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Frequency Deviation Improvement of a Hybrid Micro-Grid System Containing Wind Turbine and Controllable Load Using Fractional Order PID

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ABSTRACT

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FREQUENCY DEVIATION IMPROVEMENT OF A HYBRID MICRO-GRID SYSTEM CONTAINING WIND TURBINE AND CONTROLLABLE LOAD USING FRACTIONAL ORDER PID

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Abstract

The main goal which has been followed in this paper is to design an optimal fractional order PID (FOPID) controller that can sufficiently stabilize frequency in an isolated wind-diesel power system containing controllable load. In order to optimize parameters of the FOPID controller, an optimization problem has been implemented and solved using Jaya algorithm (JA). So, for proving the performance of applied method for damping frequency deviation in the wind-diesel system containing controllable load, the obtained results have been also compared to PID controller. The robustness of the proposed controller has been evaluated via ITAE and sensitivity analysis, which provides reasonable solutions.

Keywords: Wind-Diesel System, Jaya Algorithm (JA), FOPID Controller.

1. Introduction

One of the most demanding forms of energy, especially nowadays, is electricity which plays an important role in our daily life. Still, there are people that have not access to the grid or they are placed in either isolated or remote communities, where grid connectivity is not possible or even makes the environmental problems. For this category of people, electricity is supplied mainly by small diesel-based power generation that it has harmful effects on the environment, too [1]. So, renewable energy sources can be a good candidate for reducing the dependency of the power generation systems to the fuel and subsequently reduce the adverse effects of such systems on the environment. However, continuity of renewable energy sources is mostly unpredictable, so they may not supply desired power constantly. By combining renewable energy sources with non-renewable or storage devices, this problem can be easily addressed [2-5]. The fact that in a period of time, wind speed and load demand are not constant, bring an inequality between the power generation and load demand which subsequently

results in variation of the system frequency (f) and power (P) values.

Traditional controllers cannot ensure to control the system frequency in the presence of renewable energy sources [6] because it is not optimal for the whole set of operating conditions and configurations. Moreover, generating rate and capacity constraints in the load frequency control units are not easy to be considered in the controller design. Consequently, for an isolated Micro-Grid, it is necessary to have a robust controller over a wide range of system operating conditions [7]. The role of LFC is to maintain the power balance in the system such that the frequency deviation stays within a specified bound around its nominal value [6]. Because of taking minimum additional equipment, maintenance and etc. this control strategy may be highly cost saving and efficient.

As mentioned in the literature, different methods have been proposed by researchers in order to control the frequency instability in hybrid power system generations. Control of pitch and governor which is related to wind side and

diesel side, respectively, are main points which are involved in designation of the controllers. As mentioned before, there are many control strategies have been proposed in the literature. References [8-9] investigate optimization of the controller parameters. Also, in [10-11] PI controller, in [12-14] controller with variable structure and in [15-16] energy storage controller are mentioned. According to its simplicity in understanding the structure and its applicability for a large cluster of process which involve different dynamics, the proportional-integral-derivative (PID) controller has a widespread application and acceptance in the industrial process [17-18].

In contrast, new types of controllers may operate better in real-world, i.e. industrial applications. Thus, in this paper three FOPID controllers designed separately, one of them for diesel side, next one for pitch control of wind side and the last one is for controllable load (water-heater). It is shown that the appropriate selection of controller parameters results in satisfactory performance during system disturbances. So, for obtaining the favorable robustness, it's essential to optimize the FOPID gains. Also, optimal setting of FOPID controller gains is a multi-modal optimization problem (i.e., there is more than one local optimum) and more complex due to nonlinearity, complexity, and time-variability of the real world power system operations. Hence, local optimization techniques, which are well elaborated upon, are not suitable for such a problem. For this reason, in this paper, a simple and powerful optimization algorithm, called Jaya Algorithm (JA) is proposed for optimal tuning of the FOPID controller gains to stabilize system frequency response due to four different cases. JA has the ability to solve whether constrained or unconstrained optimization problems. The fundamental concept of the algorithm is that the solution obtained for a problem should move towards the best solution and

should avoid the worst solution. This does not need any algorithm-specific control parameters except common control parameters [19].

2. System Modeling

Figure 1 shows the configuration of the isolated hybrid wind-diesel power system.

