Chapter

Adaptive Load Frequency Control in Power Systems Using Optimization Techniques

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Abstract

At present, simple and classical tuned controllers are widely used in the power system load frequency control (LFC) application. Existing LFC system parameters are usually tuned based on experiences, classical methods, and trial and error approaches, and they are incapable of providing good dynamic performance over a wide range of operating conditions and various load scenarios. Therefore, the novel modeling and control approaches are strongly required, to obtain a new trade-off between efficiency and robustness. Thus, the proposed techniques in this chapter are referred to be an adaptive control technique based on new optimization methods such as Jaya, Practical Swarm Optimization Algorithm, etc., which are used to make an on-line tuning of the LFC parameters in order to face the previous challenges in LFC. The system under study is a small microgrid with a renewable energy source and variable demand load. Digital simulation results are discussed.

Keywords: load frequency control, power system, microgrid, adaptive control, optimization method

1. Introduction

A general power system is a complex electrical network that consists of generation networks, transmission networks, and distribution networks in addition to loads that are being distributed throughout the network over a large geographical area [1, 2]. In the power system, well-designed controllers are requested during the system variations to maintain the stability of the power system as well as guarantee its reliable operation.

The growth of the industries leads to increase the complexity of the power system. System frequency depends mainly on the active power, while system voltage depends on the reactive power. So, the control viewpoint of power systems can be classified into two independent issues. One is focusing on the control of the active power along with the frequency what is called load frequency control (LFC), while the other one is to deal with the reactive power along with the voltage regulation [3].

Load frequency control of an interconnected power system means the interconnection of more than one control area through tie lines. Sudden load variation in any control area of an interconnected power system will lead to both frequency change and tie line power deviation. Large frequency fluctuations may cause sometimes what is called system blackout [4].

The main objectives of load frequency control (LFC) are [5, 6] as follows: 1—regulating frequency and tracking the load demands. 2—Ensuring zero steady-state error for frequency deviations. 3—Maintaining frequency and power interchanges with neighboring control areas at the specified values. 4—Controlling the change in tie line power between control areas. 5—Maintaining acceptable overshoot and settling time on the frequency and tie line power deviations.

1.1 Reasons for limiting frequency deviations

Frequency deviations should be within restricted limits for some reasons [7]:

i. To keep the three phase AC machines, in which its running speed relates proportionally to the supply frequency.

ii. To keep the turbine's blades that are designed to operate at a particular speed, but the change of supply frequency will cause variation in this speed. This speed change may cause damage of the turbine blades.

iii. When frequency goes below rated frequency at the case of constant system voltage, then the flux in the core increases, and then the transformer core goes into the saturation region.

iv. The frequency error may affect negatively on the digital storage and retrieval process.

1.2 Load frequency control (LFC) problems

If it's not required to maintain the frequency constant, then the system frequency and speed change with the characteristics of the governor as the load changes, and the operator is not required to change the setting of the generator. On the other hand, if constant frequency is required, the operator can adjust the velocity of the turbine by changing the characteristics of the governor.

Most published research in this field neglects uncertainties [8] and practical constraints [9] and furthermore, suggest complex control structures with impractical frameworks, which may have some difficulties when implementing in real-time applications [10].

As a result of considerable degree of interconnection, the presence of technical and economic constraints, and the traditional requirements of system reliability and security, operating the power system in the new environment will certainly be more complex than in the past. At present, simple and classical tuned controllers are widely used in the power system LFC task. Existing LFC system parameters are usually tuned based on experiences, classical methods, and trial and error approaches, and they are incapable of providing good dynamical performance over a wide range of operating conditions and various load scenarios. Therefore, the novel modeling and control approaches are strongly required, to obtain a new trade-off between efficiency and robustness.

Thus, this chapter presents an adaptive control technique that uses new optimization methods to make an on-line tuning of the LFC parameters to deal with both load demand changes and fluctuations resulted from renewable energy sources.

2. System under study

Recently, remote off-grid MGs have been widely developed especially for rural and distant areas, in which providing electrical energy from the main utility grid is costly and has destructive environmental effects. There are many real MGs installed for providing the electrical energy for distant areas [11–14].

Low inertia and dynamic complexity are the most important challenges in the MGs. Therefore, if a mismatch between the load and power generation occurs, the MG frequency deviation is inevitable. Therefore, it seems that the robust control design strategies can be considered as powerful solutions to achieve robust performance and stability [15–16]. Several optimization techniques have been proposed by researchers to tune the control parameters using simulation of the entire system and to damp the frequency fluctuation [17] such as optimization of controller parameters [18–19].

The system used in this chapter is a microgrid power system shown in **Figure 1** consisting of a 20 MW diesel generator and 17 MW load. The nominal parameters of the system are listed in **Table 1**. The simulation results have two scenarios.

The dynamic model of the proposed microgrid power system can be described in the following equations [5]:

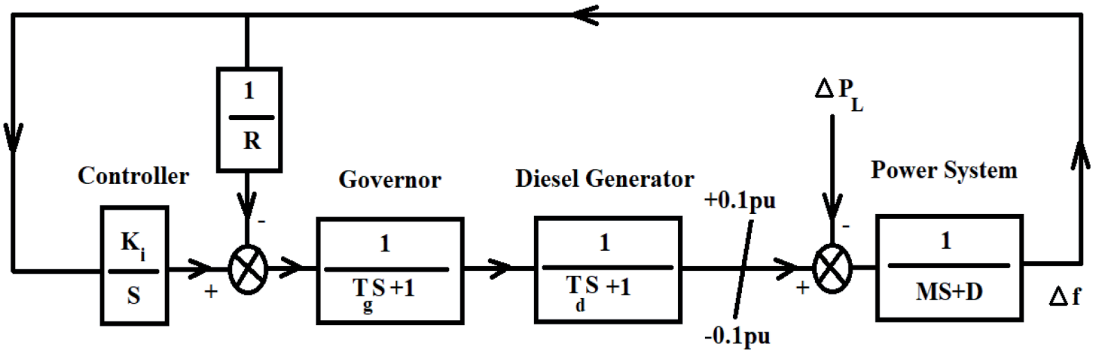

Figure 1.
Block diagram of the system under study.

