Misan Journal of Engineering Sciences ISSN: 2957-4242
Vol. 3, No. 2, Dec 2024 ISSN-E: 2957-4250

Optimal Design of PID-Load Frequency System Based on a Sine Cosine Algorithm

Ali Jasim Mohammed*

Directorate General of Education in Amarah, Ministry of Education, Amarah 62001, Iraq

**Corresponding author E-mail*: ali.jalsm99@gmail.com

(Received 5 Nov, Revised 25 Dec, Accepted 25 Dec)

Abstract: The demand on the electricity is changed daily based on the needs of consumers. In this instance, the power generation and power demand will not be matching, resulting in, fluctuating frequency in power grid. To solve this problem, a load frequency control (LFC) is created. A proportional integral dravite control (PID) is wildly utilized to design the LFC due to a simpler design. However, it is an unable to address the high oscillation case in frequency response because of its fixed parameters. In this research, the optimal PID-FLC control is designed using the sine cosine algorithm (SCA). A two-area power system network is proposed based on a MATLAB environment in order to evaluate this suggested method. Then, an integral time absolute error (ITAE) index is applied to calculate the transiting time of frequency response when the unpredictable load is change dramatically. The outcomes prove that the LFC system based on PID-SCA technique reduces the overshoot and minimize the steady state error at simple and complex disturbances. As results, it achieves an acceptable ITAE index about 6.8 seconds when it is compared with the conventional PID-FLC which reaches to 17.4 second under the complex load-change.

Keywords: load frequency control, sine cosine algorithm, proportional integral dravite control, integral time absolute error and power system

1. Introduction

In recent years, the demand on the energy of electricity has been increased dramatically. In other side, the needs of consumers from the electrical energy are changed rapidly based on the daily load factors [1]. This is case the mismatching between the load demand of consumers and power generation of the power grid. Hence, the frequency level of the power system network changes, resulting in, ensuring a weak power quality of generation units. To address this challenge, a load frequency control (LFC) is designed to regular the fuel-size of generation units with load consumers [2]. Consequently, the frequency response of the utilized grid will be restored to 50 Hz or 60 Hz based on standardisation value the power system that is designed.

A proportional integral dravite control (PID) is wildly utilized to design the LFC system for the multi area power system network due to simple design and low cost. However, it is not able to address rapid changes in load disturbances because it has fixed parameters with the time. Therefore, several studies had been investigated to address this issue. Among them, the authors in [3] proposed PID controller based on Bat algorithm for multi-area power system network. The PID-FLC system's fixed parameters are adjusted using the Bat-algorithm based on the gain controller. The findings of this study demonstrate that the suggested approach takes into account the frequency response time and power grid power supply under different condition states. Similarity, the scholars in [4] designed an optimal PID-LFC system for a hybrid power system network based on internal model control for two degrees of design-step. This model is presented an integration design of LFC to reduce the processing time. The outcomes demonstrate that the proposed model is good dynamic response to the unpredictable load disturbances of the consumers.

DOI: https://doi.org/10.61263/mjes.v3i2.120

While, the researchers in [5] presented modified PID controller based on fractional order method for the power grid. The fractional order method is used in this work to analysis the parameters of PID-LFC, resulting in, addressing the performance of the system. the finding results prove that the designed model achieves a better robustness of frequency deviation at steady state error. In advanced step, the scholar in [6] used a robust algorithm to address the uncertain parameters of PID controller such as a fish migration optimization. By using this approach, the sensitivity of LFC is decreased when it is used in a multi-area power system network. According to the research, this design can quickly adjust the load consumers while maintaining the electricity grid's frequency level. With the same way, the authors in [7] also used crow search algorithm which is classified as advanced algorithm to optimize the parameters of the PID-LFC system for a multi-area power system network. Then, it is applied on the fuzzy logic system to adjust the membership functions of the system. Hence, the proposed design is proved the robustness of LFC system to return the frequency level under different cases. Similarity, the scholars in [8] utilized a grey wolf algorithm to adjust the elements of PID-FLC controller for multi-area power system network. This advanced algorithm is applied to tune the fixed parameters of PID controller adequately. As results, the proposed design is a robust supervisor to retrieve the frequency response of the power grid under various cases.

In the same way, the scholar in [9] used particle swarm optimization and genetic algorithm to tune the PID" parameters for the hybrid power system. Those method applied to design the gain of PID controller when the renewable energies that are connected with utilized grid are changed suddenly. The outcome of this research show that the proposed methods minimize the overshoot of frequency level at transiting state. In the next step, the authors in [10] designed the robust PID-LFC for Interconnected two-area power system using a fuzzy logic technique. The fuzzy logic technique is utilized in this work to adjust the gain of PID system in different states. The results demonstrate that the proposed method superior sensitivity of the frequency response compared with a conventional PID-FLC system. similarity, the author in [11] proposed optimal LFC based on fuzzy logic controller. Then, colony optimization is used to tune the membership functions of the fuzzy-PID system. the findings of this work show the ability of proposed method to regular the parameters' variation of the power grid adequality. lastly, the artificial intelligent techniques such as neural network is used to tune the various parameters of PID-LFC such as in [12]. These types of method prove the effect of the proposed method under various state due to it is a higher robustness to address the sensitivity of power grid. As noticed that, the recent studies have been adjusted the fixed parameters of the PID controller using several techniques which prove that the ability of LFC to address the load disturbances of the consumers under various cases. However, they were presented a complex control stage when they were employed advanced techniques.

