



Control and Compensate Interconnected Power Systems Problems Using the Black Hole Optimization Method

Ali Abdyasser Kadhum

Electric Technical Dept, Kufa Technical Institute, Al-Furat Al-Awsat Technical University, Iraq

Kin.ali1@atu.edu.iq

Abstract_ The demand for power and energy has been a global problem in the electricity sector for many years while until now, the globally interconnected power systems have suffered from power losses in tie lines and frequency fluctuations. In this paper, two types of controllers, Proportional Integral Derivative (PID) and Sliding Mode Control (SMC), are proposed to overcome the problems in multi-area power systems where These controllers are used to deal with the 5% step load disturbance imposed on the gas turbine output to experiment with the robustness performance of the power system, particularly in turbo-electric propulsion systems and In addition, Load Frequency Control (LFC) is compensated and performance has been improved for 4-zone power systems during outages so finally This review also explores how cosmologically inspired algorithms affect dynamical system control issues, offering a thorough list of control applications along with their inherent benefits and drawbacks.

Keywords: drawbacks, Optimization Method, Control And Compensate, Sliding Mode Control (SMC).

I. INTRODUCTION

Harvesting energy from black holes on Earth is a topic of great scientific and technological interest, as it could offer a nearly unlimited and clean source of energy. However, the process of extracting energy from these extreme objects is not trivial and requires sophisticated and precise methods [1,2] where One of the most recent theories to achieve this goal was proposed by physicists Luca Comisso and Felipe Asenjo, who suggested that the magnetic field lines surrounding rotating black holes could be cut and reconnected, thus harnessing the kinetic energy of space-time[3,4,5,6] while This mechanism would accelerate plasma particles near the event horizon—the limit beyond which nothing can escape the black hole's gravitational pull—and cause some of them to exit with negative energies, implying that they are draining energy from the black hole as well as This theory is based on previous work by other scientists, such as Roger Penrose, Stephen Hawking, Roger Blandford, and Roman Znajek, who proposed different ways to extract energy from black holes through particle decay, quantum emission, or electromagnetic torque[7,8,9,10,11] so However, Comisso and Asenjo's method has the advantage of being more efficient and less dependent on environmental conditions[12,13,14] in addition To apply this theory in practice, artificial black holes created in Earth-based laboratories would be required, something that has not yet been achieved but could be possible in the future

with technological advances [15,16,17]also Furthermore, the magnetic field and plasma surrounding the black hole would need to be controlled to optimize the magnetic reconnection process and maximize energy extraction moreover Harvesting energy from black holes on Earth could have a major impact on human development, as it could solve the energy problem and contribute to climate change mitigation [18,19,20]and However, it also poses ethical, social, and environmental challenges that should be considered before its implementation [21,22].

II. METHOD

In this section, the theoretical background of the methods used in this work was presented such as Load Frequency Control (LFC), Sliding Mode Control (SMC), Proportional Integral Derivative (PID), and Black Hole Optimization (BHO). In addition, the mathematical model of the four-area interconnected system is included.

2.1. Load Frequency Control

- a) In order to maintain equilibrium between reactive and active powers, a variety of controller designs have been proposed for the purpose of load frequency regulation. As the loads vary, the imbalance will cause a change in the frequency levels. To this end, the implementation of a control system is imperative to counteract the

effects of random load variations and maintain the frequency within the prescribed limits [23]. Problems with load frequency control (LFC), which affected many of these interconnected systems, were of utmost importance as well as The operational objectives of the LFC encompass the regulation of tie-line power fluctuations, the maintenance of a relatively stable frequency, and the distribution of the load across the generators where The construction and analysis of a control system involves the modelling of the system using a mathematical model. Two common approaches are the state variable strategy and the transfer function technique. The state variable method has the capacity to demonstrate both nonlinear and linear systems. It is imperative to note that the linearisation of the system precedes the utilisation of linear state and transfer function equations. The subsequent model of the transfer function is created for the following elements by linearising the system's mathematical equations using the appropriate hypotheses and approximations [25]. The generators in a control zone eventually adjust their speeds synchronously to keep the relative power angles and the frequency to the predefined values in both dynamic and static conditions. The two fundamental objectives of Load Frequency Control (LFC) are as follows [26]:

- b) To control any differences in the power of tie-line power between the controlled zones.
- c) To maintain respectable time response characteristics with a predetermined margin of error.
- d) To lessen the erratic flow of the power between nearby related areas.
- e) The two main aims of LFC are to maintain the linked power system's real frequency and target power production (megawatt).

