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PI Multi-Objective Genetic for LFC Based Different Wind Penetration

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Abstract

Future energy descent systems will be expected to be controlled by the using of renewable power sources of which wind energy is one of the favorable sources. This paper treats with the implantation of genetic algorithms for making the parameters needed for PID applied to interconnected thermal and hydraulic power systems at best use and most effective. Two-areas of hydraulic and thermal power systems with wind connected parallel to each one are considered to exemplify the effective parameter investigation. First hydraulic and thermal are connected with tie line with the wind connected parallel to hydraulic or thermal, and then disturbance was made at thermal power plant, then to hydraulic power plant. Simulations are performed aided by the integrated Simulink/Matlab environment taking into consideration the genetic optimization process. Multiple integral representations variables with different cost functions were considered in the search for the effective AGC parameters. The outcomes established by this paper shows the impact of the genetic algorithms for LFC about multiple areas connected power systems based on different wind power using in the tuning of such a process.

Keywords

PID, Wind, Genetic, Multi-Objective Genetic Algorithm, LFC

1. Introduction

Now, wind energy is the fastest growing and the most widely utilized renewable energy source for the purpose of electric energy descents. Between various RES, wind energy source is the most promising [1]. As the penetration level of the wind energy to the connected power system increases, the control of voltage and frequency turns to be more significant and necessary because of sporadic impression of wind power. Thus, the problem of LFC of the interconnected power system having wind power penetration becomes all the more important [1].

The use of Doubly Fed Induction Generator (DFIG) based wind turbine in frequency control has been explored for the purpose in [2] and [3]. In the DFTG's turbine, inertia is totally decoupled from the system, which means generators are not supporting to frequency change of the system. Some methods have been reported to show how a variable speed wind turbine participates in frequency control in [4] and [5]. These are based either on inertial control or power reserve control (speed control and pitch control), or on controlling through communication. In the inertial control, an additional loop is introduced with a suitable gain, which is sensitive to the system frequency and provides kinetic energy from DFTG to support system inertia [6]. In another work, the rotor speed and active power were adapted according to de-loaded best power extraction curve to deliver ultimate power [6]. Based on the kinetic energy extract from DFIG wind turbines, there are some research works that have been reported for load frequency control [7] [8] [9].

In this work, the optimum adjustment of the LFCs used in connected hydraulic-power system investigated with the genetic optimization algorithms [10], and also a set of performance indices which are various functions of error and time [11]. In this way, the various performances that the power system might have can be observed when different performance parameters were used.

2. System Model

2.1. Single Diagram

Figure 1 shows the single diagram for the system investigated. Area 1) is the thermal always attached to area 2) hydraulic and adding wind parallel with the two areas are investigated.

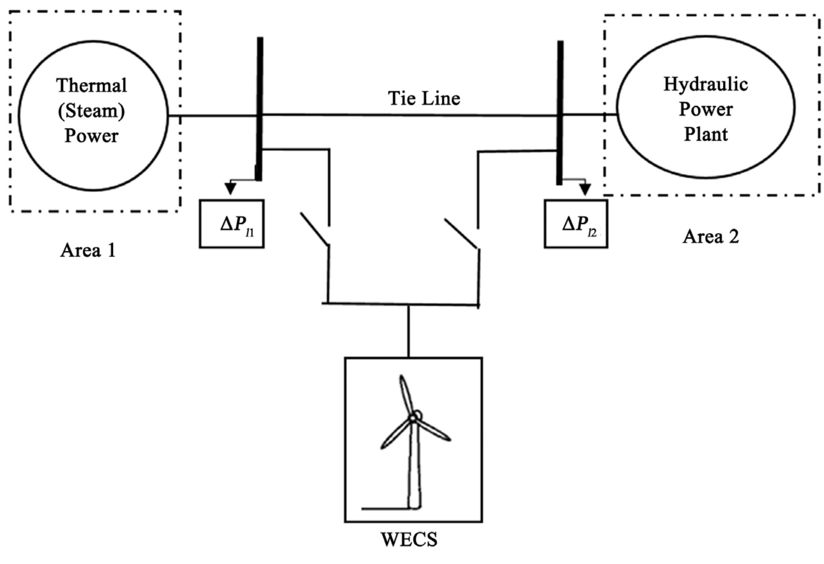

Figure 1. Single diagram.

2.2. Block Diagram

Figure 2 shows the block diagram of thermal power plant attached to wind and hydraulic power plant attached to wind.

2.3. DFIG-Based Wind Turbine

Due to the increasing of using wind turbines DFIG is desired to use and be studied. The DFIG stores the kinetic energy in its turbine blade. So the extraction of this kinetic energy depends on the inertia of the turbine. By controlling this inertia, the stored energy can be extracted from the blade. Under normal operation, the convertor controllers of the DFIG keep the turbine at its optimal speed in order to extract the maximum power. Figure 3 shows the model used for active power control.

