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A Novel Jaya Based Automatic Generation Control of Two Area Interconnected Power System with nonlinearity

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Abstract

Background: This paper presents a novel approach to design and optimize Proportional-Integral-Derivative (PID) controller for Automatic Generation Control (AGC) of two-area interconnected power system with different energy sources. **Methods**: The two area interconnected power system consists of thermal, hydro and wind energy sources in the area-1 and area-2 comprises thermal, hydro and diesel energy sources. The recently developed Jaya Optimization technique is explored to optimize PID controller parameters for the interconnected power system by Matlab. **Findings**: The dynamic responses of power system is studied including the non-linearities like Governor Dead band (GDB), Generation Rate Constraint (GRC) and boiler dynamics under 1% step load perturbation. **Novelty and applications** The beauty of Jaya algorithm is that it works with only few control parameters as compared with other algorithms which help in improving dynamic responses and performance values of power system with non-linearities. Hence, the frequency stability is achieved at faster convergence at loads. The comparative analysis of proposed technique with other techniques like Differential Evolution (DE) algorithm and Teaching Learning Based Optimization (TLBO) algorithm for the same power system justify the effectiveness of proposed approach.

Keywords: Automatic Generation Control; PID Controller; Nonlinearities; Renewable Sources; Jaya Algorithm

1 Introduction

With expansion of power system, researchers are utilizing the concept of interconnected tie-line power system with more than one area[(1–5)]. Over a few years, artificial intelligence creates interest and help in solving various practical problems of power system. Elephant herding optimization tuned parameters has been investigated in interconeceted thermal power system[(6)]. Bacterial Foraging Algorithm (BFA) tuned parameters has been designed for AGC and modeling of power system with thermal, hydro and gas energy sources[(7)]. Further, the different participation of various sources with Jaya optimization algorithm has been explored in power system[(8)]. With the increase in growth of renewable energy, existing power system is interconnected with various combination of renewable energy. Particle Swam Optimization (PSO) and Iteration Particle Swam Optimization (IPSO) techniques has been used for AGC of thermal-hydro-wind and thermal-hydro-diesel interconnected power system[9]. Invasive weed optimization parameters has been considered for multi area power system[10]. Firefly algorithm (FA) tuned PI controller has been presented for PV grid and thermal two area interconnected power system[11]. A new concept of tilt derivative and integral gains with improved chaos game optimization for power system has been linked with renewable sources[12]. Improved frequency deviation tolerance concept has been proposed for wind integrated AGC with non-linearity[13]. Generally, practical power system works with non-linearity. Nowadays, researchers explore latest emerging artificial techniques to design controllers for practical system with non-linearity. Power system including non-linearities with thermal-hydro-nuclear and thermal-hydro-gas has been studied[14]. Multi source power system has been recced with fuzzy controller for three control area[15]. Along with PSO technique, Different energy sources like battery energy source improves the stability of system[16] The effect of participation factor of various sources in power system has been considered[17,18]. Fractional order PID controller has been studied[19,20]. Two degree freedom for renewable sources has been applied in interconnected power system[21]. In spite of ongoing development of optimization techniques challenge still lies in its application to power system with diverse sources. Most of these optimization methods are complex and require large number of variables but Jaya designed has proved to better than other algorithms[22]. Converging the sturdy searching and quick moving ability with a smaller number of variables consideration is the beauty of this algorithm[23,24].

Literature shows that less work has been carried out for renewable integrated power system including non-linearity with the application of novel jaya technique. In the present paper, a novel technique is applied to design and optimize PID controller for AGC of interconnected power system having different energy sources with nonlinearity. First area has reheat-thermal, hydro and wind sources and second area has reheat-thermal, hydro and diesel sources. PID controller is designed by recently developed Jaya Optimization technique. The dynamic performance of power system including nonlinearities like GDB, GRC and boiler dynamics is studied. Hence, the novelty of the proposed jaya technique is done by doing comparative analysis with DE and TLBO.