In this work, the parameters of a PID-FLC for a two-area power system are addressed using the sine cosine algorithm (SCA). Then, the transiting time of frequency response when the unpredictable load changes significantly is calculated using an integral time absolute error (ITAE) index. Therefore, when compared to the classical approaches for the PID controller, the optimal PID-LFC system becomes the more robust controller to dampen the oscillation in frequency level of the multi-area power system network under various condition tests because of its quick response and low sensitivity. The remainder of the paper is organized as follows: Section 2 describes how to model a two-area power system test. Next, Section 3 describes the framework of the FLC-based PID approach. The SCA algorithm is then presented in Section 4, and the suggested PID-FLC approach is given in Section 5. While, Section 6 discusses the application test's main findings. Lastly, the results of this study are presented in Section 7.

2. The modeling of power grid

Generally, a grid-power system network's primary phases are load-demand, generator, and turbine. This system's main function is to use the turbine's mechanical energy to generate electrical energy in relation to the consumer's load [13]. Because of their superior performance, steam turbines are typically used for these kinds of systems. The primary outlook components of the steam turbine are a governor and reheater, ashown in Fig. (1).

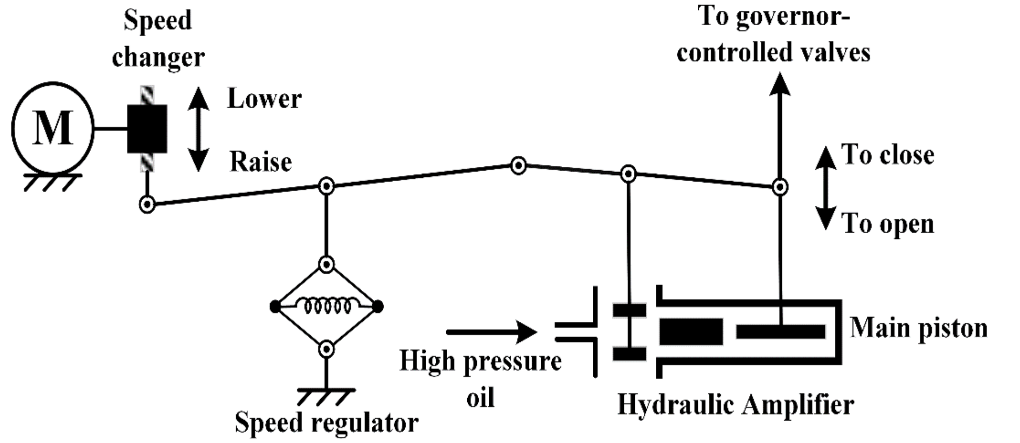

Figure 1. The outlook of a standard steam turbine.

The goal is to balance the generator's output energy with the load of the consumer. As a result, the accelerating turbine modifies the size value of an input steam to regulate the load-consumers. The frequency response will therefore deviate from the standard value. Recently, a number of proposed controls known as the AGC have been developed to modify the turbine's speed error. Equation (1) provides a mathematical basis for calculating the synchronous generator's speed:

$$\Omega(s) = \frac{1}{2Hs}(\Delta P_m - \Delta P_e) \tag{1}$$

where ΔPm and ΔPe represent the historical change in mechanical power and electrical power, respectively, and **Ω**(s) is the accelerating generator and H is the generator's inertia. Conversely, the consumer's load is determined using Equation (2).

$$\Delta P_e = \Delta P_L + D\Delta\omega \tag{2}$$

where ΔPL is a resister's load-demand and $\Delta\omega$ is a motor's miss. To determine the steam turbine, Eq. (3) is utilised:

$$\frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1 + \tau_T(s)} \tag{3}$$

where τ_T is the acceleration time of the speed generator and Pv is the steam-size of turbine. Finally, Equation (4) is used to compute the required steam.

$$\Delta P_g = \Delta P_{ref.} - \frac{\Delta\Omega(s)}{R} \tag{4}$$

where Pref. is the generating power and R is the regulator-speed, while Pg is the electrical power production. Equation (5) indicates how the generator's output power varies with the steam turbine's size:

$$\Delta P_v(s) = \frac{1}{1 + \tau_g}\Delta P_g(s) \tag{5}$$

where ΔPv denotes the turbine's change in steam size and τg denotes the turbine's time-constant speed. The block diagram of the two-area power system network based on the transfer function is shown in Fig. 2. In this work, the MATLAB Simulink for the two-area power system network will be deigned to assess the performance of optimal PID-LFC under different cases.