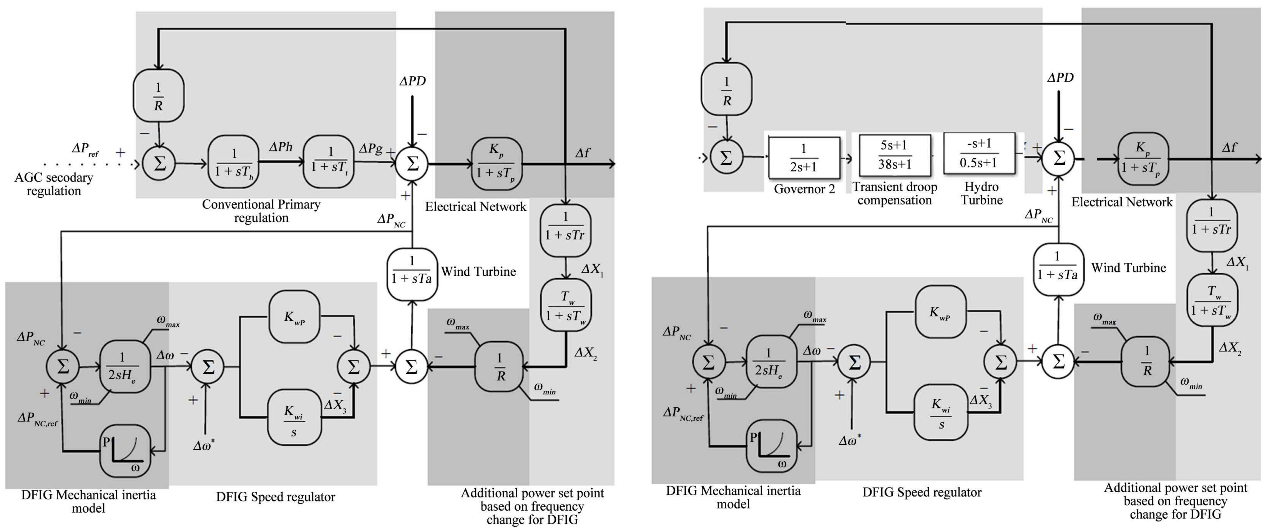

Figure 2. Block diagram.

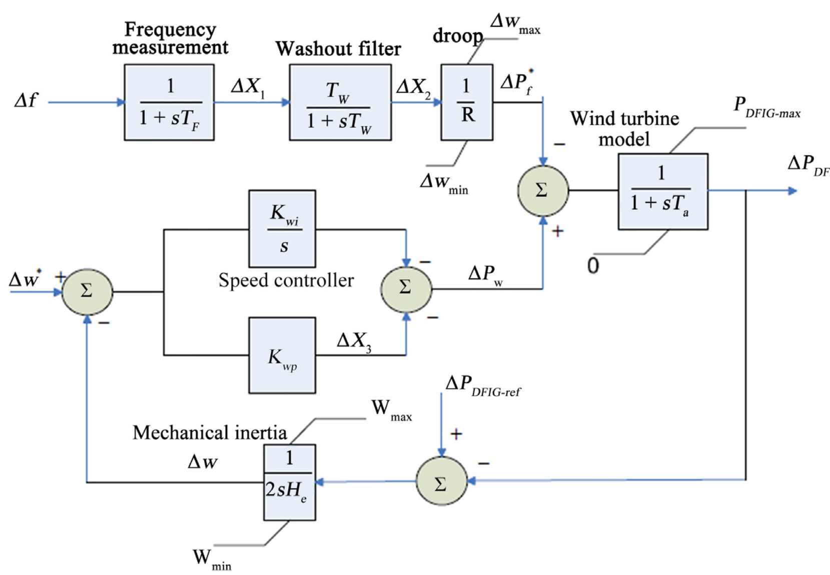

Figure 3. Wind model.

3. Multi-Objective Genetic Algorithm (MO-GA)

3.1. Genetic Algorithm (GA)

The GA is a utilization search technique depending on the principles of genetics selection. Population used to evolve under selection rules were allowed by GA to a state that maximizes the "fitness" (*i.e.*, minimizes the cost function), GA was first rise by John Holland in 1975, various versions of programming have been contributed with different prosperity degrees.

Some of the advantages of a GA include [12] [13]:

- Variables (continuous - discrete) utilization.
- No need for derivative parameters.
- Looking simultaneously from many sampling of the cost surface.
- Extremely complex utilization of the variables.
- Variables encoding so that the utilization encoded variables could be used.
- Many data such as numerically generated data, experimental data, or analytical functions can be used by GA.

These advantages made outstanding outcomes when conventional optimization approaches cannot get the results.

There are wide types of the GAs but the main form is simple genetic algorithm (SGA). SGA functions with various population of candidate solution introduced as strings. The first population assembled by random individual generation. Subsequently the fitness of all individual in this population is calculated. Then the population is converted in stages to achieve a new current population for incoming iteration. The conversations were usually calculated in three steps by three genetic operators: 1) Selection genetic operator, 2) Crossover genetic operator, and 3) Mutation genetic operator were detail discussed in [14].

Because of the properties of genetic, which is population based approach, it can be used to solve multi-objective problems [15].

Many various algorithms introduced and perfectly applied to different problems like [16] [17] [18]: Vector-Evaluated GA (VEGA), Multi-Objective GA (MOGA), A Non-Dominated Sorting GA (NSGA) and Non-Dominated Sorting GA (NSGA II) which is used in the proposed research. The Non-Dominated Sorting Genetic Algorithm [19] (NSGA) which is used to find the solutions of multi objective optimizations problems was written by Srinivas and Deb. But has little disadvantages such as wide computational complexity. To decrease these, Deb et al. developed NSGA-II [20]. Mohamed *et al.* [21] reduce the computational complexity of NSGA II and choose new fitness assignment with Global Ranking Genetic Algorithm (GRGA).

This paper present work achieved by GRMOGA algorithm to solve the LFC problem of two area interconnected power system. The major steps in GRMOGA algorithm are:

1) Global Ranking Fitness Assignment

2) Dominance Rank

3) Crowding Distance.

3.2. Cost Functions

In this paper, the optimal parameters were investigated to adjust of the load frequency controllers used in an interconnected hydraulic-thermal and wind power system, with the aim of multi objective genetic algorithms to minimize a set of performance indices which are various functions of error and time. These indices include:

$$e(t) = |\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}| \quad (1)$$

1) The integral of the square of the error criterion (ISE) which is given by:

$$\text{ISE} = \int_0^\infty e^2(t)\,\mathrm{d}t \quad (2)$$

2) The integral of time-multiplied absolute value of the error criterion (ITAE) which is given by:

$$\text{ITAE} = \int_0^\infty t\,|e(t)|\,\mathrm{d}t \quad (3)$$

This criterion penalizes long duration transients and is much more selective than the ISE. A system designed by use of this criterion exhibits small overshoot and well damped oscillations.