2 Methodology

Various energy sources namely wind, thermal, hydro and diesel sources are considered in two area interconnected power systems. Nonlinearities like boiler dynamics, GDB and GRC and participation factors are incorporated in the power system to make it more realistic. Power systems consist of thermal, hydro and wind sources as first area, and thermal, hydro and diesel sources as second area. A novel algorithm called Jaya algorithm is proposed to design PID controller for AGC of two area interconnected power systems including and excluding nonlinearities. To make the system realistic, nonlinearities and participation factors of each source are included. Nonlinearities namely boiler dynamics in thermal source, GRC in thermal and hydro sources, GDB in thermal and hydro sources are incorporated in power system as presented in Figure 1. Turbine and boiler control act once after observing deviations in steam flow and pressure[13]. Speed GDB in other words as total magnitude of speed change while there is no change in valve position. GDB nonlinearity for two seconds oscillations occurs due to backlash non-linearity. Value of Backlash non-linearity as 0.02% (hydro sources) and 0.05% (thermal sources) is taken into account in the present work. GRC is defined as specified maximum rate for changed power generation. For thermal units, a GRC for 3% per minute is considered in the present study. Modeling for power system with nonlinearities is given in[25]. Value of part (0.575) and parh (0.3) are supposed as the participation factor for reheat thermal and hydro sources. Participation factor of parw (0.125) is supposed for both wind and diesel sources. Appendix A describes other parameter values of power system.

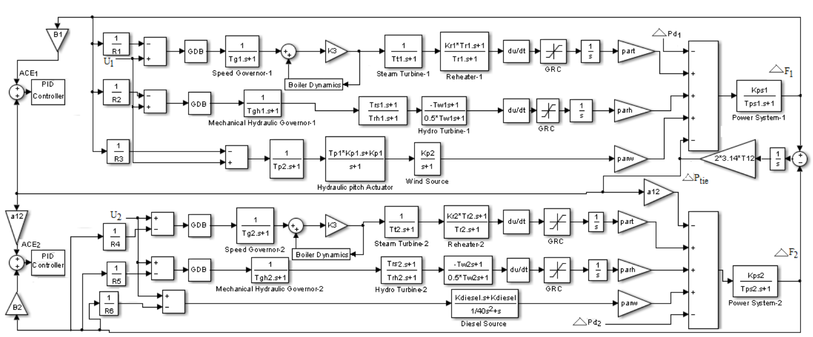

Fig 1. Two Area Interconnected Power System Including Nonlinearities

PID controller with AGC is a popular and well accepted controller in literature[20]. It helps in attaining faster response and stability for interconnected power system. Controlling the minimum incremental change in frequency and tie-line deviation of the considered power system models at 1% step load perturbation is the target set by the system. This can be achieved by tuning PID controllers which reduces the values of performance parameters with respect to settling time (ST), peak and performance index. Jaya, DE, TLBO and IPSO algorithm help in the attainment of the result and using these values, the power system is tested. When compared Jaya algorithm with the other optimization techniques on the basis of the result, is proved to be better among them. Amongst various performance criteria applied in AGC studies, integral of time multiplied of absolute error (ITAE) proves to be better in performance[16], ITAE defined via. Equation no. 1 is used as the performance index to tune PID controller.

$$\text{ITAE} = \int_0^T \left(|\Delta f_1| + |\Delta f_2| + |\Delta P_{12}|\right) \cdot t\,dt \quad (1)$$

Where Δf_1 and Δf_2 is frequency deviation of area-1 and area-2, ΔP_{12} is tie line power deviation, T is simulation time range.

Equation for control input for i^{th} area is defined via. Equation no. 2.

$$U_i = K_{Pi} ACE_i + K_{Ii} \int ACE_i\,dt + K_{Di} \frac{dACE_i}{dt} \quad (2)$$

Where ACE_i is the area control error. U_i is the control input for i^{th} area. Proportional (K_{Pi}), Integral (K_{Ii}) and Derivative (K_{Di}) are the PID controller parameter for i^{th} area, $\triangle P_{di}$ is taken as load disturbance at i^{th} area..

PID controller for power system including nonlinearities is tuned by Jaya techniques by considering Equation no. 1 as performance index.

Rao developed Jaya algorithm[22] which is sturdy and fits well to give solution. This algorithm is named Jaya as it strives for reaching the best solution. This is a specific algorithm with less parameter whereas other algorithm demands specific control parameters.