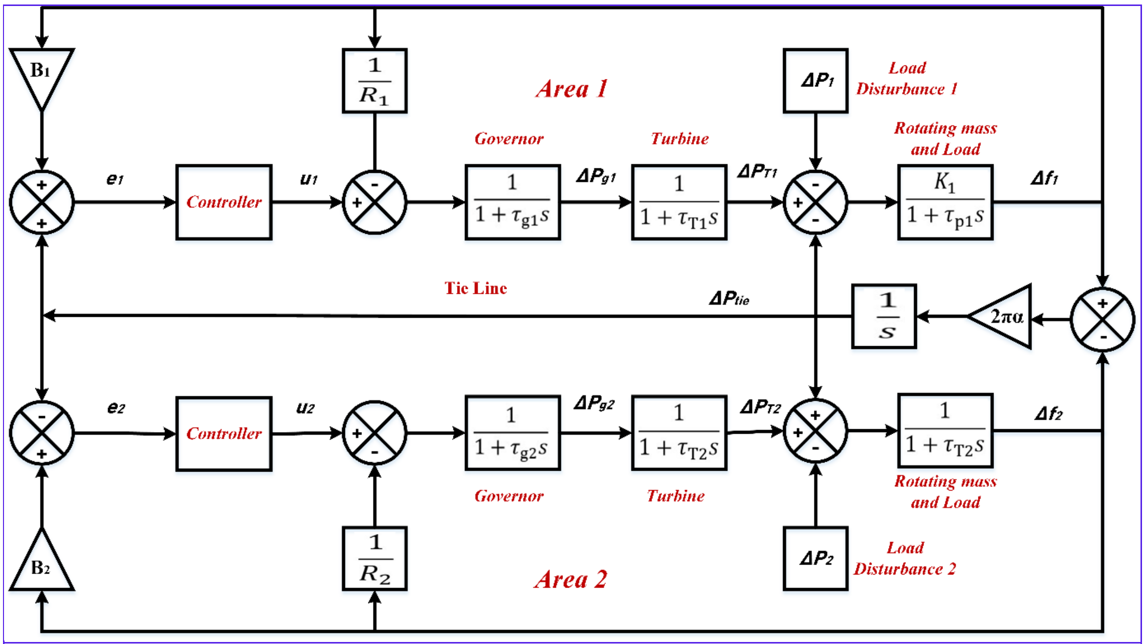

Figure 2. The power grid model.

3. The PID Controller based on LFC

Because of its speed and ease of use, the PID controller is said to be the most popular kind in manufacturing applications [14]. Furthermore, most engineers who are not controlling experts can understand it and it does not require a precise model of the plant. For a processing plant with a very dynamic variable time, like FLC, it is inefficient. Equation (6) provides a mathematical expression for the traditional PID controller based on FLC:

$$u(t) = K_p ACE + K_i \int ACEdt + K_d \frac{dACE}{d(t)} \tag{6}$$

where Kd represents the derivative gain, Ki represents the integral gain, and Kp represents the proportional gain. In contrast, ACE stands for processing plant error, which can be expressed mathematically as Equation (7):

$$e(t) = \Delta P_{tie} + \beta \Delta f \tag{7}$$

where, β is the base frequency of the power system. When using an optimal PID controller in an industrial facility, the main problem is addressing the values of Kp, Ki, and Kd. Consequently, the first step in implementing an effective PID controller is to regulate them. Try-and-error and Ziegler-Nichols are the two main approaches that are used to adjust the PID controller's components. However, processing plants with extremely dynamic fluctuations, like the power system network, are not suited for those technologies. So, a number of scholars have looked into optimization methods to change the PID controller's parameters. This study employs one of the optimization algorithms which is the SCA algorithm to appropriately address the PID controller's parameters. The transient reaction time is then calculated using the ITAE performance index approach to evaluate the proposed PID controller based on the multi-area power system network