3) The integral of time-multiplied square of the error criterion (ITSE) which is given by:

$$\text{ITSE} = \int_0^\infty te^2(t)\,\mathrm{d}t \quad (4)$$

This criterion weights large initial error lightly, while errors occurring late in the transient response are penalized heavily. This criterion has a better selectivity than the ISE.

4) The integral of squared time-multiplied absolute value of the error criterion (ISTAE) which is given by:

$$\text{ISTAE} = \int_0^\infty t^2\,|e(t)|\,\mathrm{d}t \quad (5)$$

5) The integral of squared time-multiplied square of the error criterion (ISTSE) which is given by:

$$\text{ISTSE} = \int_0^\infty t^2 e^2(t)\,\mathrm{d}t \quad (6)$$

Equations (4)-(6) shows cost functions.

4. Simulation Result and Discussion

This section shows the simulations results of the proposed power system with the results of first disturbance area 1, then area 2, then changing the level of wind penetration. Our power system is thermal connect to hydraulic with tie line, and then adding wind to each side with disturbance at area 1. And do the same but with disturbance at area 2.

4.1. Disturbance Area 1

The change of frequency of area 1, 2 and power of tie line was studied with our three models hydraulic with thermal, then hydraulic with thermal parallel to wind, at last hydraulic parallel to wind tied with thermal.

4.1.1. Thermal Tied Line with Hydraulic thermal $\xleftrightarrow{\text{Tie line}}$ hydraulic

Figure 4 shows thermal power system connected to hydraulic power system with tie-line and using MO-GA to calculate the parameters of PID controller and the bias frequency B_1 and B_2 without wind turbine.

The parameters calculated using MO-GA are shown in Table 1.

4.1.2. (Wind Parallel Thermal) Tied Line with Hydraulic wind & thermal $\xleftrightarrow{\text{Tie line}}$ hydraulic

Figure 5 shows thermal power system connected to hydraulic power system with tie-line and using MO-GA to calculate the parameters of PID controller, with wind turbine connected parallel to thermal power system.

The parameters calculated using MO-GA are shown in Table 2.

Table 1. The parameters calculated using MO-GA for thermal tied line with hydraluic with disturbance at area 1.

P_1	I_1	P_2	I_2	B_1	B_2
0.399	1.884	13.962	0.1	1	0.996

Table 2. The parameters calculated using MO-GA for thermal parallel to wind tied line with hydraluic with disturbance at area 1.

P_1	I_1	P_2	I_2	B_1	B_2	K_{wp}	k_{wi}
0.399	1.884	13.962	0.1	1	0.996	0.225	0.901

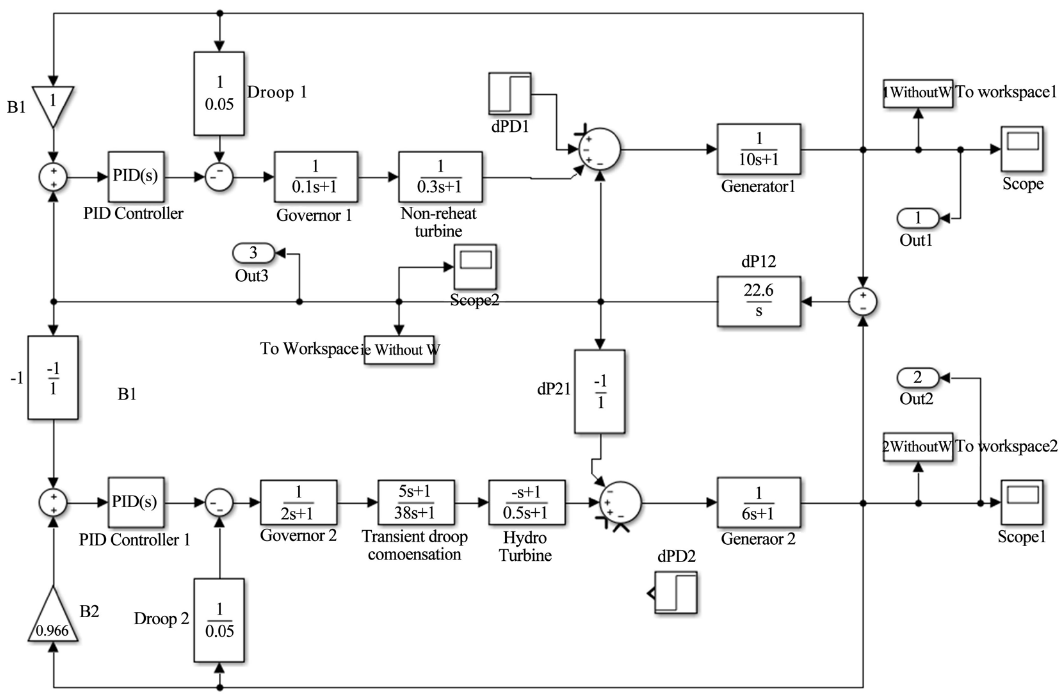

Figure 4. Hydraulic connected with tie-line to thermal with disturbance at area 1.