K_i	D (pu/Hz)	M (pu.sec)	R (Hz/pu)	T_g (sec)	T_d (sec)
−0.3	0.015	0.08335	3	0.08	0.4

Table 1.
Data of the microgrid power system [5].

$$\Delta\dot{f} = \left(\frac{1}{M}\right).\Delta P_d - \left(\frac{1}{M}\right).\Delta P_L - \left(\frac{D}{M}\right).\Delta f \quad (1)$$

$$\Delta\dot{P}_d = \left(\frac{1}{T_t}\right).\Delta P_g - \left(\frac{1}{T_t}\right).\Delta P_d \quad (2)$$

$$\Delta\dot{P}_g = \left(\frac{1}{T_g}\right).\Delta P_c - \left(\frac{1}{R.T_g}\right).\Delta f - \left(\frac{1}{T_g}\right).\Delta P_g \quad (3)$$

and ($\Delta\dot{f}$, $\Delta\dot{P}_d$, $\Delta\dot{P}_g$) equal to $\left(\frac{df}{dt}, \frac{dP_d}{dt}, \frac{dP_g}{dt}\right)$, respectively.

3. Optimization techniques

3.1 Particle swarm optimization (PSO)

PSO is one of the famous optimization techniques. It has been derived from the social-psychological theory. PSO has some features such as:

PSO is basically developed through simulation of the bird flocking in two-dimensional space. The position of each particle is represented by XY axis position, and the velocity is represented by Vx and Vy. The position and velocity information will guide the modification of the particle position. Bird flocking optimizes a certain objective function. Each particle knows both of its XY position and its best value (P_{best}). Each particle knows the best value so far in the group (g_{best}) among (P_{best}).

This information is analogy of knowledge of how the other particles around them have performed. Namely, each particle tries to modify its position using the following information [20–22]:

- The distance between the current position and P_{best} and the distance between the current position and g_{best}.
- The current positions (x, y) and the current velocities (Vx, Vy).

Velocity of each particle can be modified by the following equation:

$$V_i^{k+1} = wV_i^k + c_1 * rand_1 \left(P_{best,i}^k - s_i^k\right) - c_2 * rand_2 \left(g_{best,i}^k - S_i^k\right) \tag{4}$$

where

S_i^k	current position of particle i at iteration k
V_i^k	velocity of particle i at iteration k
$p_{best,i}^k$	personal best of ith particle at iteration k
$g_{best,i}^k$	global best of ith particle at iteration k.
c1, c2	social parameters
w	the inertia weight used to accelerate the obtaining of the global best solution in the search space.
rand1, rand2	positive random numbers drawn form a uniform distribution between [0,1].

The inertia weighting function is utilized as follows:

$$w = \frac{w_{\max} - w_{\min}}{iter_{\max}} \times Iter \tag{5}$$

where:

$w_{\max}$	Initial velocity
$w_{\min}$	Final velocity
$iter_{\max}$	Maximum iteration number

Using Eq. (4) and Eq. (5), a certain velocity (which gradually gets close to (P_{best} and g_{best})) can be calculated, and the current position can be modified by the following equation:

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{6}$$

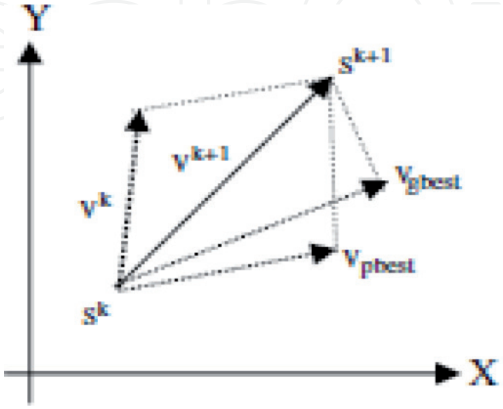

Figure 2.
PSO's concept of searching point.