4. SCA algorithm

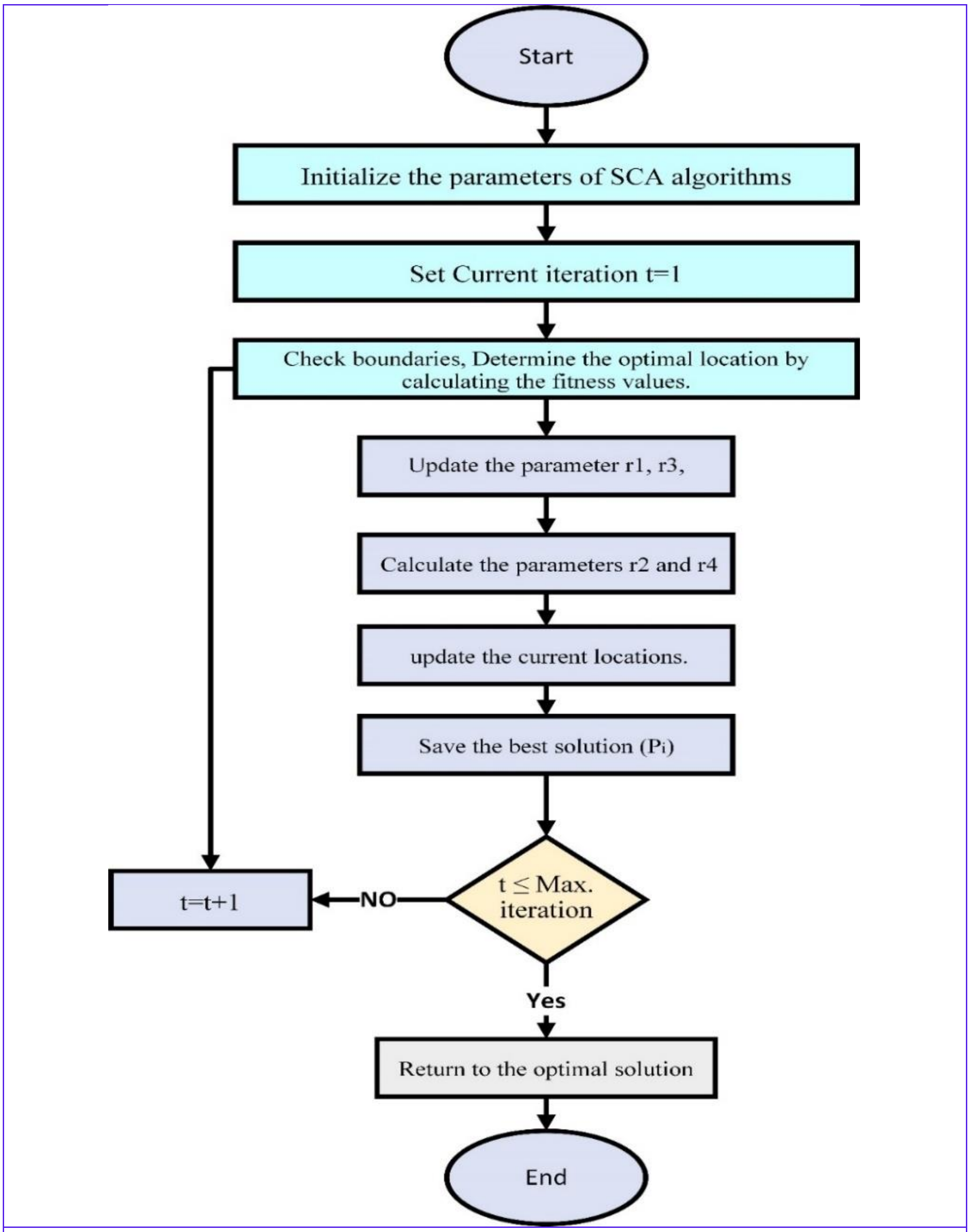

Figure 3. Flowchart of SCA algorithm.

The SCA algorithm uses the sine and cosine properties of the trigonometric function that have been utilized to address the best candidate solutions, as explained in ref. [15]. The search equations used in SCA to ascertain the location of potential solutions are defined by equations (8) and (9).

$$\boldsymbol{Y_i^{g+1} = Y_i^t + r_1 \sin(r_2) \times \left|r_3 P_i^t - Y_i^t\right|} \tag{8}$$

$$\boldsymbol{Y_i^{t+1} = Y_i^t + r_1 \cos(r_2) \times \left|r_3 P_i^t - Y_i^t\right|} \tag{9}$$

where, the variables, Y_i^t and Y_i^{t+1} represent the i^{th} location of the current solution during iteration 't' and the next iteration 't+1', respectively. The $r_1, r_2, and\ r_3$ denote randomly generated integers, whereas P_i^t refers to the most optimal solution at the i^{th} position in the collection of solutions. Equations (8) and (9) are utilised in the SCA methodology as equation (10):

$$\boldsymbol{Y_i^{t+1}} = \begin{cases} \boldsymbol{Y_i^t + r_1 sin\,(r_2) \times \left|r_3 P_i^t - V_i^t\right|, r_4 < 0.5} \\ \boldsymbol{Y_i^t + r_1 cos\,(r_2) \times \left|r_3 P_i^t - V_i^t\right|, r_4 \geq 0.5} \end{cases} \tag{10}$$

According to the given equations, SCA is distinguished by the following four parameters: r_1, r_2, r_3, and r_4. The parameter r_1 defines the potential area where the solution and the target can be positioned, potentially within a specific region. This parameter allows for the examination and utilisation of a search area while maintaining an optimal balance between them. The process divides the maximum iteration count in half, allocating one half to diversification and the other half to enhancing exploration within a feasible search area [16]. The parameter r_2 determines the orientation of the moment for a particular solution. The parameter r_3 quantifies the significance of the weight assigned to P_i^t. By manipulating the parameter r_4, Equation (9) facilitates the transition from sine to cosine functions. The mathematical updates for the parameters $r_1, r_2, r_2,$ and r_4 are as following:

$$\begin{cases} \boldsymbol{r_1 = a - a \times \frac{t}{T}} \\ \boldsymbol{r_2 = (2 \times \pi) \times rand} \\ \boldsymbol{r_3 = 2 \times rand} \\ \boldsymbol{r_4 = rand} \end{cases} \tag{9}$$

where ‘T’ is the highest iteration, 't' is the present iteration, and 'a' is a constant. The flowchart of the SCA algorithm is presented in Figure 3. In this work, the parameters of PID-LFC will be adjusted when the SCA algorithm will be employed based on the ITAE fitness function.