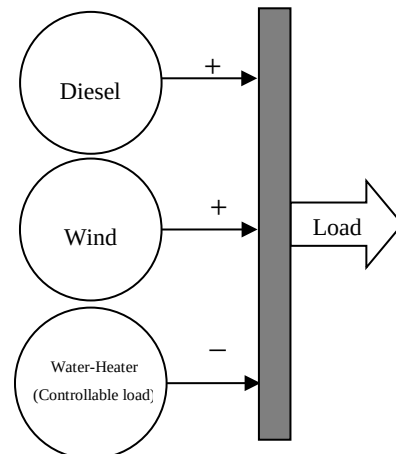


Figure 1. A simple scheme of the proposed micro-grid

Also, transfer function model of this system is shown in Figure 2 and its parameters are given in [11]. Various types of controllable loads are washing machines, air conditioners, water heating and vehicle-to-grid to name a few. Here, we have consider water-heater as a controllable load.

3. Proposed Controllers

Below are different controllers which have been used in this investigation are discussed.

3.1. PID

Below you can see the transfer function of the well-known PID controller.

$$U(s) = \left[k_p + \frac{K_i}{s} + K_d s \right] \Delta \omega(s) \quad (1)$$

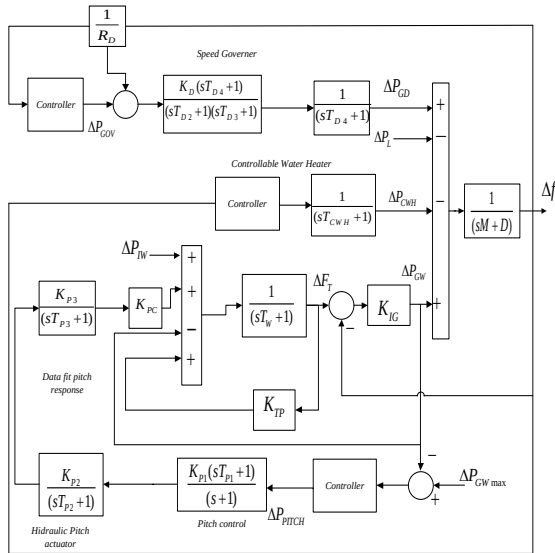


Figure 2. Block diagram of hybrid system containing controllable load

3.2. FOPID

To improve the robustness and performance of PID control systems, Podlubny proposed an extension to the PID controllers, which can be called $PI^\lambda D^\mu$ (FOPID) controller because of involving a differentiator of order μ and integrator of order λ . Many applications have been provided for this controller and detailed information about it is presented in the literature [20]. The commonly used concept for the fractional differ integral is the Riemann–Liouville (RL) definition. The transfer function of FOPID can be written as follows:

$$G(s) = [k_p + K_i s^{-\lambda} + K_d s^\mu] \quad (2)$$

In this work, a comparison between PID and $PI^\lambda D^\mu$ controller is considered in order to see which one can prove greater damping of isolated power system. The transfer function of the FOPID to modulate the excitation voltage is given by:

$$U(s) = [k_p + K_i s^{-\lambda} + K_d s^\mu] \Delta\omega(s) \quad (3)$$

In the following, you can see Simulink implementation of FOPID, in which coefficient “a₁” and “b₁” represent “λ” and “μ”, respectively.

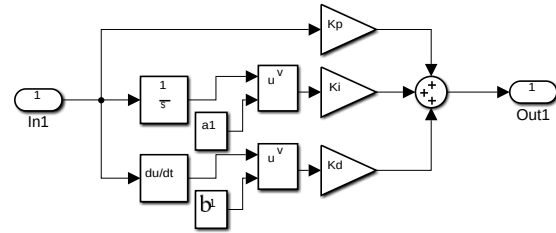


Figure 3. Simulink implementation of the FOPID controller

4. Jaya Algorithm (JA)

Regarding to the success of the TLBO algorithm, another algorithm-specific parameter-less algorithm is proposed in this paper [14]. As we remember from TLBO algorithm, there are two phases, one is teacher phase and the other is learner phase. But Jaya algorithm has only one phase and it is very easy to use, whether the problem is constrained or unconstrained.

Imagine $f(x)$ as the objective function to be minimized, which here we have used ITAE error criteria. At any iteration i , ‘ m ’ indicates the number of the design variables (i.e. $j=1, 2, \dots, m$) and ‘ n ’ indicates the number of the candidate solutions (i.e. population size, $k=1, 2, \dots, n$). Amongst the entire candidate solutions, best candidate best obtains the best value of $f(x)$ (i.e. $f(x)_{\text{best}}$) and the worst candidate worst obtains the worst value of $f(x)$ (i.e. $f(x)_{\text{worst}}$).