2.2. Four Area Power System Mathematical Model

Iraqi Middle Area consists of four interconnected gas-turbine power systems. Figure 2 shows the overall diagram of a single area for a power system [27].

The Iraqi Middle Area power system consists of four interconnected gas-turbine power systems, each interconnected by tie-lines. The system's interconnected nature allows for the transmission of electricity across designated regions while simultaneously supplying customer bases. A disturbance in one region can impact the output frequencies of all areas and power at the tie-line. To maintain steady frequency, the control system of each area requires knowledge of the transient status of both areas. Four distinct control actions are employed for the four interconnected power systems to regulate frequency. The initial coarse correction of frequency is performed via the Proportional Integral Derivative (PID) and Sliding Mode Control (SMC) controls.

PID control is often considered the best technique for controlling industrial processes, especially those involving the LFC problem. SMC is a reliable, accurate, and user-friendly control method for non-linear systems impacted by unknown external disturbances and parametric uncertainties. The SMC is constructed to function on a specific surface, known as a sliding surface, and uses the control law to maintain the operating point close to the sliding surface.

Population separation is the foundation of Black Hole Optimization (BH), an optimization technique used to enhance parameters. A space-based entity with a concentrated mass can enter and exit the universe, a phenomenon known as the black hole. The process begins by calculating a cost function for workable solutions to an optimization problem, selecting the best option each time. The Schwarzschild radius is the event horizon's diameter, and the BH begins sucking neighboring stars. Since the BH absorbs stars in its local vicinity, the integral square error (ISE) is used as a cost function to determine the radius of the event horizon. The BHO has a simple construction, is easy to design, and has no issues with parameter change. The simulation findings demonstrate the influence of the PID-BHO and SMC-BHO approaches on resolving tie-line power variations and frequency fluctuations, as well as frequency deviations in output signals for all locations.

[Figure 1 about here.]

2.3. Uncontrolled system results

[Figure 2 about here.]

[Figure 3 about here.]

[Figure 4 about here.]

Figure 5 shows the frequency deviation of the third and fourth areas using PID with EHO. Consequently, it is shown that the $\Delta F_{3,4}$ are reduced to zero which means the PID-EHO has controlled the frequency fluctuation in both areas.

[Figure 5 about here.]

Figure 6 explains the power changes at both the first and second areas tuned using PID and EHO. Consequently, it can be seen that the ΔP_{12} are approached zero which means that the PID-EHO has been controlled successfully.

[Figure 6 about here.]

Figure 7 presents the power changes in the third and fourth areas. Consequently, it is shown that the $\Delta P_{3,4}$ are reduced to zero which means that the PID-EHO has successfully controlled the frequency fluctuation in both areas.

[Figure 7 about here.]

Figure 8 shows the control actions that applied to both the first and second areas. Moreover, it shows the control signals that are applied in both the first and second areas. It can be seen that the PID-EHO has controlled the power change signals in the first 5 sec.

[Figure 8 about here.]

[Figure 9 about here.]

[Figure 10 about here.]

[Figure 11 about here.]

[Figure 12 about here.]

[Figure 13 about here.]

[Figure 14 about here.]

[Figure 15 about here.]

[Figure 16 about here.]

[Figure 17 about here.]

[Figure 18 about here.]

2.4. SMC-BHO results with Tan-hyperbolic Function

[Figure 19 about here.]

[Figure 20 about here.]

[Figure 21 about here.]

[Figure 22 about here.]

[Figure 23 about here.]

[Figure 24 about here.]

[Figure 25 about here.]

III. RESULT AND DISCUSSION

In this section, the results have been discussed in detail using tables. The following table contains the parameters of each area of the power system that is listed by name.