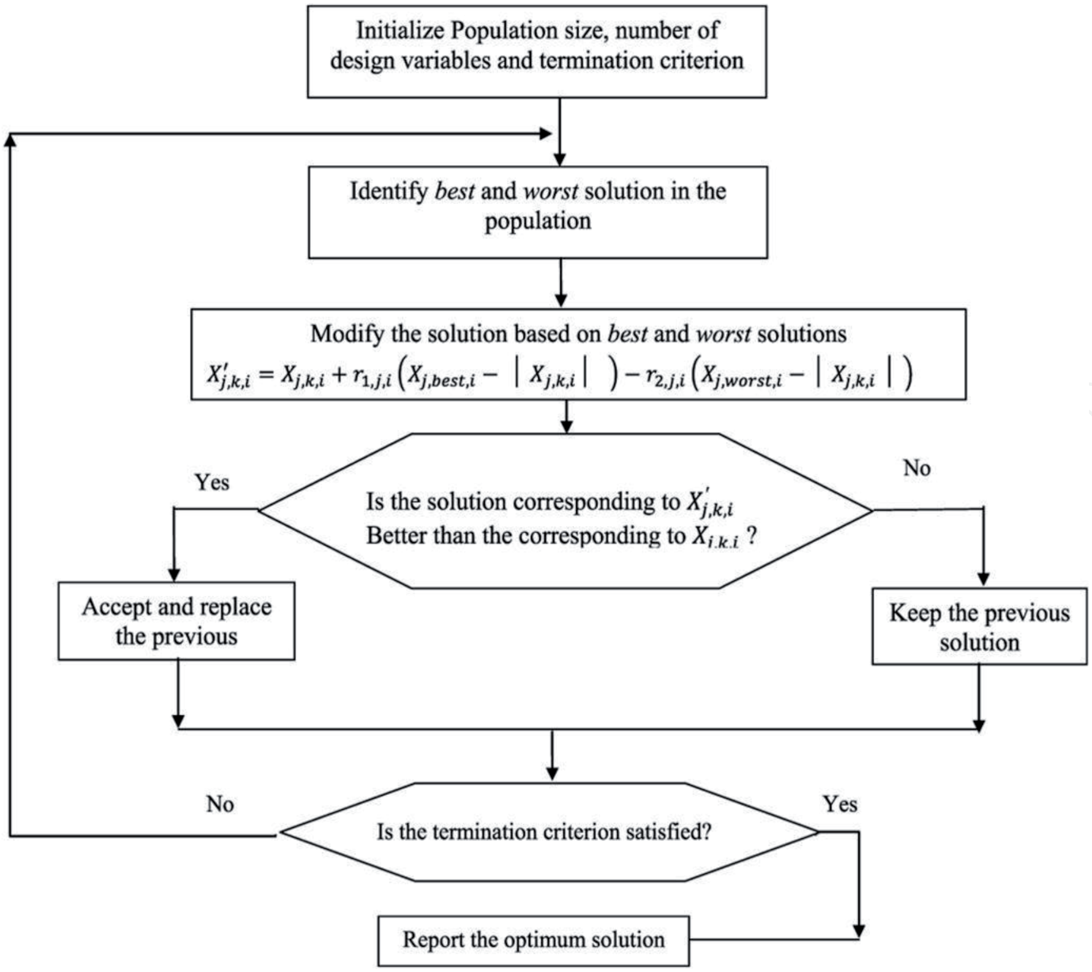

Figure 3.
Flow chart of Jaya method [10].

where

S_i^{k+1} : modified position of particle i at iteration k.

V_i^{k+1} : modified velocity of particle i at iteration k.

Figure 2 illustrates the modification concept of searching point by PSO.

3.2 Jaya optimization method

In2015, Venkata Rao has presented as a new optimization algorithm. One of the main advantages of Jaya is that there is no need to tune of its parameters. There are similarities between Jaya and the Teaching-Learning-Based Optimization (TLBO) [22].

The idea of Jaya is pushing the problem to move towards the best solution and avoid moving towards the worst solution. The flowchart illustrated in **Figure 3** shows the work procedures of the Jaya algorithm.

The advantages of Jaya algorithm can be concluded as follows [23, 24]:

1. It does not contain the problem of the selection of algorithm-specific control parameters.

2. It can solve unconstraint and constraint problems.

3. It is suitable for discrete optimization problems.

4. Ease of solving.

5. Jaya algorithm has a victorious nature, and this leads it to be more powerful.

4. Simplified microgrid model for optimization methods

It will be more effective to build the objective function of the optimization algorithm, if the total transfer function of the controlled system is in standard second order form, so it will be easy to use the standard parameters such as natural frequency, settling time, and rise time $\omega_n, T_s, \ and\, T_r$.

A simplified microgrid model shown in **Figure 4** is applied to drive the standard second order transfer function

$$T.F = \frac{\omega_n^2}{S^{2+2\eta\omega_n S+\omega_n^2}} = \frac{\left({k_i}/{M}\right)}{S^{2+\left({R}/{M.(1+R)}\right)S+\left({k_i}/{M}\right)}} \tag{7}$$

From this transfer function, the parameters $\omega_n, T_s, and\ T_r$ can be calculated. These parameters can be applied in the objective function of the optimization methods.

$$J = \omega_n + T_s + T_r \tag{8}$$

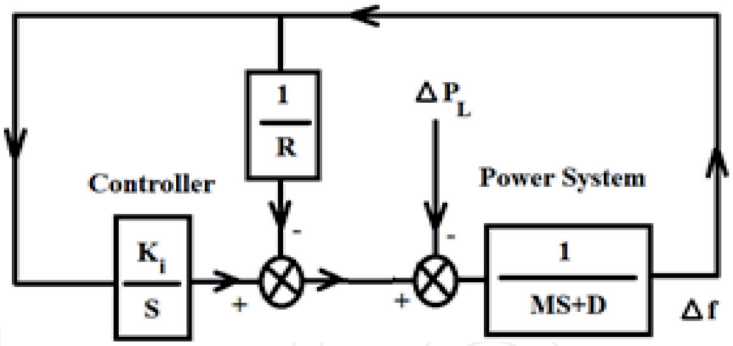

Figure 4.
Block diagram of simplified microgrid model.

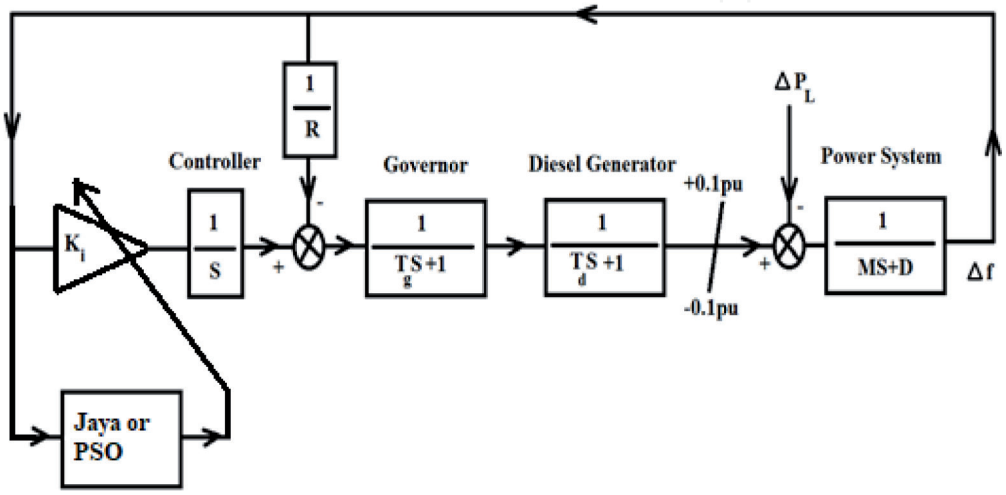

Figure 5.
Block diagram of the adaptive LFC system.