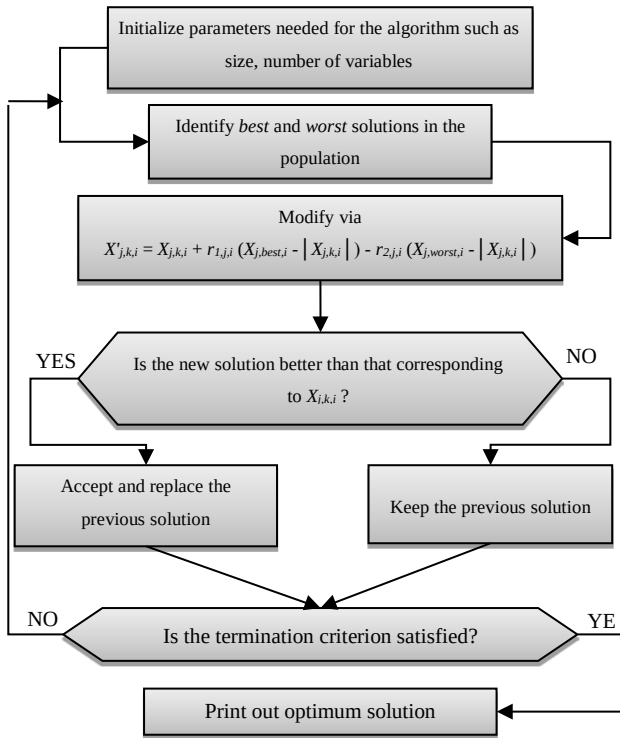


Figure 4. Flowchart of the proposed algorithm

If $X_{j,k,i}$ is the value of the j th variable for the k th candidate during the i th iteration, then the modification of its value will be done by Equation (1).

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} (X_{j,worst,i} - |X_{j,k,i}|) \quad (4)$$

where, $X_{j,best,i}$ and $X_{j,worst,i}$ shows the value of the variable j for the best and worst candidate respectively. $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$ while $r_{1,j,i}$ and $r_{2,j,i}$ are the two random numbers for the j th variable during the i th iteration in the range $[0, 1]$. The term “ $r_{1,j,i} (X_{j,best,i} - |X_{j,k,i}|)$ ” indicates the willing of the solution to move closer to the best solution and the term “ $-r_{2,j,i} (X_{j,worst,i} - |X_{j,k,i}|)$ ” indicates the willing of the solution to avoid the worst solution. $X'_{j,k,i}$ is accepted if it gives better function value. All the accepted function values at the end of iteration are maintained and these values become the input to the next iteration. The flowchart of the proposed algorithm can be seen in Figure 3. The main idea behind the name of Jaya algorithm is the fact that, the algorithm has the willing get closer to

success (i.e. obtaining the best solution) and tries to move away from failure (i.e. avoiding the worst solution). Reaching the best solution somehow considered as achieving victory and hence it is named as Jaya (a Sanskrit word meaning victory).research method section covers elaborations about the conceptual framework, research design, utilized method, analytic approaches and validation phases.

5. Problem Formulation

There are four kinds of performance criteria, generally considered in the control design, IAE, ITAE, ISE, and ITSE. However, ITAE and ISE criteria are mostly used in LFC studies for their better performance as compared to ISTE and IAE criterion. So, we just have selected ITAE for further investigations due to its quick setting feature.

$$J = \int_0^{t_s} t \times |\Delta F| dt \quad (5)$$

Where, t_s is total simulation time and ΔF is the variations in system frequency.

In the optimization process, it is tended to minimize J in order to damp frequency oscillations. The design problem can be formulated as the following constrained optimization problem, where the constraints are the limits of the gains of the controllers[21].

Minimize J Subject to:

$$\begin{aligned} 0 &\leq K_p, K_i, K_d \leq 15 \\ 0.5 &\leq \mu, \lambda \leq 1 \end{aligned} \quad (10)$$

Results of the controller parameters based on the objective function J , solved using the proposed Jaya algorithm, are given in Table 1. Figure 5 shows the minimum fitness functions evaluating process.

6. Analysis & Results

In order to expose the effectiveness of the proposed controller, the power system under study is faced to different disturbances based on wind speed and load

demand. There are four case of simulations are considered in this section.