[Table 1 about here.]

Where R is governor speed regulation and $T_t = T_g = T_r = T_s$ for different types of turbines.

Table 1 contains the parameters of the PID control after applying the BHO method to tune them. In this scenario, the parameters of the PIDs have been tuned using the BHO method after it has been connected to the MATLAB Simulink of the system.

Figure 26 contains the parameters of the SMC control with sign function after applying the BHO method to tune them. In the second scenario, the parameters are tuned using the BHO method after it has been implemented in the power system.

[Figure 26 about here.]

[Figure 27 about here.]

[Figure 28 about here.]

IV. CONCLUSION

In this paper, two types of controllers have been implemented (PID and SMC) in order to overcome the power systems issues with frequency deviation and power changes also. The system under consideration consists of four interconnected areas of turbine power systems in addition to. The efficacy of the proposed controllers in addressing frequency deviation and power changes within the system is evidenced by their ability to overcome a 5% step load disturbance in the first area and. To address these challenges, the interconnected system was subjected to three distinct scenarios.

REFERENCES

- [1] S. Kim, P.-I. Hwang, and J. Suh, "Automatic Generation Control Ancillary Service Cost-Allocation Methods Based on Causar-Pays Principle in Electricity Market," *Energies*, vol. 17, no. 11, 2024. [Online]. Available: <https://doi.org/10.3390/en17010011>
- [2] L. Xi, L. Zhou, Y. Xu, and X. Chen, "A Multi-Step Unified Reinforcement Learning Method for Automatic Generation Control in Multi-Area Interconnected Power Grid," *IEEE Transactions on Sustainable Energy*, vol. 12, no. 2, pp. 1406–1415, 2021. [Online]. Available: <https://doi.org/10.1109/TSTE.2020.3047137>
- [3] A. Daraz, S. A. Malik, A. Waseem, A. T. Azar, I. U. Haq, Z. Ullah, and S. Aslam, "Automatic Generation Control of Multi-Source Interconnected Power System Using FOI-TD Controller," *Energies*, vol. 14, no. 5867, 2021. [Online]. Available: <https://doi.org/10.3390/en14185867>
- [4] I. Jayawardene, Y. Wei, and G. Venayagamoorthy, "Optimized Automatic Generation Control in a Multi-Area Power System with Particle Swarm