5. Proposed Method

Figure 4 illustrates the use of the suggested PID control in conjunction with an LFC for a two-area power system. While, the parameters of power system based on area-1 and area-2 are listed in Table 1. As represented in equations. (6) and (7), the governor's signal is used as the output of the optimal PID-LFC, whiles, the historical changing error for the frequency response and power generation of the application test is used as the input signal. Hence, the SCA algorithm that is applied on the power system network handles the precise parameters of the ideal PID-LFC system with the minimal ITAE performance index as stated in the equation (11) [17]:

$$\text{ITAE} = \int_0^t (/\Delta \text{F}_\text{i}/+/\Delta P_{tie}/.\, t\, dt \tag{11}$$

where t stands for the time simulation test, ΔFi is the area-based power grid frequency deviation, and ΔPtie is the utilized grid's tie-line power. According to the optimal control theory, this objective function is utilized to reduce the oscillations and minimize the overshoot in the frequency response state and power delivery case of the power system network. As a result, as shown in Table 2, the ideal PID control parameters are addressed to construct the reliable FLC system for the teas tares of the multi-area power system network. This is due to the fact that optimal state feedback control provides superior behavior through systematic tuning trade-offs between frequency response control activity and the tracking signal of power disturbances [18]. In the next step, the simulation model of power system network will be proposed based on two-area to assess the optimal PID-LFC under various states compression with the conventional PID-LFC.

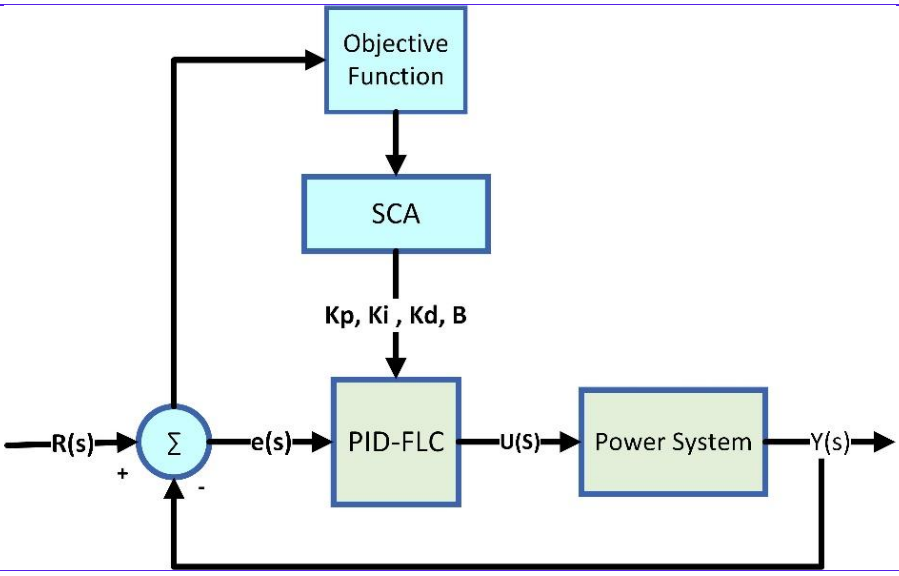

Figure 4. The diagram of PID-FLC based on the SCA algorithm.

Table 1. The main parameters of power system based on the area.

Parameters	Area 1	Area 2
P-output (MW)	250	400
f-response (Hz)	50	50
τg (pu)	0.05	0.0625
τ_T - governor (sec.)	0.2 sec	0.3 sec
τ_T - turbine (sec.)	0.5 sec	0.6 sec
H- governor (sec.)	5	4
The sensitivity factor of load	0.6	0.9

Table 2. The elements of Optimal PID-LFC vs Conventional PID-LFC.

The area	Conventional PID-LFC	Optimal PID-LFC
Area-1	B1= 20	B1=20
	Kp= 0.7	Kp= 8.4
	Ki= 2	Ki= 9.7

	Kd= 1	Kd= 3.5
Area-2	B= 16.92	B=16.92
	Kp= 0.7	Kp= 7.5
	Ki= 2	Ki= 9.7
	Kd= 1	Kd= 5.7

6. Results and Discussion

In this study, the optimal PID-FLC system is tested using a MATLAB Simulink model environment for a two-area power network. To illustrate its effectiveness and scalability, it is then contrasted with the conventional PID-FLC. Next, the system's transient response time under three disturbance scenarios is calculated using the ITAE performance index. The two simulation scenario cases are applied, simple, and complex load-disturbance to assess the performance and the sensitivity of the optimal PID-FLC control for each area.

Simple step-load disturbances are reproduced in the first scenario using the fast change from 0% to 60% at 50 seconds and the constant state for areas 1 and 2, respectively. Figure 5 (a) and (b) show that, nevertheless, both the robust controller and the classical controllers have independent frequency responses for these straightforward load changes. In contrast to FLC-AGC and PID-AGC, which have been oscillating around the reference test signal with more overshoots, the LFC system of the optimized PID controller was the most dependable in responding to the deviation loads of customer testing. Comparing the generating units' power deliveries to the same methods, they also showed the highest stability and the lowest steady state inaccuracy. Additionally, Figure 5 (b) and (c) demonstrate that the power deliveries from the generating units had the least overshoot and the maximum stability with the lowest steady state error when compared to the similar approaches. In comparison to the suggested approach, the traditional PID-LFC take a bit longer to address the frequency response reference value, with a higher maximum increase time for different changing steps. The lowest ITAE index was attained in approximately 2.7 seconds, whereas the traditional PID-LFC was approximately 3.9 seconds.