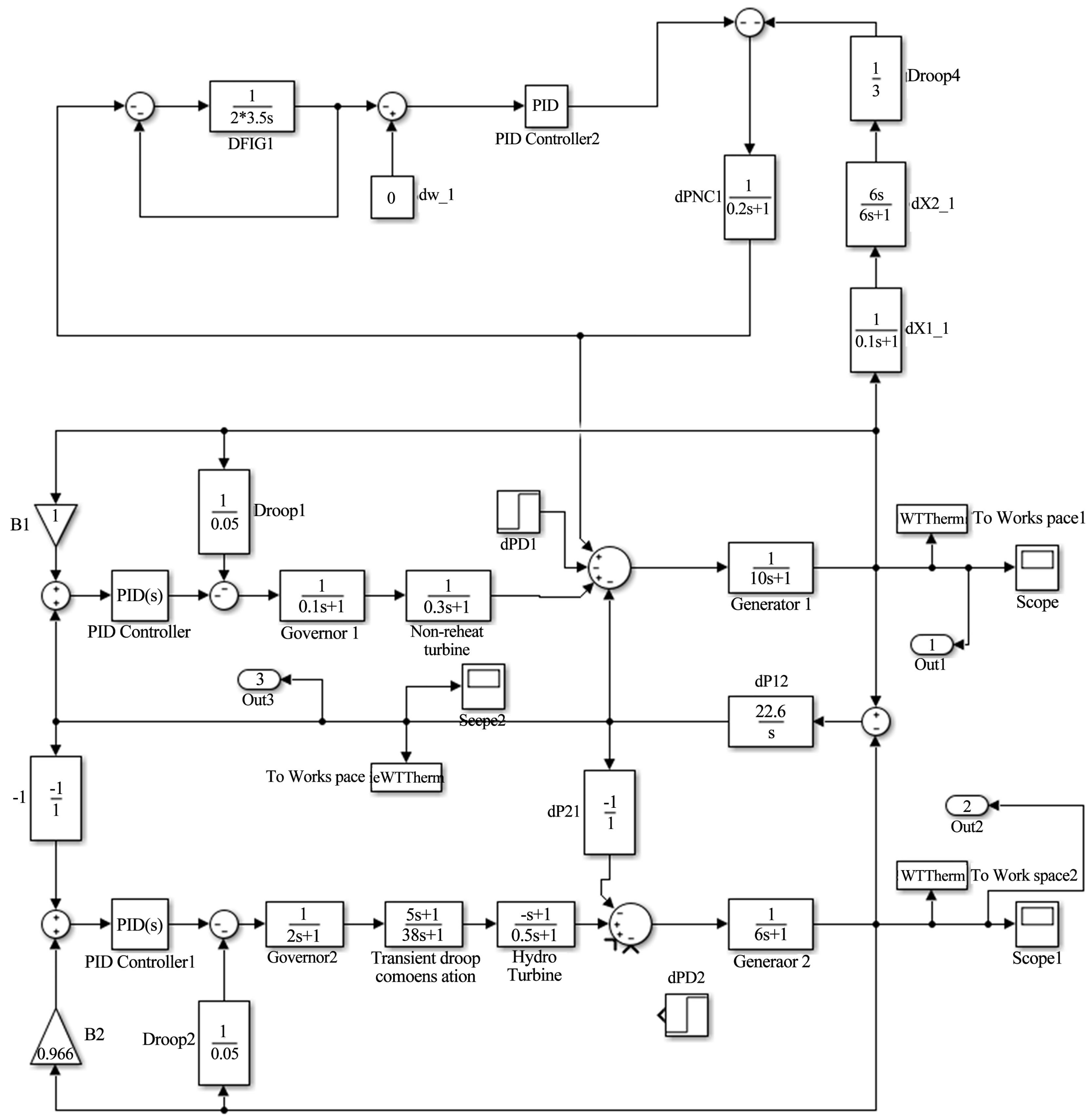

Figure 5. Hydraulic connected with tie-line to thermal parallel to wind with disturbance at area 1.

4.1.3. (Wind Parallel Hydraulic) Tied Line with Thermal

$$\text{wind \& hydraulic} \xleftrightarrow{\text{Tie line}} \text{thermal}$$

Figure 6 shows thermal power system connected to hydraulic power system with tie-line and using multi-objective GA to calculate the parameters of PID controller, with wind turbine connected parallel to hydraulic power system.

Figure 7 shows a) Δf_1 b) Δf_2 c) ΔP_{tie} with disturbance at area 1 with the three models of our power systems.

The parameters calculated using MO-GA are shown in Table 3.

4.2. Disturbance Area 2

4.2.1. Thermal Tied Line with Hydraulic $\text{thermal} \xleftrightarrow{\text{Tie line}} \text{hydraulic}$

Same as section 4.1.1 but with disturbance at area 2

The parameters calculated using MO-GA are shown in Table 4.

4.2.2. Thermal Tied Line with Hydraulic $\text{thermal} \xleftrightarrow{\text{Tie line}} \text{hydraulic}$

Same as section 4.1.2 but with disturbance at area 2

The parameters calculated using MO-GA are shown in Table 5.