- Optimization,” in *Proc. IEEE Symp. Series Comput. Intell. (SSCI)*, 2017. [Online]. Available: <https://doi.org/10.1109/SSCI.2017.8285386>
- [5] Z. Qu, W. Younis, Y. Wang, and P. M. Georgievitch, “A Multi-Source Power System’s Load Frequency Control Utilizing Particle Swarm Optimization,” *Energies*, vol. 17, no. 517, 2024. [Online]. Available: <https://doi.org/10.3390/en17020517>
- [6] A. J. Sultan and F. N. Saeed, “AGC of Multi Area Power System Based PSO under Deregulated Conditions,” *Int. J. Eng. Technol.*, vol. 7, no. 3, p. 1446, 2021. [Online]. Available: <https://doi.org/10.14419/ijet.v7i3.13076>
- [7] G. Eappen and T. Shankar, “Optimization of Two Area AGC Based Power System Using PSO Tuned Fuzzy PID Controller and PSO Trained SSSC and TCPS,” *Int. J. Eng. Technol.*, vol. 7, no. 4.10, p. 163, 2020. [Online]. Available: <https://doi.org/10.14419/ijet.v7i4.10.20828>
- [8] D. Aklilu, “Automatic Generation Control of Two Area Thermal Power System Using Single Objective PSO and DE Optimization Techniques,” *Int. J. Innov. Technol. Explor. Eng.*, vol. 9, no. 5, pp. 1436–1441, 2020. [Online]. Available: <https://doi.org/10.35940/ijtee.e2842.039520>
- [9] V. Dhawane and D. Bichkar, “Load Frequency Control Optimization Using PSO Based Integral Controller,” *Int. J. Recent Technol. Eng. (IJRTE)*, vol. 8, no. 6, pp. 97–103, 2020. [Online]. Available: <https://doi.org/10.35940/ijrte.e6749.038620>
- [10] A. Falehi, “Optimal Design of Fuzzy-AGC Based on PSO and RCGA to Improve Dynamic Stability of Interconnected Multi Area Power Systems,” *Int. J. Autom. Comput.*, vol. 17, no. 4, pp. 599–609, 2020. [Online]. Available: <https://doi.org/10.1007/s11633-017-1064-0>
- [11] A. Daraz, S. Malik, H. Mokhlis, I. Haq, G. Laghari, and N. Mansor, “Fitness Dependent Optimizer-Based Automatic Generation Control of Multi-Source Interconnected Power System with Non-Linearities,” *IEEE Access*, vol. 8, pp. 100989–101003, 2020. [Online]. Available: <https://doi.org/10.1109/ACCESS.2020.2998127>
- [12] V. Dhawane and R. Bichkar, “Automatic Generation Control of a Thermal Power Plant with Reheat Turbine Using PSO Optimized Integral Controller,” *Int. J. Electr. Eng. Technol.*, vol. 11, no. 4, 2020. [Online]. Available: <https://doi.org/10.34218/ijet.11.4.2020.036>
- [13] V. Veerasamy *et al.*, “A Hankel Matrix Based Reduced Order Model for Stability Analysis of Hybrid Power System Using PSO-GSA Optimized Cascade PI-PD Controller for Automatic Load Frequency Control,” *IEEE Access*, vol. 8, pp. 71422–71446, 2020. [Online]. Available: <https://doi.org/10.1109/ACCESS.2020.2987387>
- [14] F. Zwayyer, A. Abood, and J. Hussein, “Improved Grey Wolf Optimizer Algorithm for PIDF Controller for AGC of Multi-Area Multi-Source Interconnected Power System,” in *Proc. IEEE Int. Conf. Autom. Control Intell. Syst. (I2CACIS)*, 2021. [Online]. Available: <https://doi.org/10.1109/I2CACIS52118.2021.9495884>
- [15] S. Nayak, S. K. Kar, and S. S. Dash, “Performance Comparison of hSGA-PS Procedure with PIDA Regulator in AGC of Power System,” in *Proc. Odisha Int. Conf. Electr. Power Eng. Commun. Comput. Technol. (ODICON)*, 2021. [Online]. Available: <https://doi.org/10.1109/ODICON50556.2021.9428929>
- [16] K. Derbel and K. Beneda, “Sliding Mode Control for Micro Turbojet Engine Using Turbofan Power Ratio as Control Law,” *Energies*, vol. 13, no. 4841, 2020. [Online]. Available: <https://doi.org/10.3390/en13184841>
- [17] L. Abualigah *et al.*, “Black Hole Algorithm: A Comprehensive Survey,” *Appl. Intell.*, vol. 52, pp. 1–24, 2022. [Online]. Available: <https://doi.org/10.1007/s10489-021-02980-5>
- [18] J. Luo, Y. Tian, and Z. Wang, “Research on Unmanned Aerial Vehicle Path Planning,” *Drones*, vol. 8, no. 2, p. 51, 2024. [Online]. Available: <https://doi.org/10.3390/drones8020051>
- [19] H. Ma, S. Lin, and B. Jin, “Oppositional Particle Swarm Optimization Algorithm and Its Application to Fault Monitor,” in *Proc. Chinese Conf. Pattern Recognit.*, Nanjing, China, 2009, pp. 1–5. [Online]. Available: <https://doi.org/10.1109/CCPR.2009.5344006>
- [20] A. Żyluk, K. Kuźma, N. Grzesik, M. Zieja, and J. Tomaszewska, “Fuzzy Logic in Aircraft Onboard Systems Reliability Evaluation—A New Approach,” *Sensors*, vol. 21, no. 23, p. 7913, 2021. [Online]. Available: <https://doi.org/10.3390/s21237913>
- [21] M. Pasieka, N. Grzesik, and K. Kuźma, “Simulation Modeling of Fuzzy Logic Controller for Aircraft Engines,” *Int. J. Comput.*, vol. 16, pp. 27–33, 2017. [Online]. Available: <https://doi.org/10.47839/ijc.16.1.868>
- [22] A. Barzkar and M. Ghassemi, “Electric Power Systems in More and All Electric Aircraft: A Review,” *IEEE Access*, vol. 8, pp. 169314–169333, 2020. [Online]. Available: <https://doi.org/10.1109/ACCESS.2020.3024168>

