0.008
-0.01
-0.012
-0.014
-0.016
delta f(pu)
0
10
20
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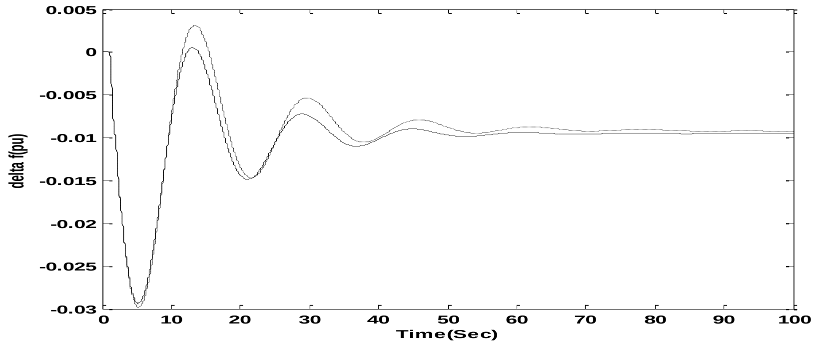
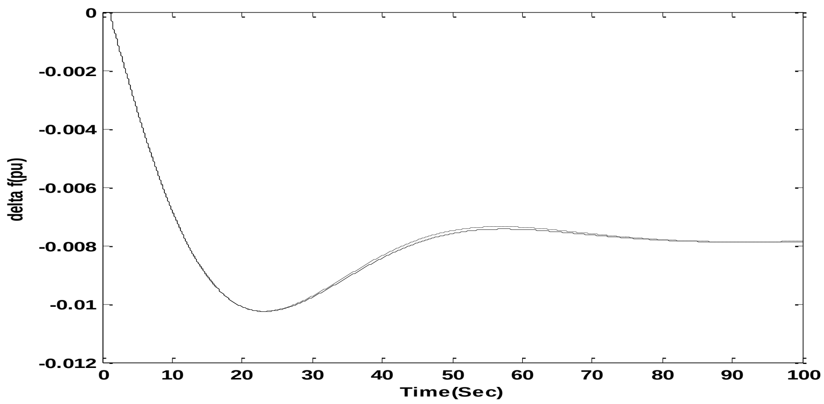
40
50
60
70
80
90
100
Time(Sec)

(f)


0.005
0
-0.005
-0.01
-0.015
-0.02
-0.025
-0.03
delta f(pu)
0
10
20
30
40
50
60
70
80
90
100
Time(Sec)

(g)


0
-0.002
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-0.006
-0.008
-0.01
-0.012
delta f(pu)
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70
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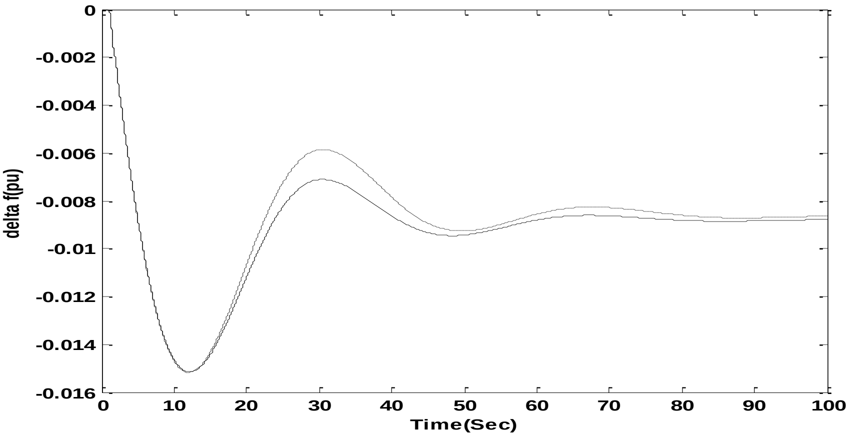
90
100
Time(Sec)

(h)



(i)

Fig.4 Unit frequency deviation with load disturbance (0.3pu) for (a) T1, N1; (b) T2, N2; (c) T1, N3; (d) T2, N1; (e) T2, N2; (f) T2, N3 ; (g) T3, N1; (h) T3, N2 and (i) T3, N3; Solid (IWO), Dashed (ABC)

Nine cases are used to evaluate performance of the proposed algorithm. Tables 4 illustrates the results of analysis hydro Turbine system with load disturbance in different metrics presented above and table 5 illustrates the comparison between the presented algorithms performance index to the other three on the basis of overshoot, settling time, undershoot and Figure of Demerit error utilized.