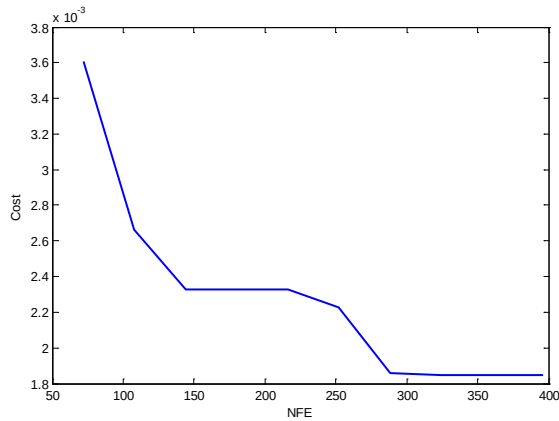


Figure 5. Fitness Convergence of FOPID using Jaya algorithm

Table 1. The optimum controller parameters obtained using jaya algorithm

Coefficient	FOPID			PID		
K_p	10.64	0	8.73	1.04	15	0.89
K_i	15	4.19	15	0	15	0.25
K_d	4.51	0	6.01	0.07	0.44	15
μ	0.5	0.94	0.94			
λ	0.82	0.66	0.87			

Case 1. Step change in both load demand and wind speed

In this case, it is assumed that in $t = 1$ sec, a step change ($\Delta P_L = 0.01$ pu, $\Delta P_{IW} = 0.01$ pu) occurred in both load demand and wind speed. Figure 6 shows the frequency response of the system with JA-FOPID and JA-PID.

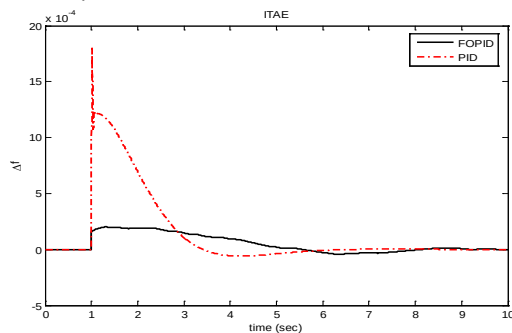


Figure 6. Frequency deviation against a step change in load and wind speed considering ITAE criterion

Case 2. Step change just in load demand

In this case of the simulations it's assumed that in $t = 1$ sec, a step change ($\Delta P_L = 0.01$ pu) occurred just in load demand. Figure 7

show the frequency response of the system with JA-FOPID and JA-PID controllers.

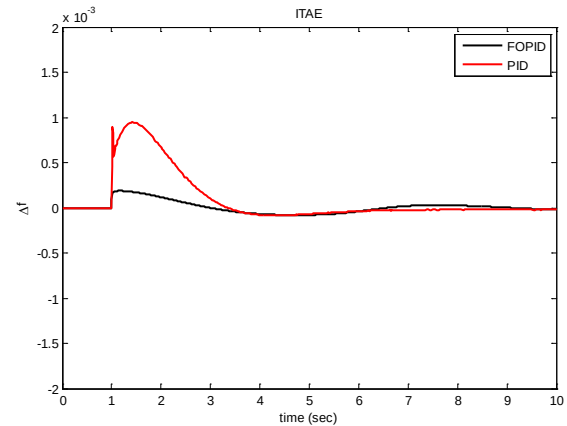


Figure 7. Frequency response for load change (ITAE)

Case 3. Step change just in wind speed

In this case, that in $t = 1$ sec, a step change ($\Delta P_{IW} = 0.01$ pu) occurred just in wind speed. Figure 8 shows that the control effect of the JA-FOPID controller on the system frequency deviation is superior to that of the JA-PID.

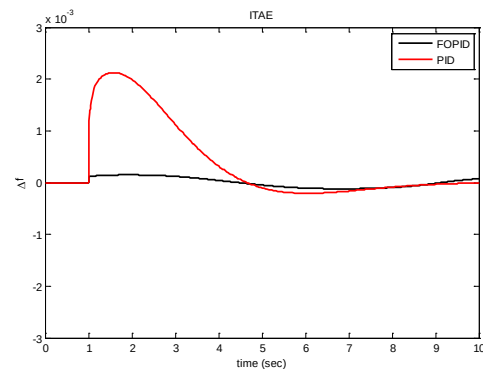


Figure 8. Frequency response for wind speed change (ITAE)

Case 4. Sensitivity analysis

In order to analyse the robustness of the controller, random load change (shown in figure 9) and random wind speed (shown in figure 10) are applied to the system.