In the second scenario, the area-1 is subjected to sophisticated step-load disturbances that change by 40%, 80%, 40%, and 20% at 10 seconds, 0 seconds, 30 seconds, and 40 seconds, respectively. At 10 seconds, 30 seconds, and 40 seconds, the area-2's step-load disturbance varies from 0% to 40% to 10% to 40% to 20%. When applied to those variable load disturbances with respect to the comparison controller cases, the test results demonstrate that the robust PID controller also achieves the highest stability for frequency response with the least fluctuation around the standard frequency response of the power grid, as shown in Figures 6 (a) and (b). Furthermore, as shown in Figures 6(c) and (d), the power generation of both areas is verified to have improved performance in terms of its minimizing convergence time with the lowest oscillation when compared to the other approach controllers. On the other hand, the traditional FLC-AGC and PID-AGC performed less dynamically in addressing oscillation and overshoot at different time tests. Because the robust PID-AGC reaches the stability state at an ITAE index of 6.8 seconds, it is accepted as the best validation test, whereas the traditional FLC-AGC and PID-LFC reach the stability state at 14.5 seconds. Finally, the summarized results of the ITAE index are listed in Table 3, for proposed method and conventional PID method.

Table 3. The ITAE index for proposed method and conventional PID method.

Method	Case-1	Case-2
Optimal PID-LFC	2.7	6.8
Conventional PID-LFC	3.9	14.5

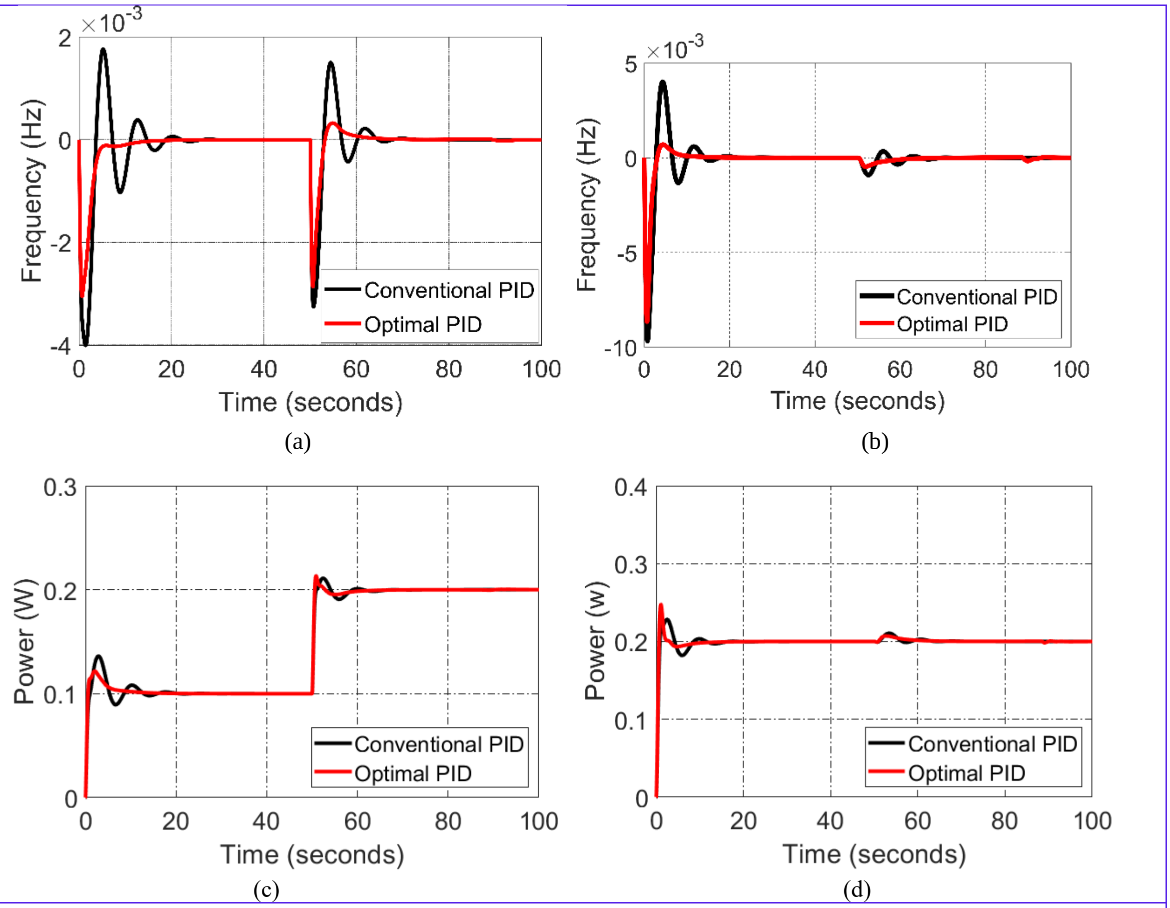

Figure 5. The frequency response and power delivery for case-1.