5. Adaptive load frequency controller-based optimization techniques

Figure 5 illustrates the block diagram of an adaptive load frequency controller of micro-grid power system. In this technique, optimization methods such as Jaya and PSO are used to make on-line tuning of the gain of the area controller.

6. Simulation results

6.1 Adaptive LFC-based PSO

Figure 6 shows the system response of the system with adaptive LFC controller-based PSO in case of step load demand ($ÄP_L = 0.02\ pu$. At t = 3 s). Both frequency and diesel power are illustrated in the figure. It can be noted clearly that the adaptive controller could improve the system responses compared with fixed parameters controller. **Figure 7** shows the output of PSO.

6.2 Adaptive LFC-based Jaya algorithm

Figure 8 illustrates the system response of the system with adaptive LFC controller-based Jaya algorithm in case of the same step load demand. The figure supported that the system with the adaptive controller gives more robust performance compared with the system with fixed parameters controller. Also, **Figure 9** shows the output of Jaya.

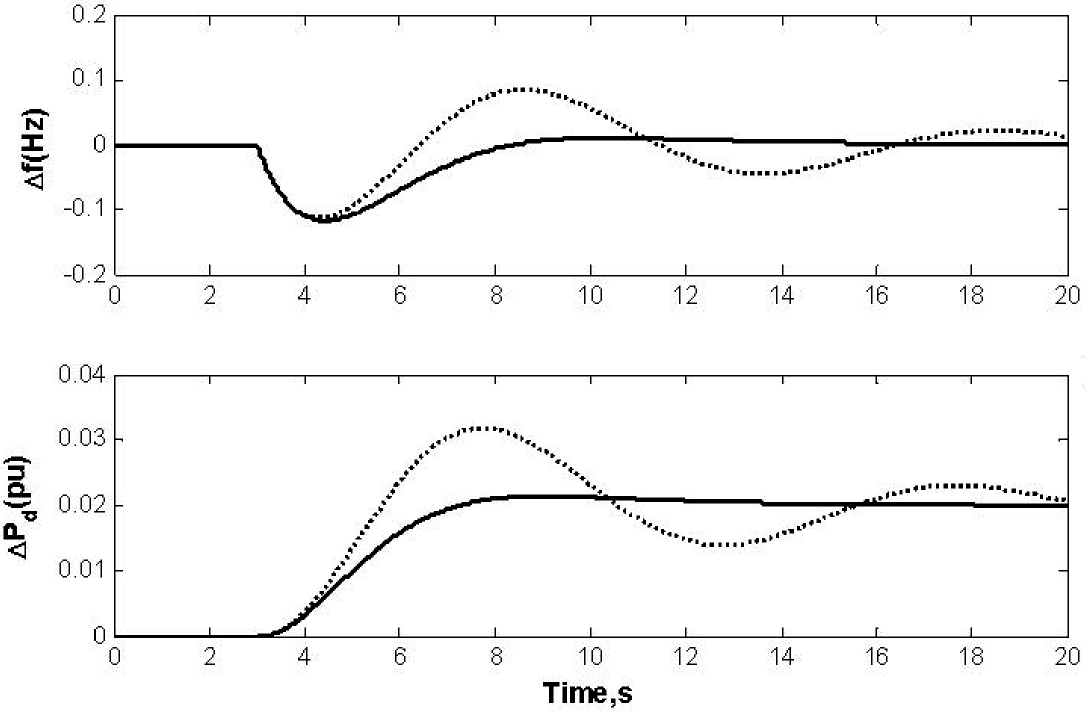

Figure 6.
System response using adaptive LFC-based PSO (...... fixed parameters controller —— adaptive controller-based PSO).

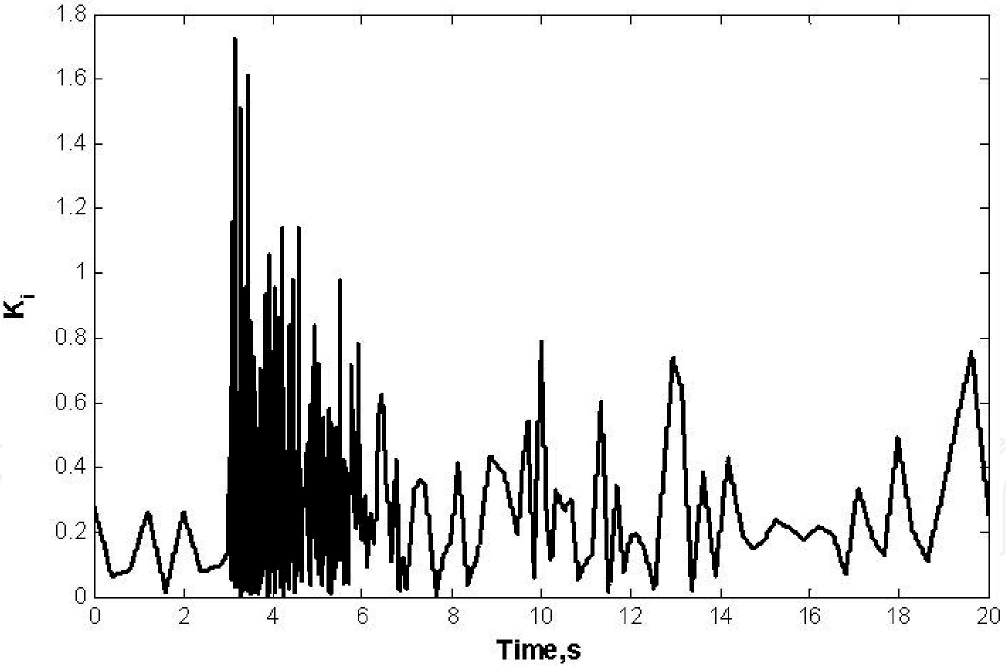

Figure 7.
Tuned controller gain using PSO.