*Correspondent e-mail address Kin.ali1@atu.edu.iq

Peer reviewed under responsibility of Universitas Muhammadiyah Sidoarjo, Indonesia

© 2025 Muhammadiyah University Sidoarjo, All right reserved, This is an open access article under the CC BY license(<http://creativecommons.org/licenses/by/4.0/>)

Received: 2025-10-30

Accepted: 2025-10-31

Published: 2025-10-31

LIST OF TABLE

Table 1. Results of the parameters of four areas power system.....	98
--	----

Table 1. Results of the parameters of four areas power system

Area	Type	D	H	T_g	T_t	R
1	Gas-turbine	0.8	6	0.1	0.6	0.04
2	Gas-turbine	0.8	6	0.1	0.6	0.04
3	Gas-turbine	0.8	6	0.1	0.6	0.04
4	Gas-turbine	0.8	6	0.1	0.6	0.04

LIST OF FIGURES

Figure 1. Overall diagram of the power system with LFC diagram	100
Figure 2. Assessment explain in above the frequency changes of the first.....	100
Figure 3. Rate explain The frequency changes of the third and fourth areas of the uncontrolled system.....	100
Figure 4. The frequency changes of the first and second areas after applying PID-EHO.	101
Figure 5. The frequency changes of the third and fourth areas after applying PID-EHO.....	101
Figure 6. The AGC of the first and second areas after applying PID-EHO.....	101
Figure 7. The AGC of the third and fourth areas after applying PID-EHO	102
Figure 8. Assessment The control actions of the first and second areas after applying PID-BHO.....	102
Figure 9. Assess The control actions of the third and fourth areas after applying PID-BHO.....	102
Figure 10. Outcome The error convergence of PID and BHO	103
Figure 11. Distribution of The frequency changes of the first and second areas after applying SMC-BHO.....	103
Figure 12. assess The frequency changes of the third and fourth areas after applying SMC-BHO	103
Figure 13. Results pf The ACE of the first and second areas after applying SMC-BHO	104
Figure 14. Rate The ACE of the third and fourth areas after applying SMC-BHO	104
Figure 15. Estimate The control actions of the first and second areas after applying SMC-BHO	104
Figure 16. Results The control actions of the third and fourth areas after applying SMC-BHO	105
Figure 17. Outcome of the error convergence of SMC and BHO	105
Figure 18. Results of The frequency changes of the first and second areas after applying PID-BHO	105
Figure 19. Rate of The frequency changes of the third and fourth areas after applying SMC-BHO	106
Figure 20. Assessment The ACE of the first and second areas after applying PID-BHO	106
Figure 21. Assessment The ACE of the third and fourth areas after applying SMC-BHO	106
Figure 22. Outcomes The control actions of the first and second areas after applying PID-BHO	107
Figure 23. Rate of The control actions of the third and fourth areas after applying SMC-BHO	107
Figure 24. Results of the error convergence of SMC and BHO	107
Figure 25. Outcomes of study according to The parameters of PIDs using BHO	108
Figure 26. Outcomes of study according to The parameters of SMCs with sign using BHO.....	108
Figure 27. Outcomes of study according to The parameters of SMCs with tanh using BHO	108