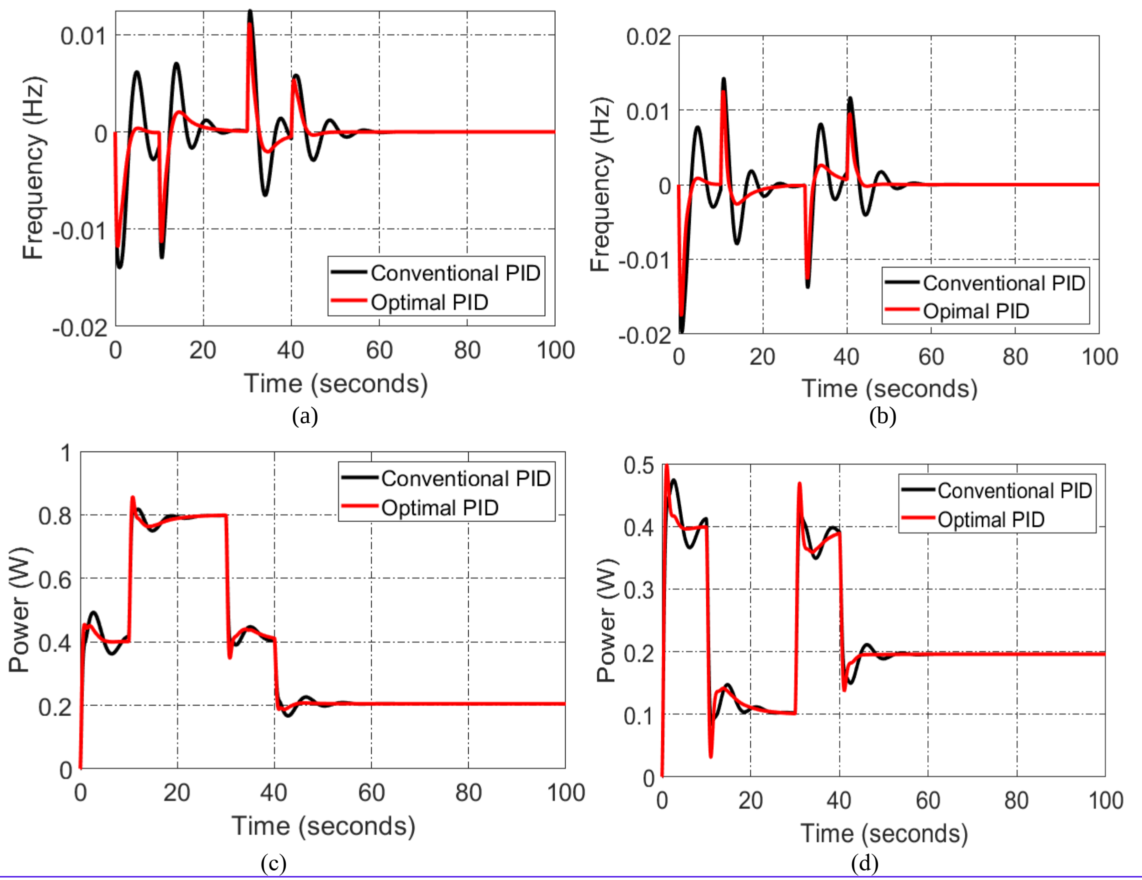

Figure 6. The frequency response and power delivery for case-2.

7. Conclusion

The optimal PID controller for the higher performance LFC in a two-area power system network has been designed in this study using the SCA algorithm. First, the primary components of the PID controller have been addressed by the implementation of the SCA optimization tools. Then, it is applied on the real-time application of a two-area power system network based on the simple and complex tests. This two-area power system network is built on the MATLAB environment. To calculate the transiting time of restored frequency, the ITAE index is employed as fitness function. The findings show that, in comparison to the traditional PID approach, the suggested method enhances the power delivery of the multi-area power grid by iterating the frequency operation value to the standard value of the power system in less time while resolving the fluctional condition under several states. As a result, it is attaining the lowest ITAE index, which is approximately 2.7 second under simple fluctuation test and 6.8 seconds under complex fluctuation test, whereas the conventional PID-LFC controller achieves 3.9 second and 14.5 seconds, respectively.

Author Contributions: The authors contributed to all parts of the current study.

Funding: This study received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

References

[1] S. Mohammed Radhi, S. Al-Majidi, M. Abbod, and H. Al-Raweshidy, "Predicting Solar Power Generation Utilized in Iraq Power Grid using Neural Network," Misan J. Eng. Sci., vol. 3, no. 1, pp. 38–62, 2024, doi: 10.61263/mjes.v3i1.72.

[2] R. Shankar, S. R. Pradhan, K. Chatterjee, and R. Mandal, "A comprehensive state of the art literature survey on LFC mechanism for power system," Renewable and Sustainable Energy Reviews, vol. 76. Elsevier Ltd, pp. 1185–1207, 2017. doi: 10.1016/j.rser.2017.02.064.