6.3 Comparing Jaya algorithm with PSO

Table 2 presents a comparative performance analysis of Jaya algorithm with PSO. Each test function used the same number of iterations and population. PSO parameters are stated in **Table 3**. **Table 2** shows that the Jaya technique can give good speed convergence characteristics as compared to PSO.

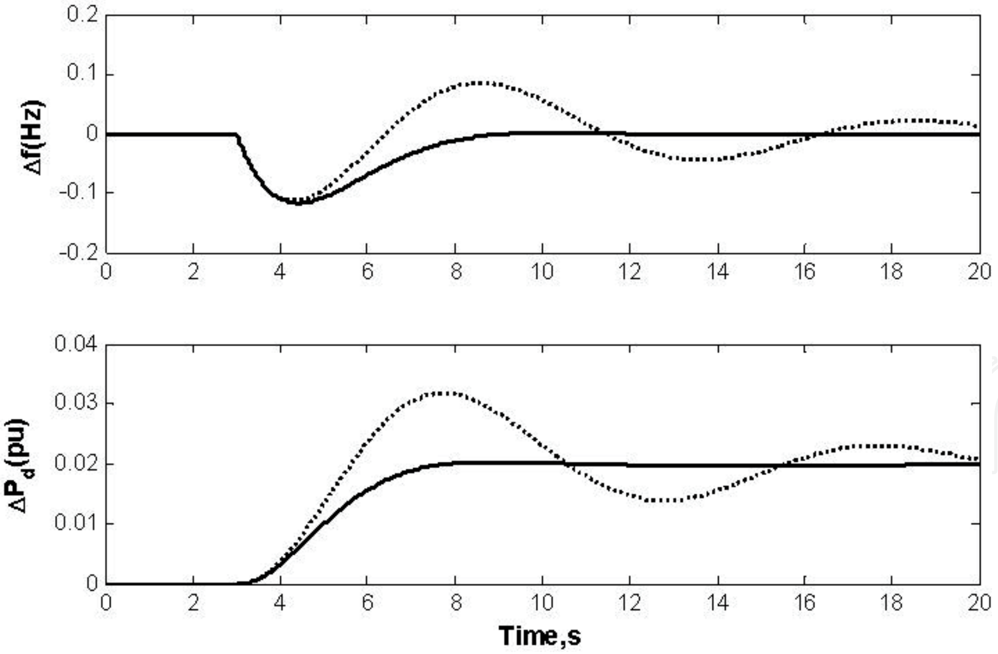

Figure 8.
System response using adaptive LFC-based PSO (...... fixed parameters controller —— adaptive controller-based Jaya).

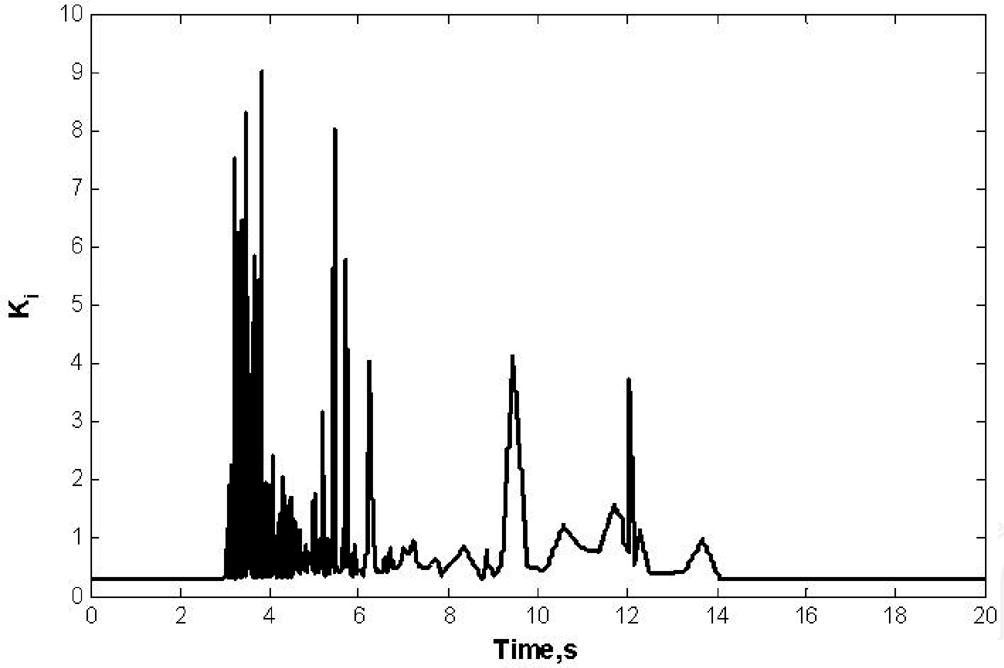

Figure 9.
Tuned controller gain using Jaya.

Functions	D[a]	Search space	Statistical values	PSO	Jaya
Ackley	5	[−10,10]	Best	3.85e−05	2.70e−16
			Worst	3.88e−05	2.70e−16
Sphere	5	[−10,10]	Best	1.79e−08	4.77e−14
			Worst	1.82e−08	4.77e−14

Table 2.
Comparative performance indexes of different test functions.