The gains of PID controllers for two power system model are optimized using Jaya algorithm. Jaya begins with an initial population and maximum number of iteration just like any other algorithm. In Jaya algorithm, failure is tried to be avoided so that success can be obtained. After considering the objective function given in Eqn. no.1, population is updated as $X'_{k,p,i}$ by using following equation:-

$$X_{k,p,i} + r_{1k,i}\left(X_{k,best,i} - \left(X_{k,p,i}\right|\right) - r_{2k,i}(X_{k,worst,i} - \left(X_{k,p,i}\right|) \quad (3)$$

Where $X_{k,p,i}$ is k^{th} variable value for p^{th} population at i^{th} iteration, $r_{1k,i}$ and $r_{2k,i}$ are random variables.

This procedure is repeated till the last iteration and designing of PID controller is accomplished with parameter values of PID controller. For novel Jaya tuned PID controller, parameters (k = 6), and population (p = 25) are considered. Controller provides six parameters each for two area power system including or excluding nonlinearities as given in Table 1.

Table 1. Parameters for power system with nonlinearities

PID Controller		Power system model
	K_{P1}	5
area - 1	K_{I1}	5
	K_{D1}	4
	K_{P2}	3.6
area - 2	K_{I2}	3.7
	K_{D2}	5

3 Results and Discussion

Two-Area interconnected power systems basically composed of four different sources namely reheat thermal, hydro, wind and diesel sources. Six parameters of PID controllers for power system including nonlinearities are shown in Table 1. Using these values, the power system model are tested and further compared with DE, IPSO, BFA and TLBO algorithm. For power system with nonlinearities, the comparative performance values and percentage improvement with implementation of various AI techniques is demonstrated in Table 2. PIV for Jaya-PID (0.06) is comparatively 95% better than DE-PID (1.32), 92.84% than TLBO-PID (0.92) and 85.47% than TLBO-PIDD (0.45) and hence proves that the proposed technique of Jaya Algorithm is far better than the other optimization techniques used. Also, there is vast percentage improvement in settling time for Jaya in comparison of DE-PID as 67.68%, TLBO-PID as 65.09% and TLBO-PIDD as 60.59%. So, novel Jaya Algorithm is used as the choice for power system including nonlinearities. Dynamic responses of power system with load at different area is depicted in Figure 2 and Figure 3 respectively. It is apparent that the proposed approach of Jaya based PID controller shows substantial improvement in frequency and tie line deviation as compared to other TLBO based PIDD and DE based PID approach as shown in Figure 2.

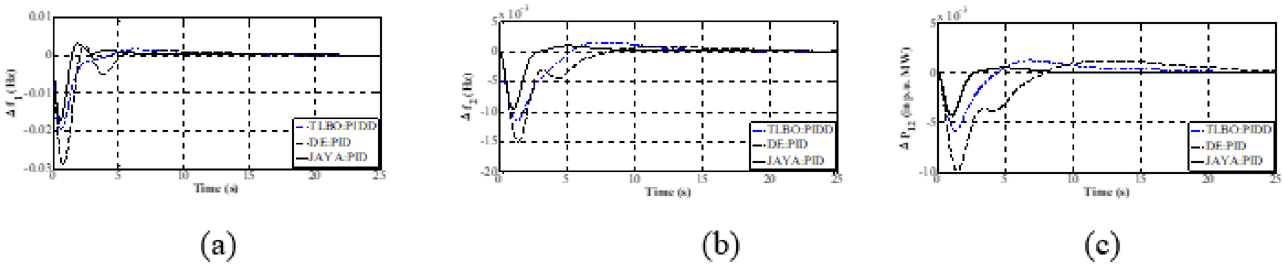

Fig 2. Dynamic response of power system with nonlinearities at 1% step load perturbation in area-1 a) $\triangle f_1 Vs\ Time$b) $\triangle f_2 Vs\ Time$ c) $\triangle P_{12} Vs\ Time$