[3] M. R. Sathya and M. Mohamed Thameem Ansari, "Load frequency control using Bat inspired algorithm based dual mode gain scheduling of PI controllers for interconnected power system," Int. J. Electr. Power Energy Syst., vol. 64, pp. 365–374, 2015, doi: 10.1016/j.ijepes.2014.07.042.

[4] J. Singh, K. Chattterjee, and C. B. Vishwakarma, "Two degree of freedom internal model control-PID design for LFC of power systems via logarithmic approximations," ISA Trans., vol. 72, pp. 185–196, 2018, doi: 10.1016/j.isatra.2017.12.002.

[5] S. Sondhi and Y. V. Hote, "Fractional order PID controller for load frequency control," Energy Convers. Manag., vol. 85, pp. 343–353, 2014, doi: 10.1016/j.enconman.2014.05.091.

[6] B. Guo, Z. Zhuang, J. S. Pan, and S. C. Chu, "Optimal Design and Simulation for PID Controller Using Fractional-Order Fish Migration Optimization Algorithm," IEEE Access, vol. 9, pp. 8808–8819, 2021, doi: 10.1109/ACCESS.2021.3049421.

[7] J. R. Nayak, B. Shaw, B. K. Sahu, and K. A. Naidu, "Application of optimized adaptive crow search algorithm based two degree of freedom optimal fuzzy PID controller for AGC system," Eng. Sci. Technol. an Int. J., vol. 32, p. 101061, 2022, doi: 10.1016/j.jestch.2021.09.007.

[8] B. P. Sahoo and S. Panda, "Improved grey wolf optimization technique for fuzzy aided PID controller design for power system frequency control," Sustain. Energy, Grids Networks, vol. 16, pp. 278–299, 2018, doi: 10.1016/j.segan.2018.09.006.

[9] Z. Qu, W. Younis, X. Liu, A. K. Junejo, S. Z. Almutairi, and P. Wang, "Optimized PID Controller for Load Frequency Control in Multi-Source and Dual-Area Power Systems Using PSO and GA Algorithms," IEEE Access, no. October, 2024, doi: 10.1109/ACCESS.2024.3445165.

[10] M. A. Magzoub and T. Alquthami, "Optimal Design of Automatic Generation Control Based on Simulated Annealing in Interconnected Two-Area Power System Using Hybrid PID—Fuzzy Control," Energies, vol. 15, no. 4, Feb. 2022, doi: 10.3390/en15041540.

[11] G. Chen, Z. Li, Z. Zhang, and S. Li, "An Improved ACO Algorithm Optimized Fuzzy PID Controller for Load Frequency Control in Multi Area Interconnected Power Systems," IEEE Access, vol. 8, pp. 6429–6447, 2020, doi: 10.1109/ACCESS.2019.2960380.

[12] M. I. Mosaad and F. Salem, "LFC based adaptive PID controller using ANN and ANFIS techniques," J. Electr. Syst. Inf. Technol., vol. 1, no. 3, pp. 212–222, 2014, doi: 10.1016/j.jesit.2014.12.004.

[13] S. D. Al-Majidi, H. D. S. Altai, M. H. Lazim, M. K. Al-Nussairi, M. F. Abbod, and H. S. Al-Raweshidy, "Bacterial Foraging Algorithm for a Neural Network Learning Improvement in an Automatic Generation Controller," Energies, vol. 16, no. 6, Mar. 2023, doi: 10.3390/en16062802.

[14] M. K. Al-Nussairi, S. D. Al-Majidi, A. J. Mshkil, A. M. Dakhil, M. F. Abbodm, and H. S. Al-Raweshidy, "Design of a Two-Area Automatic Generation Control Using a Single Input Fuzzy Gain Scheduling PID Controller," Int. J. Intell. Eng. Syst., vol. 15, no. 6, pp. 443–455, 2022, doi: 10.22266/ijies2022.1231.40.

[15] A. B. Gabis, Y. Meraihi, S. Mirjalili, and A. Ramdane-Cherif, "A comprehensive survey of sine cosine algorithm: variants and applications," Artif. Intell. Rev., vol. 54, no. 7, pp. 5469–5540, Oct. 2021, doi: 10.1007/s10462-021-10026-y.

[16] S. Gupta and K. Deep, "A hybrid self-adaptive sine cosine algorithm with opposition based learning," Expert Syst. Appl., vol. 119, pp. 210–230, Apr. 2019, doi: 10.1016/j.eswa.2018.10.050.

[17] S. D. Al-Majidi, M. Kh. AL-Nussairi, A. J. Mohammed, A. M. Dakhil, M. F. Abbod, and H. S. Al-

Raweshidy, "Design of a Load Frequency Controller Based on an Optimal Neural Network," Energies, vol. 15, no. 17, Sep. 2022, doi: 10.3390/en15176223.

[18] M. Ma, X. Liu, and C. Zhang, "LFC for multi-area interconnected power system concerning wind turbines based on DMPC," IET Gener. Transm. Distrib., vol. 11, no. 10, pp. 2689–2696, 2017, doi: 10.1049/iet-gtd.2016.1985.