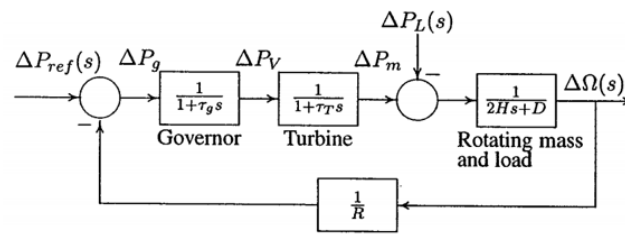


Figure 1. Overall diagram of the power system with LFC diagram

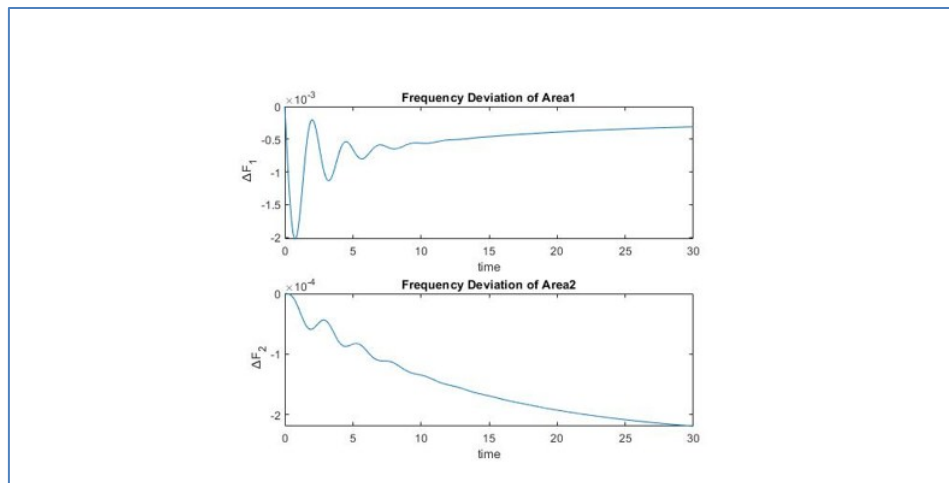


Figure 2. Assessment explain in above the frequency changes of the first

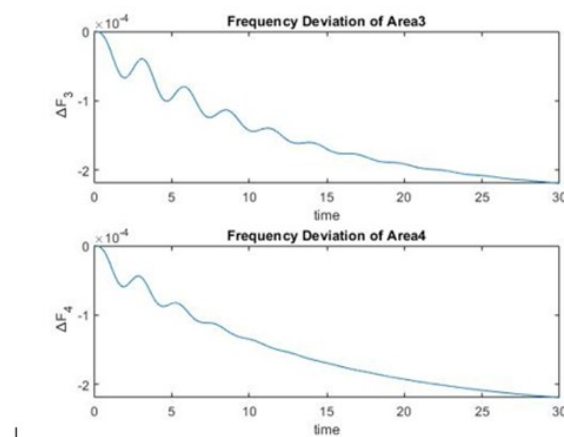


Figure 3. Rate explain The frequency changes of the third and fourth areas of the uncontrolled system

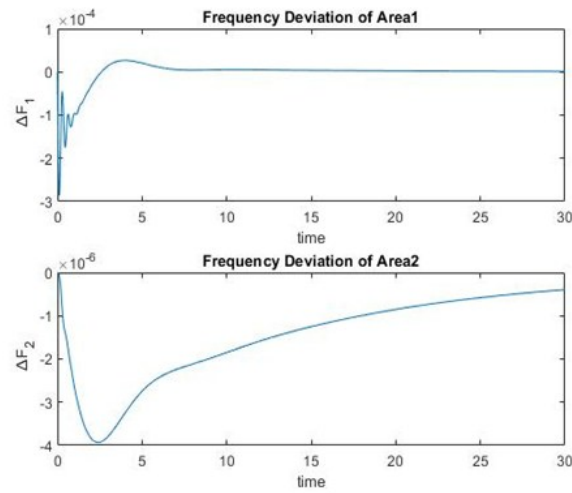


Figure 4. The frequency changes of the first and second areas after applying PID-EHO.