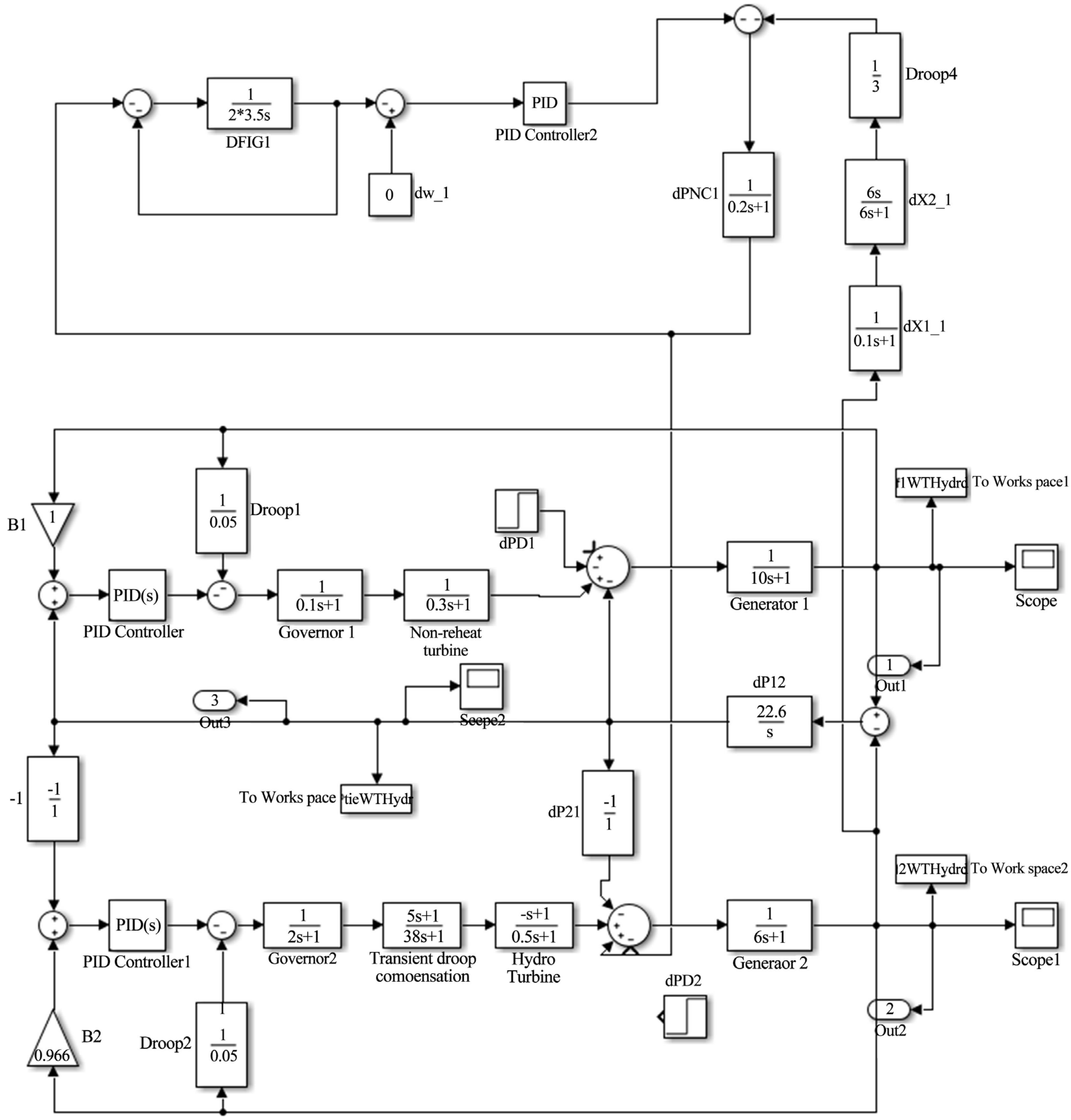

Figure 6. Hydraulic parallel to wind connected with tie-line to thermal with disturbance at area 1.

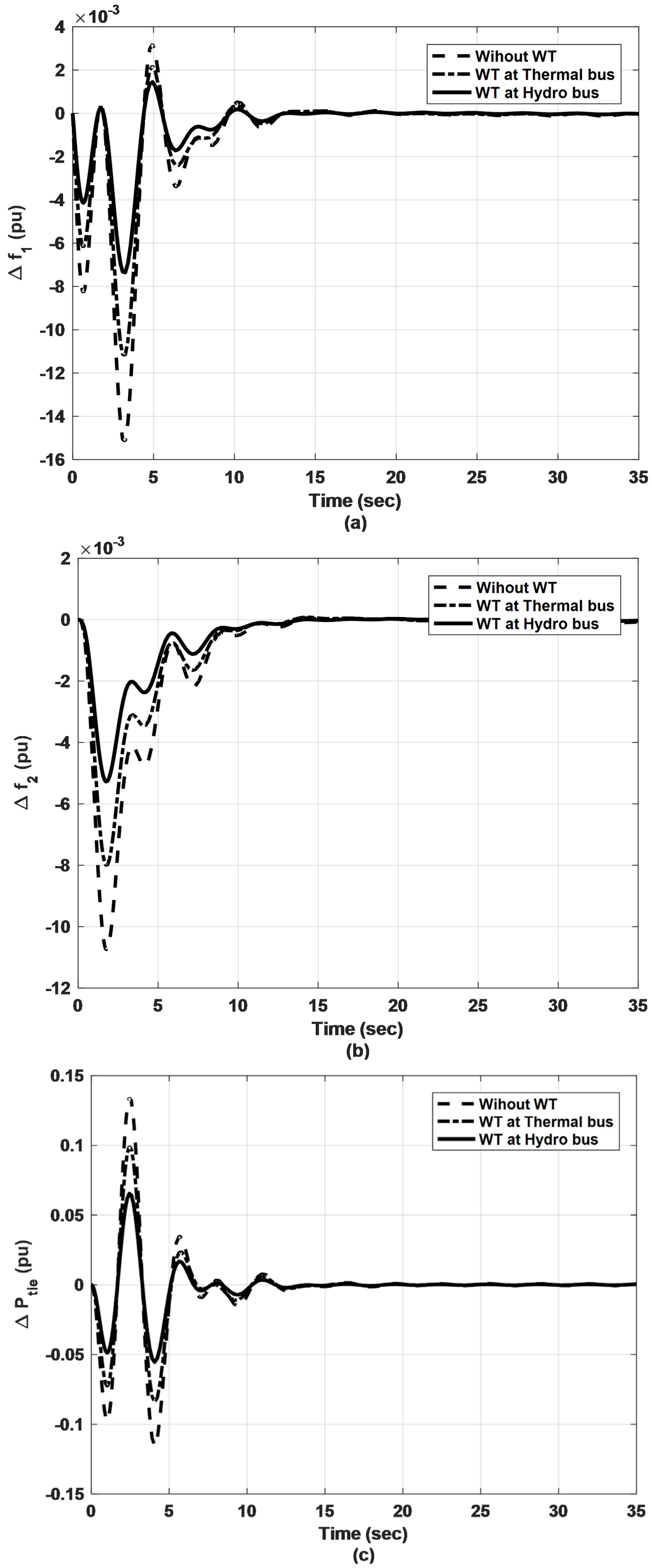

Figure 7. (a) Δf_1 (b) Δf_2 (c) ΔP_{tie} .