Parameters	Values
Swarm size	50
Inertia weight (w)	1
Inertia weight damping ratio (w_{damp})	0.99
Personal learning coefficient (C1)	1.5
Global learning coefficient (C2)	2.0

Table 3.
Algorithm-specific parameters values for PSO.

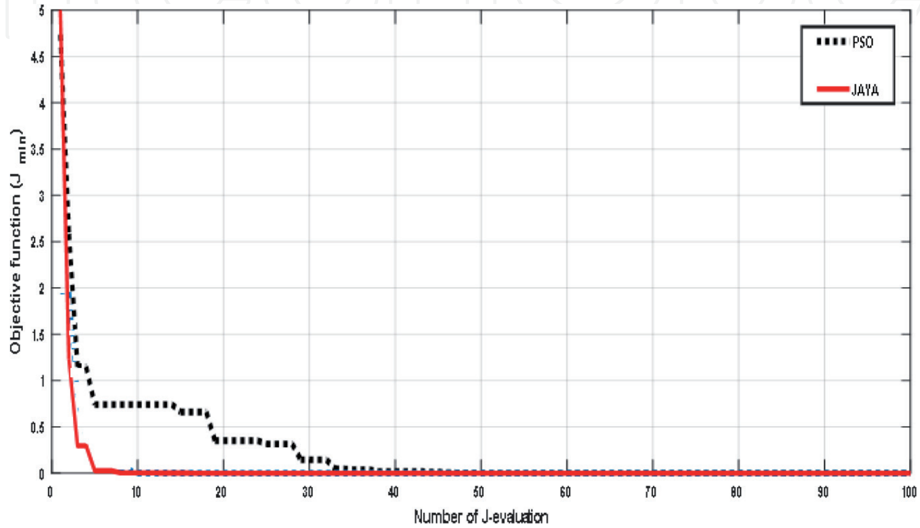

Figure 10.
Convergence characteristics for Matyas function.

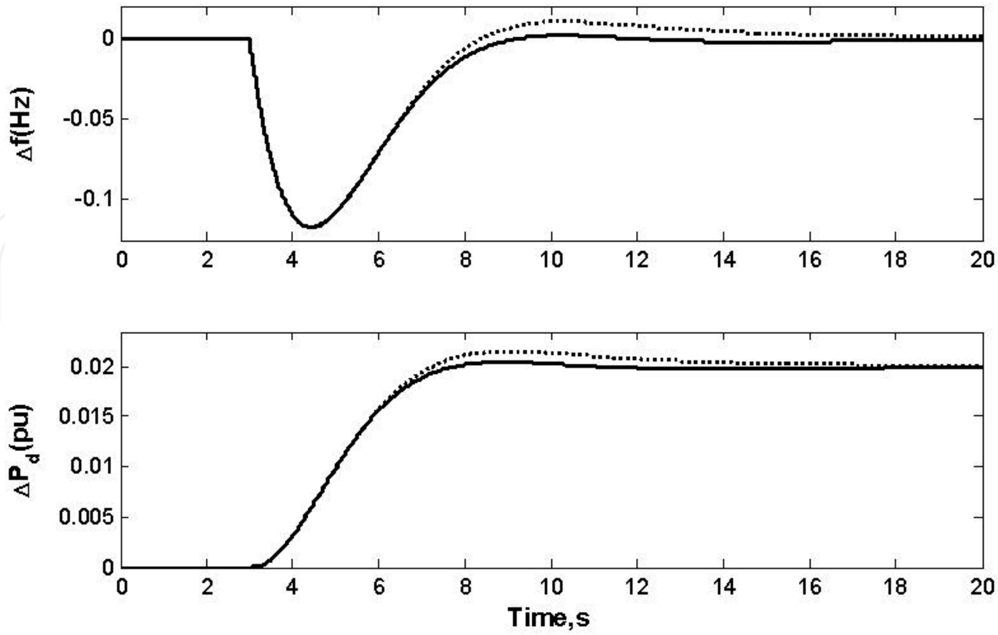

Figure 11.
System response using adaptive LFC-based PSO (...... adaptive controller-based PSO —— adaptive controller-based Jaya).

Figure 10 shows the value of the objective function (J_{min}) with the number of J-evaluation in case of using Matyas function for 50 population size. It can be noted that the Jaya technique converges relatively faster than PSO.

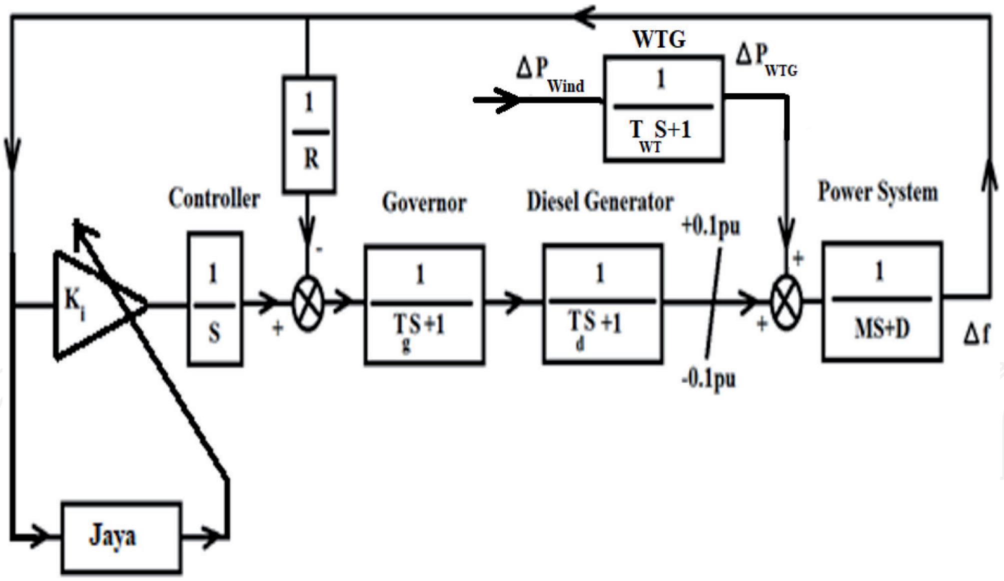

Figure 12.
Block diagram of the adaptive LFC system in the presence of a wind energy source.