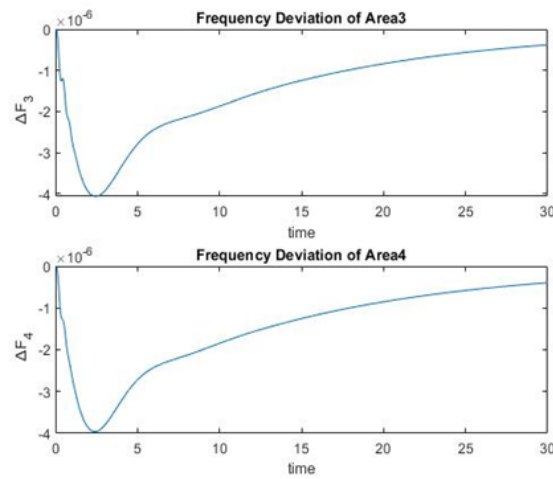


Figure 5. The frequency changes of the third and fourth areas after applying PID-EHO

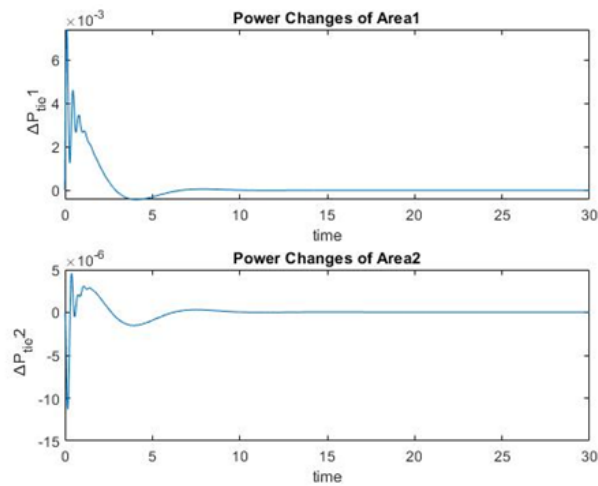


Figure 6. The AGC of the first and second areas after applying PID-EHO

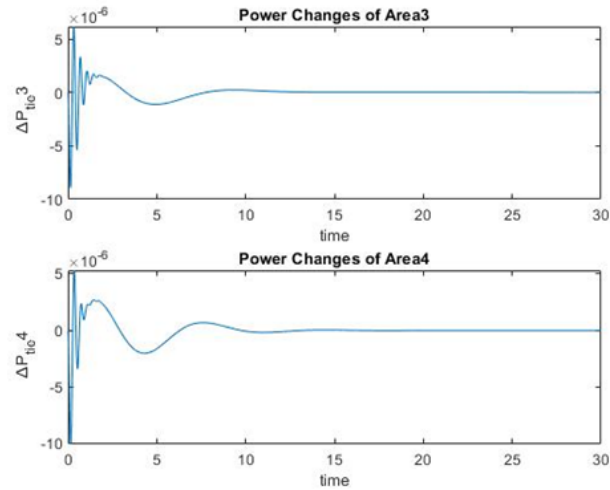


Figure 7. The AGC of the third and fourth areas after applying PID-EHO

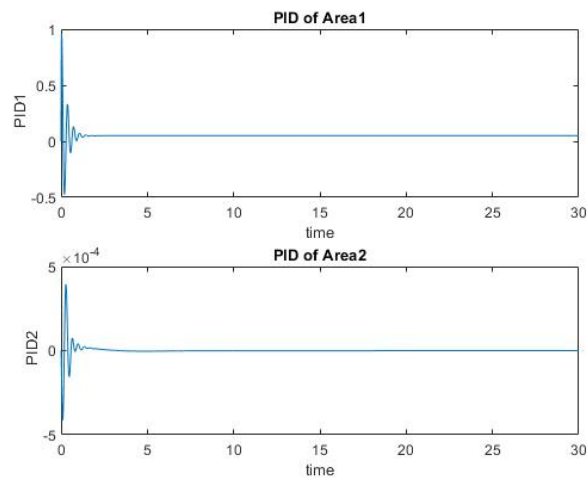


Figure 8. Assessment The control actions of the first and second areas after applying PID-BHO.