Table 3. The parameters calculated using MO-GA for hydraluic parallel to wind tied line with thermal with disturbance at area 1.

P_1	I_1	P_2	I_2	B_1	B_2	K_{wp}	k_{wi}
0.399	1.884	13.962	0.1	1	0.996	0.105	0.832

Table 4. The parameters calculated using MO-GA for thermal tied line with hydraluic with disturbance at area 2.

P_1	I_1	P_2	I_2	B_1	B_2
0.381	2.084	14.814	0.8	1.112	1.303

Table 5. The parameters calculated using MO-GA for thermal parallel to wind tied line with hydraluic with disturbance at area 2.

P_1	I_1	P_2	I_2	B_1	B_2	K_{wp}	k_{wi}
0.381	2.084	14.814	0.8	1.112	1.303	0.1	0.343

4.2.3. Thermal Tied Line with Hydraulic thermal $\xleftrightarrow{\text{Tie line}}$ hydraulic

Same as section 4.1.3 but with disturbance at area 2

The parameters calculated using MO-GA are shown in Table 6.

Figure 8 shows a) Δf_1 b) Δf_2 c) ΔP_{tie} with disturbance at area 2 with the three models of our power systems.

4.3. Disturbance Area 2 (Pen 10%, 25%, 100%)

Figure 9 shows a) Δf_1 b) Δf_2 c) ΔP_{tie} with different wind Penetration with disturbance at area 2.

4.4. Change Time Constant Hydraulic (±10%, ±25%)

Figure 10 shows (a) Δf_1 (b) Δf_2 (c) ΔP_{tie} with change ±10% time constant of hydraulic power plant with disturbance at area 2.

Figure 11 shows (a) Δf_1 (b) Δf_2 (c) ΔP_{tie} with change ±25% of hydraulic power plant with disturbance at area 2.

5. Conclusion

In this paper, MO-GA optimization algorithm has been investigated for optimal LFC in multi-area interconnected power systems. The proposed approach is applied to obtain the optimal PID controller parameters to solve frequency regulation problem. A comparative study between the systems with wind turbine and without wind turbine scheme is carried out in this work. The test systems have been simulated for step load disturbance in multi-area. The results are compared with the systems without any renewable energy. Among all the responses and results obtained, it is observed that adding wind turbines parallel with hydraulic give the best performances, achieving good response and stability with minimum error or disturbance, and are better in terms of rise time, settling time, oscillations and overshoot for both frequency and tie-line power. From the qualitative and

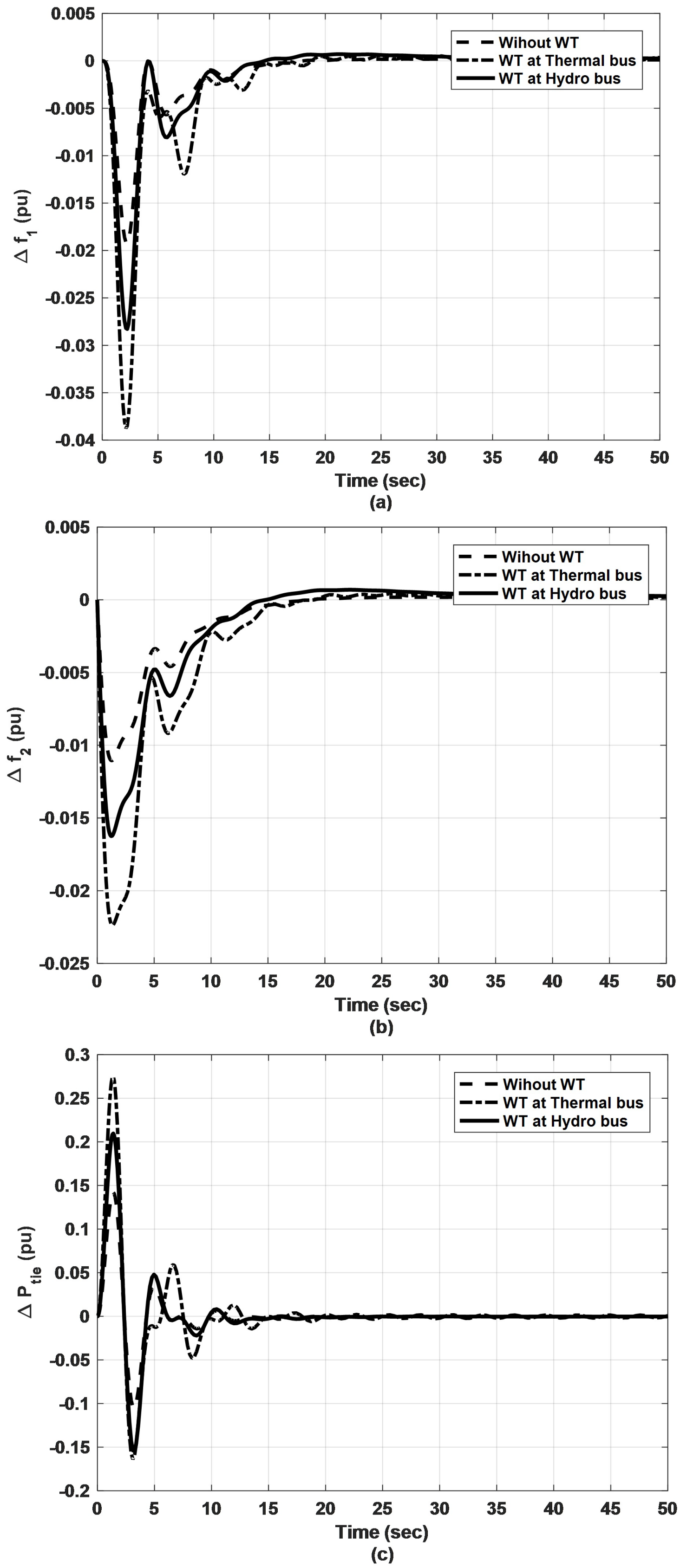

Figure 8. (a) Δf_1 (b) Δf_2 (c) ΔP_{tie} .