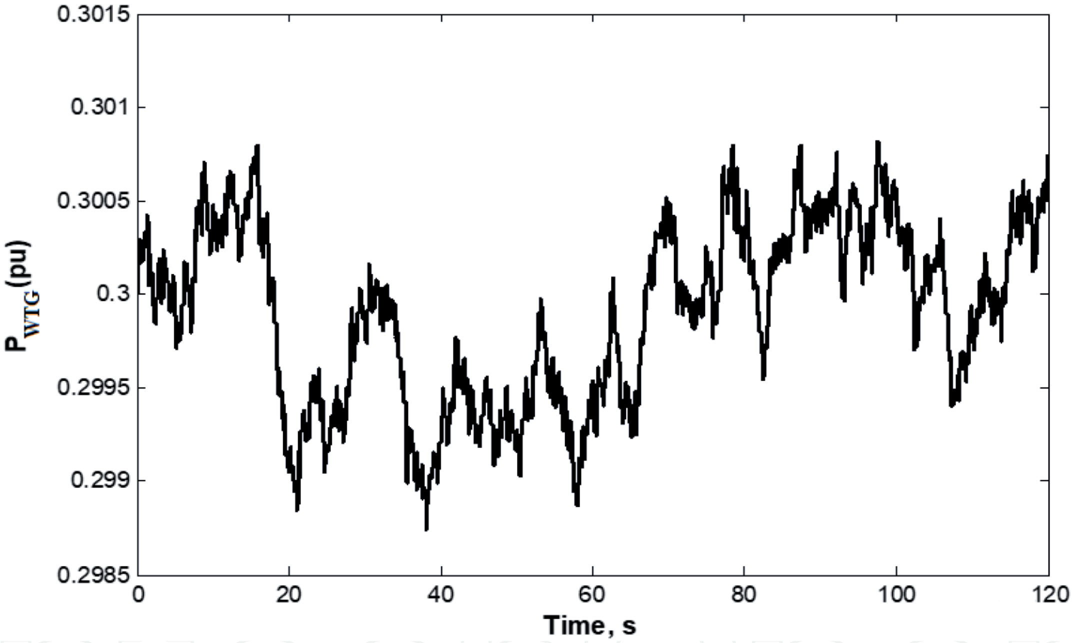

Figure 13.
Output power of the wind turbine.

Figure 11 illustrates a comparison between Jaya and PSO using the proposed objective function presented in Eq. (8). The figure indicates that system with adaptive controller tuned by the Jaya optimization method gives good response compared with the system with adaptive controller tuned by PSO. It could minimize the overshoot and the settling time.

6.4 Case of presence of renewable energy source

In this case of study, the system with proposed controller has been tested under fluctuation resulted from renewable power generation such as power generated from wind turbine as shown in **Figure 12**. The simplified dynamic model of the wind turbine is presented in the following transfer function:

$$\Delta P_{WTG} = \left(\frac{1}{T_{WT}S+1}\right)\Delta P_{wind} \tag{9}$$

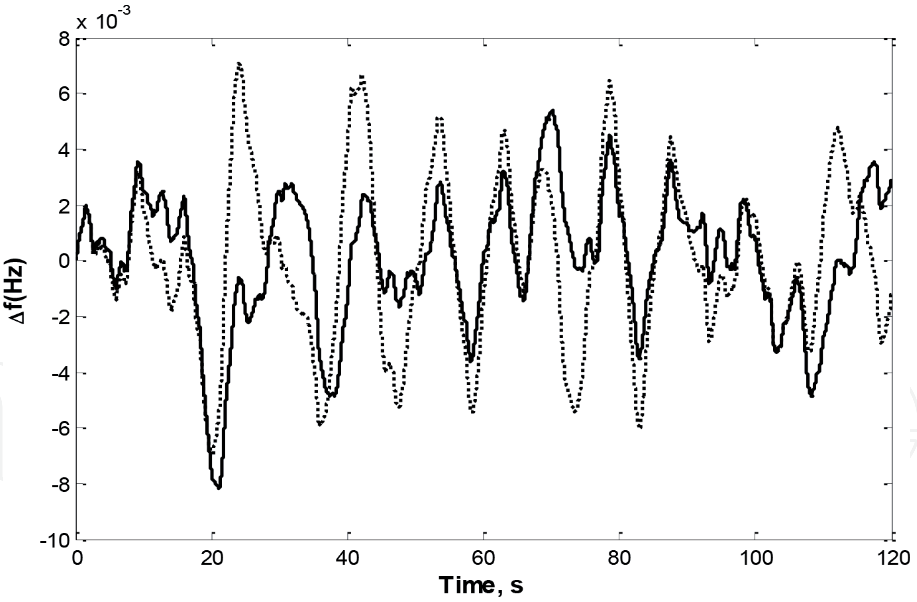

Figure 14.
Frequency response in case of presence of the wind energy source (...... fixed parameters controller —— adaptive controller-based Jaya).

Figure 13 illustrates the power of the wind turbine.

The system with proposed controller tuned by Jaya algorithm has been compared with the system with conventional fixed parameter controller, and the result is shown in **Figure 14**. this result supports the efficiency of the controller with Jaya optimization in dealing with frequency variation that resulted from the wind energy source.