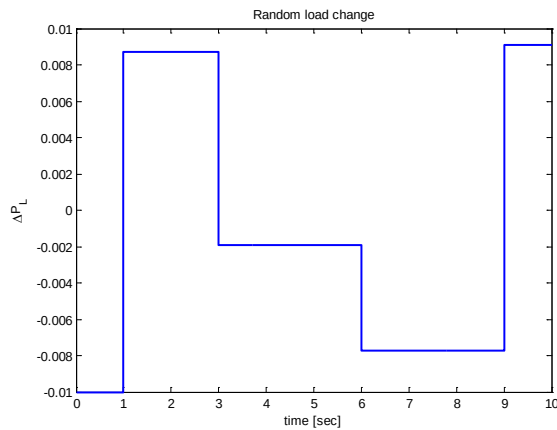


Figure 9. Random change in load demand

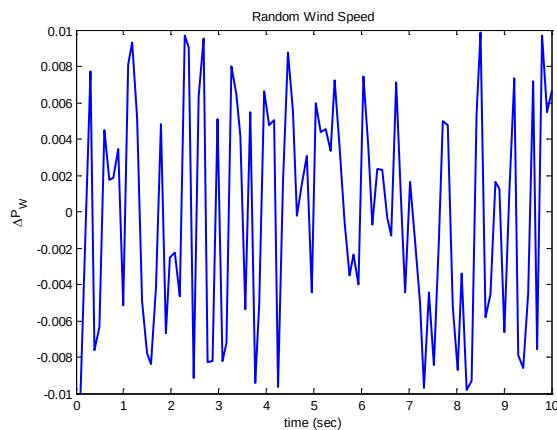


Figure 10. Random change in wind speed

Considering the obtained results, presented in figures 11 and 12, it's obviously clear, that the proposed method works well and proves the simulation results obtained in the previous cases.

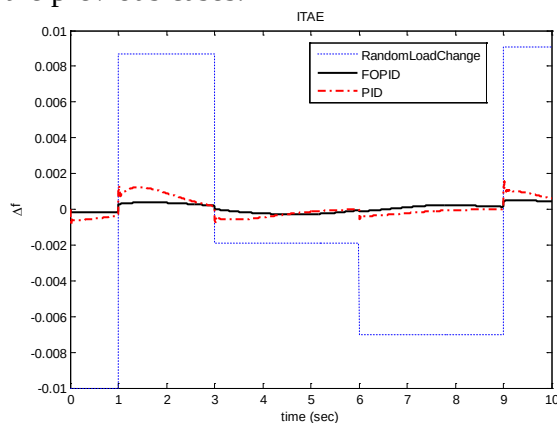


Figure 11. System frequency response under random change in load demand

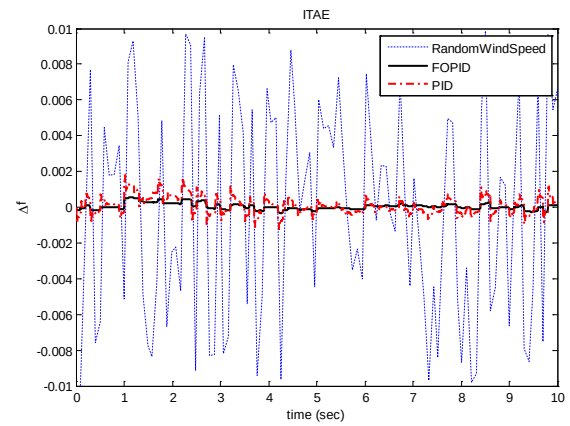


Figure 12. System frequency response under random change in wind speed

By a simple review of what we have shown in the above figures, its clearly obvious that are presented method can efficiently lower the frequency deviation for the applied micro-grid.

7. Discussion & Conclusion

In this paper, optimal FOPID controller design for the frequency control of a wind-diesel hybrid system containing controllable load is formulated as an optimization problem and solved using Jaya Algorithm (JA). The results of the proposed controller are compared with PID controller. In order to prove the performance of proposed method, simulations carried out in four cases. First step change in both load demand and wind speed. Then a step change just in load demand. Next, a step change just in wind speed. And finally, we considered a random change in the wind speed and a random change in the load demand, regarding sensitivity analysis of the system. Simulation results show that the JA-based FOPID controller (JA-FOPID) has better performance compared with JA-based PID (JA-PID) controller from the perspective of the response to change (whether step or random change) in load demand and wind speed. Also, ITAE performance index defined for JA-FOPID and JA-PID controllers, which proves that the proposed JA-FOPID controller is very effective and robust compared to JA-PID.

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