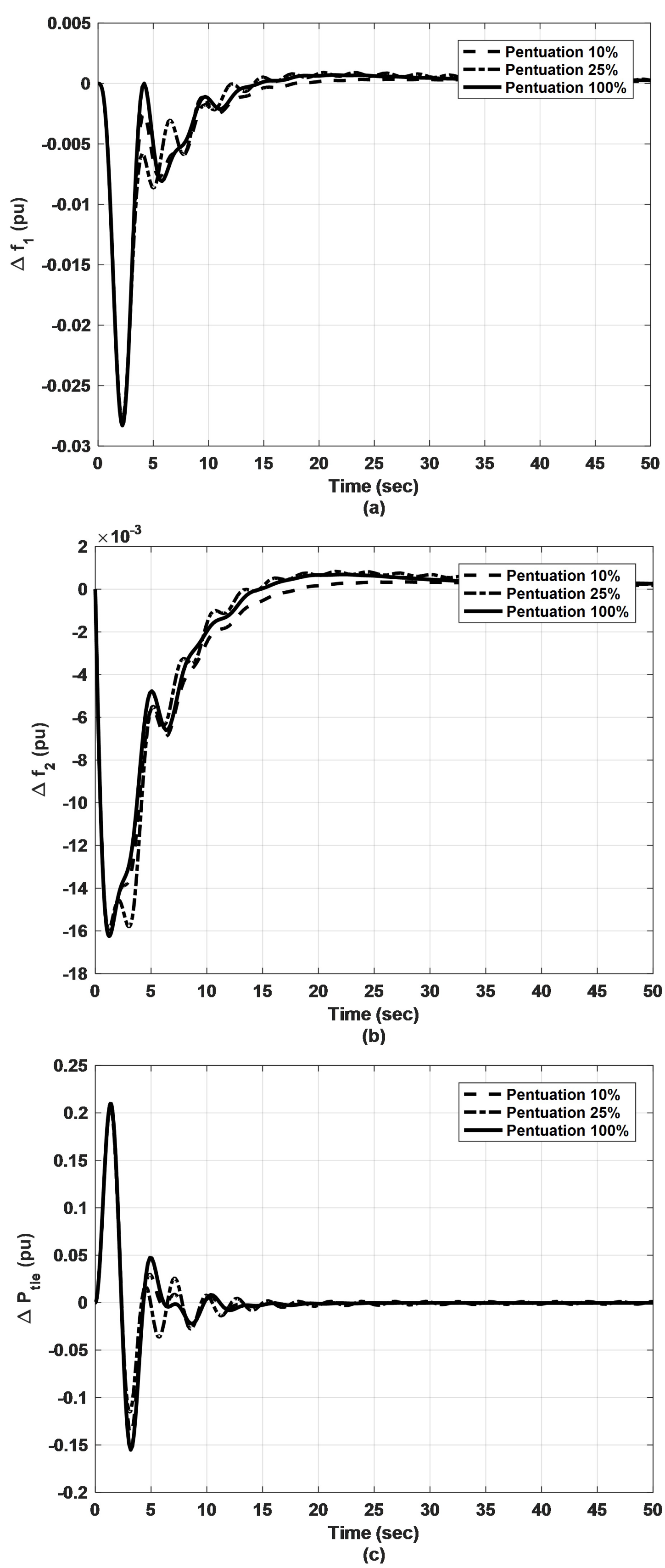

Figure 9. (a) Δf_1 (b) Δf_2 (c) ΔP_{tie}.