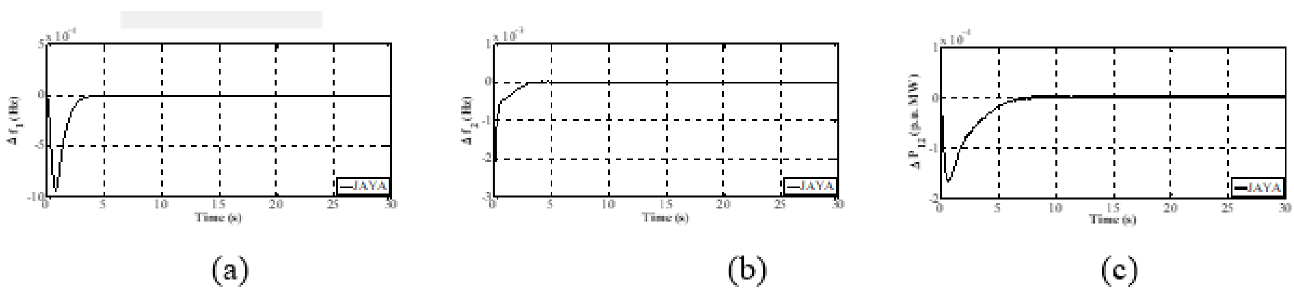

Fig 3. Dynamic response of power system with nonlinearities at 1% step load perturbation in area-2 a) $\triangle f_1 Vs\ Time$ b) $\triangle f_2 Vs\ Time$ c) $\triangle P_{12} Vs\ Time$

Table 2. Comparative performance value and Percentage improvement of power system including nonlinearities

	ST				% Improvement in terms of ST			
Techniques	$\triangle f_1$	Δf_2	ΔP_{12}	**ITAE**	$\triangle f_1$	Δf_2	ΔP_{12}	**ITAE**
DE (PID) (25)	19.68	21.93	25.89	1.32	67.68	47.33	63.07	95
TLBO (PID) (25)	18.22	18.88	16.28	0.92	65.09	38.82	41.27	92.84
TLBO (PIDD) (25)	16.14	16.79	12.77	0.45	60.59	31.20	25.13	85.47
JAYA (PID)	6.36	11.55	9.56	0.06				

Performance parameter values in terms of settling time (ST), peak undershoot (PU) and performance index of system are shown in Table 3. It shows reduced deviation in terms of ST, PU and PIV when applied load in area-2 as compared to area-1. By comparative analysis, it has been notice that reduced PIV is received for both the power system model under load in area-2 (thermal-hydro-wind) as compared to area-1 (thermal-hydro-diesel). It shows that the dynamic responses of power system with nonlinearities gets more PU and ST values when the load is considered in the area which has wind source as one of the multi-source.

Table 3. Performance Parameters values of power system including nonlinearities

ST (s)						**PU × (-)0.01 (Hz)**						**PIV × 0.01**	
area-1			**area-2**			**area-1**			**area-2**			**area-1**	**area-2**
$\triangle f_1$	Δf_2	ΔP_{12}	$\triangle f_1$	Δf_2	ΔP_{12}	$\triangle f_1$	Δf_2	ΔP_{12}	$\triangle f_1$	Δf_2	ΔP_{12}	**ITAE**	**ITAE**
6.36	11.55	9.56	3.55	2.83	6.23	1.74	0.95	0.43	0.09	0.22	0.02	6.6	0.18

4 Conclusion

In this paper, an attempt is made to propose novel technique to optimize and design controller for AGC of interconnected power system by considering nonlinearities. Diverse sources consist of reheat-thermal, hydro, diesel and wind sources. Nonlinearities namely GRC in thermal and hydro sources, GDB in thermal and hydro sources and boiler dynamics in thermal source are incorporated in power system. Dynamic responses of power system with load at different area is considered. The dominance of present approach is established by comparing the dynamic responses and performance parameter value with recently published approach (DE, TLBO) applied for the same system. Significant improvement in percentage illustrates the efficacy of present approach. It is seen that the dynamic responses gives more PU, ST and PIV values when the load is considered in the area-1 (thermal-hydro-wind) which has wind source as one of the multi-source as compared to other area-2 (thermal-hydro-diesel). Hence, the novelty of the proposed technique is legitimized.

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