Table4. The results of analysis hydro Turbine system with load disturbance (30%) for operating points

Case No.	Symbol	IAE		ISE		ITSE		ISTSE	
		IWO	ABC	IWO	ABC	IWO	ABC	IWO	ABC
1	T1,N1	22.5136	23.1509	26.4259	25.1034	21.1962	20.478	29.2572	24.50
2	T1,N2	10.5241	10.5231	3.3159	3.5253	3.3967	3.1667	7.8634	7.4846
3	T1,N3	14.249	14.387	6.4268	6.5048	7.3859	7.564	14.446	14.174
4	T2,N1	21.5622	20.633	23.2173	22.6018	15.1825	15.3868	16.239	16.40
5	T2,N2	10.5766	10.7942	3.4825	3.5845	3.5973	3.3397	9.4857	8.1803
6	T2,N3	15.3482	15.6843	7.8291	7.4333	8.4628	9.1289	16.0857	17.376
7	T3,N1	22.974	21.36	21.1239	21.8228	16.6719	16.9775	19.3249	20.331
8	T3,N2	10.6176	10.3821	3.9426	3.4944	3.2473	3.0862	7.1538	7.1619
9	T3,N3	12.1956	12.7353	5.1642	5.6327	5.1143	5.8391	10.0276	9.9035

Table5. The characteristics of output response system with load disturbance (30%) for operating points

Case No.	Symbol	OS		US		ts		FD	
		IWO	ABC	IWO	ABC	IWO	ABC	IWO	ABC
1	T1,N1	0.0108	0.012	0.0395	0.0398	99.9643	99.988	18.5786	17.9126
2	T1,N2	0.0065	0.0079	0.0176	0.0182	99.9769	99.9949	4.9637	4.9157
3	T1,N3	0.0078	0.088	0.0214	0.0244	99.9927	99.9970	7.8134	7.7373
4	T2,N1	0.0092	0.0095	0.0604	0.0401	99.9936	99.9953	18.2541	17.9951
5	T2,N2	0.0073	0.0079	0.0162	0.0182	99.9819	99.9810	4.9183	4.9377
6	T2,N3	0.0072	0.0087	0.0238	0.0246	99.9876	99.9915	7.8839	7.7937
7	T3,N1	0.0093	0.01	0.0382	0.0389	99.9831	99.9983	17.1042	17.155
8	T3,N2	0.0067	0.0079	0.0195	0.0181	99.957	99.9799	4.9249	4.9002
9	T3,N3	0.0082	0.0088	0.0245	0.0239	99.9935	99.9862	7.6482	7.5020

6. Conclusions

In this paper a new robust design based on IWO algorithm is proposed to control the hydro-turbine governor to improve the system performance. The simulation results showed that the proposed technique can be extended as a mechanism to be used in the varying system dynamics. The main purpose of the analyzed performance index is to design a robust and optimal controller. The robustness design for the system is applied by assigning the system operation point varies which is shown in system parameters indefinitely. In this study, after modeling the hydro turbine system and analyzing the system performance in the control system during disturbance occurs, the controllers rule is assigned in the system stabilization. The final results are achieved by a comparison in between ABC based PID controller as a new introduced algorithm and the proposed technique. This comparison illustrated that the considered approach can develop the dynamic performance of the system in a better way. Final results showed the high efficiency of the proposed system for the hydro turbine system control.

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_Z: 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_D : Time constant in regulation feedback circuit (4Sec).
R : Governor steady-state regulation (4%).
B : Base changer.
T_S : Mechanical start time of equivalent system.
D_S : Equivalent system damping factor (1).
T_G : Time constant of equivalent system (10Sec).
R_G : Equivalent system regulation (4%).
T_N : Time constant of speed filter (0.06Sec).

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