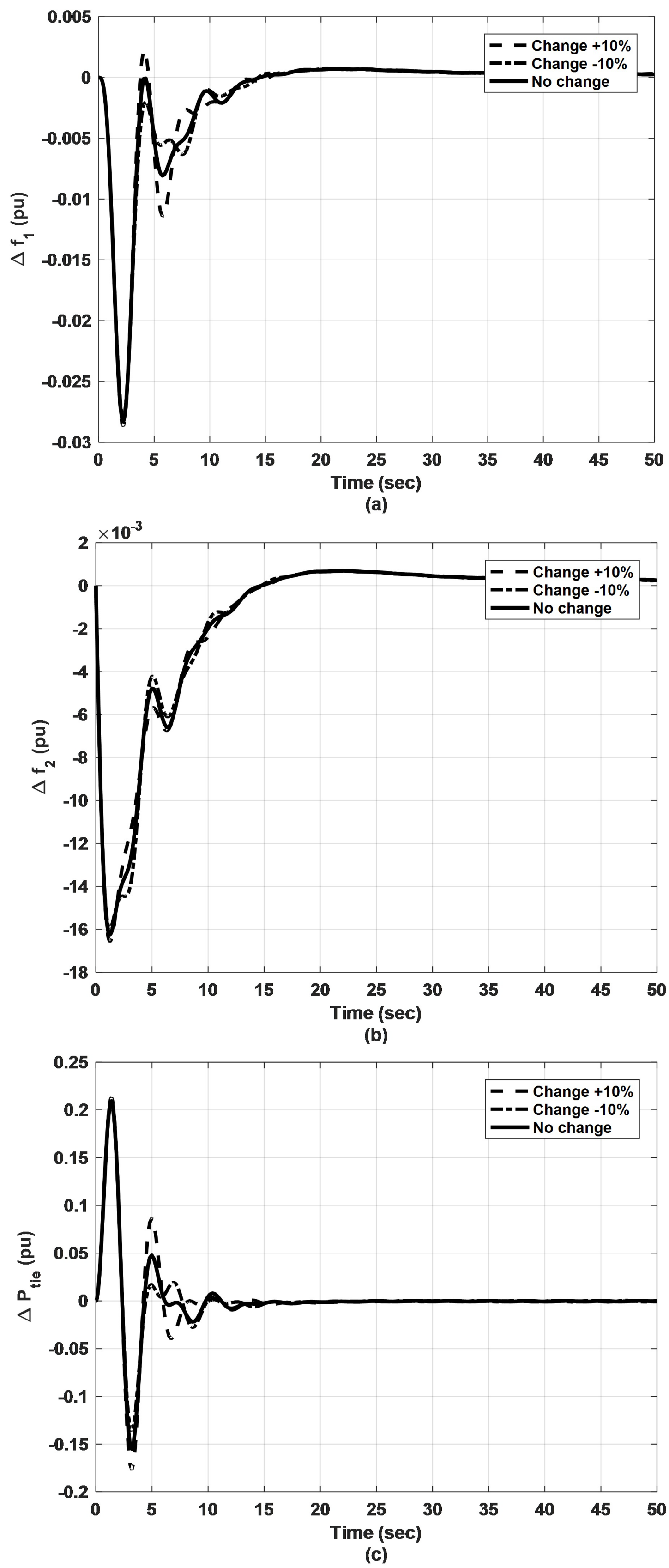

Figure 10. (a) Δf_1 (b) Δf_2 (c) ΔP_{tie} .

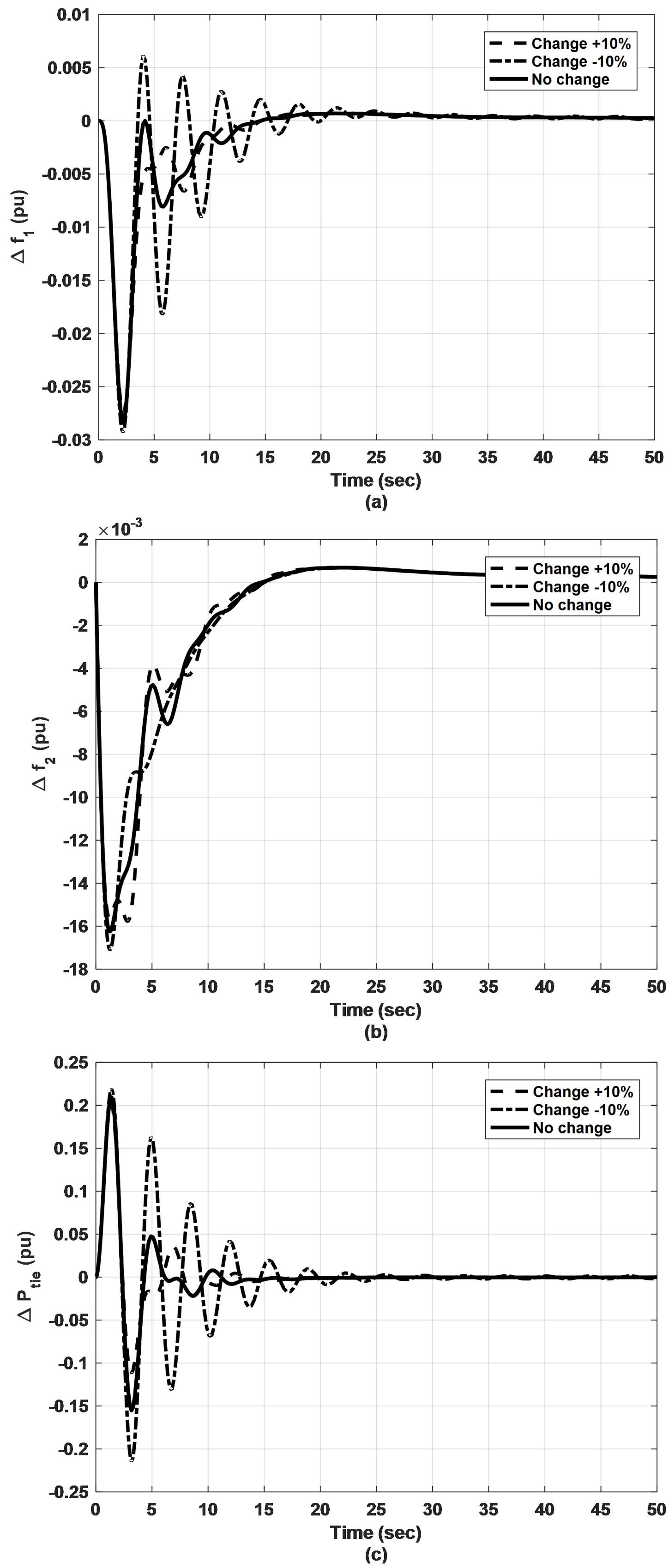

Figure 11. (a) Δf_1 (b) Δf_2 (c) ΔP_{tie}.

Table 6. The parameters calculated using MO-GA for hydraluic parallel to wind tied line with thermal with disturbance at area 2.

P_1	I_1	P_2	I_2	B_1	B_2	K_{wp}	k_{wi}
0.381	2.084	14.814	0.8	1.112	1.303	0.345	0.784

quantitative comparison of the results, adding wind turbines with hydraulic yield better results and the superiority of this method is compared with adding wind turbine with thermal to solve load frequency.

Acknowledgements

H_e =3.5 PU.MW.sec, K_{agc} = 0.05, R = 3 Hz/PU.MW, T = 0.07 PU.MW/Hz, T_a = 0.2 Sec, T_h = 0.1 Sec, T_p = 10 sec, T_r = 0.1 Sec, T_t = 1 Sec, T_w = 6 Sec.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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