7. Conclusions

This chapter presents an adaptive load frequency controller in a microgrid power system. The gain of the proposed controller is tuned by optimization techniques. The system under study consists of a microgrid with a 20 MW diesel generator and 17 MW demand load. PSO and Jaya optimization algorithms have been used to tune the gain of the system controller. The system with Jaya has been compared to the system with PSO and the system with fixed controller parameters in the case of step load change. Simulation results indicated that the system with Jaya optimization can give the best performance at the moment of step load demand. In addition, the system with Jaya algorithm has been compared to the system with a conventional controller in case of frequency fluctuations resulting from a wind energy source. Digital simulations supported the superiority of the Jaya optimization method.

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References

[1] Kundur P. Power System Stability and Control. New York: McGraw-Hill Education; 1994

[2] Zhang Y, Dong L, Gao Z. Load frequency control for multiple-area power systems. In: American Control Conference, Louis, MO, USA. 2009

[3] Kothari DP, Nagrath IJ. Modern Power System Analysis. 3rd ed. New Delhi: Tata McGraw-Hill; 2003

[4] Kirby BJ, Dyer J, Shoureshi DRA, Guttromson R, Dagle J. Frequency Control Concerns In the North American Electric Power System. USA: SciTech Connect; 2003

[5] Bevrani H. Robust Power System Frequency Control. New York: Springer; 2009. pp. 15-61. DOI: 10.1007/978-0-387-84878-5

[6] Mukta, Surjan BS. Load frequency control of interconnected power system in deregulated environment: A literature review. International Journal of Engineering and Advanced Technology (IJEAT). 2013;**2**(3):435-441

[7] Wadhwa CL. Electrical Power System. New Delhi: New Age International Publisher; 2010

[8] Wen T. Load frequency control: Problems and solutions. In: The 30th Chinese IEEE Control Conference (CCC), Yantai. 2011

[9] Ohba S, Ohnishi H, Iwamoto, Shinichi. An advanced LFC design considering parameter uncertainties in power systems. In: The 39th North American IEEE conference on Power Symposium, Las Cruces, NM. 2007. DOI: 10.1109/NAPS.2007.4402376

[10] Jaleeli N, Ewart DN, Fink LH, et al. Understanding automatic generation control. IEEE Transactions on Power Systems. 1992;**7**(3):1106-1122. DOI: 10.1109/59.207324

[11] Al-Saedi W, Lachowicz SW, Habibi D, Bass O. Power quality enhancement in autonomous microgrid operation using particle swarm optimization. International Journal of Electrical Power & Energy Systems. 2012;**42**(1):139-149. DOI: 10.1155/2014/342019

[12] Dekker J, Nthontho M, Chowdhury S, Chowdhury SP. Economic analysis of PV/diesel hybrid power systems in different climatic zones of South Africa. International Journal of Electrical Power & Energy Systems. 2012;**40**(1):104-112. DOI: 10.1155/2014/626251

[13] Kamalapur GD, Udaykumar RY. Rural electrification in India and feasibility of photovoltaic solar home systems. International Journal of Electrical Power & Energy Systems. 2011;**33**(3):594-599. DOI: 10.1016/j.ijepes.2010.12.014

[14] Alzola JA. Microgrids project, Part 2: Design of an electrification kit with high content of renewable energy sources in Senegal. Renewable Energy. 2009;**34**(10):2151-2159. DOI: 10.1016/j.renene.2009.01.013

[15] Gu W, Liu W, Wu Z, Zhao B, Chen W. Cooperative control to enhance the frequency stability of islanded microgrids with DFIG-SMES. Energies. 2013;**6**(8):3951-3971. DOI: 10.3390/en6083951

[16] Serban I, Marinescu C. Aggregate load-frequency control of a wind-hydro autonomous microgrid. Renewable Energy. 2011;**36**(12):3345-3354. DOI: 10.1016/j.renene.2011.05.012

[17] Lei Y, Lin X, Zhu Y. Passivity-based control strategy for SMES under an

unbalanced voltage condition. IEEE Access. 2018;**6**:28768-28776. DOI: 10.1109/ACCESS.2018.2831251

[18] Wang Y, Zhou R, Wen C. Robust load-frequency controller design for power systems. In: IEE Proceedings C (Generation, Transmission and Distribution). 1993. pp. 11-16

[19] Bohn E, Miniesy SM. Optimum load-frequency sampled-data control with randomly varying system disturbances. IEEE Transactions on Power Apparatus and Systems. 1972:1916-1923. DOI: 10.1109/TPAS.1972.293519

[20] Kennedy J, Eberhart R. Particle swarm optimization. In: Proceedings of the IEEE International Conference on Neural Networks, Perth: Australia. vol. 4. 1995. pp. 1942-1948

[21] Shi Y, Eberhart R. A modified particle swarm optimizer. In: Proceedings of the IEEE International Conference on Evolutionary Computation, Anchorage, UK. 1998. pp. 69-73

[22] Yoshida H, Kawata K, Fukuyama Y. A particle swarm optimization for reactive power and voltage control considering voltage security assessment. IEEE Transactions on Power Systems. 2000;**15**:1232-1239. DOI: 10.1109/59.898095

[23] Venkata Rao R. Jaya: A simple and new optimization algorithm for solving constrained and unconstrained optimization problems. International Journal of Industrial Engineering Computations. 2016;**7**:19-34. DOI: 10.5267/j.ijiec.2015.8.004

[24] Rao R, Rai D, Ramkumar J, Balic J. A new multi-objective Jaya algorithm for optimization of modern machining processes. Advances in Production Engineering & Management. December 2016;**1**(4):271-286. DOI: 10.14743/apem2016.4.226