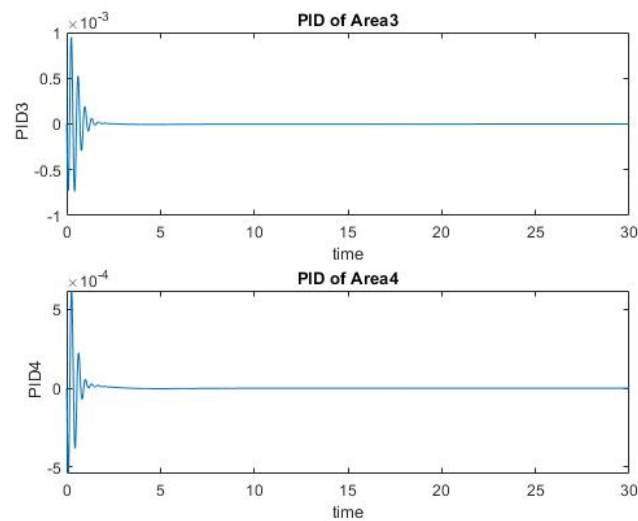


Figure 9. Assess The control actions of the third and fourth areas after applying PID-BHO

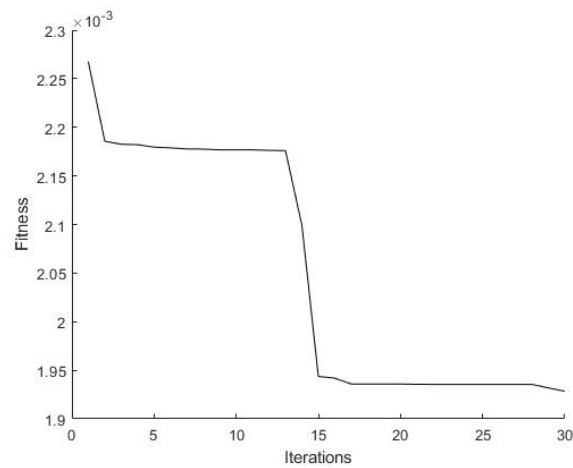


Figure 10. Outcome The error convergence of PID and BHO

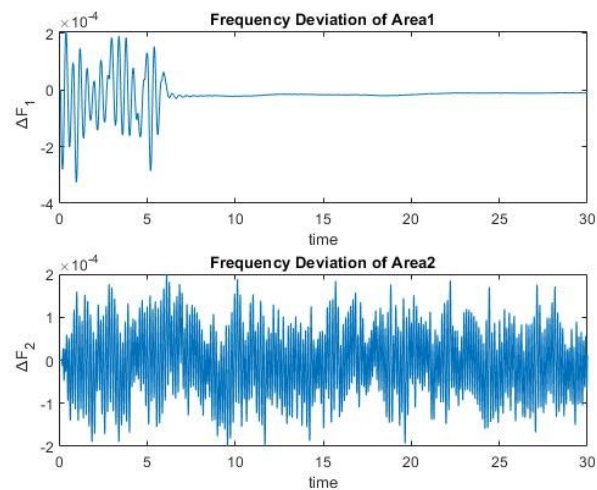


Figure 11. Distribution of The frequency changes of the first and second areas after applying SMC-BHO.

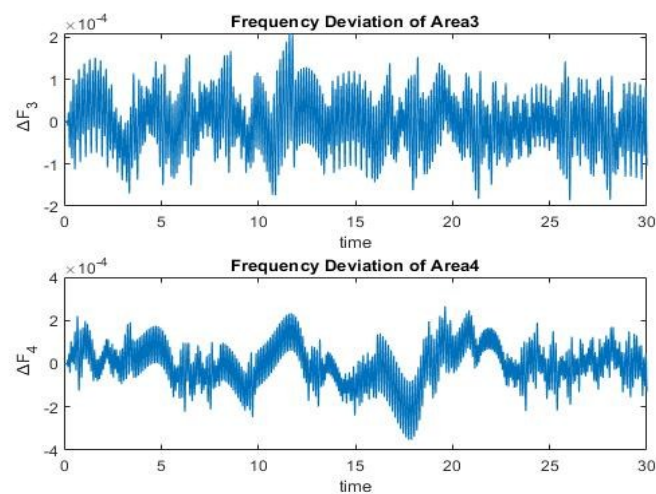


Figure 12. assess The frequency changes of the third and fourth areas after applying SMC-BHO

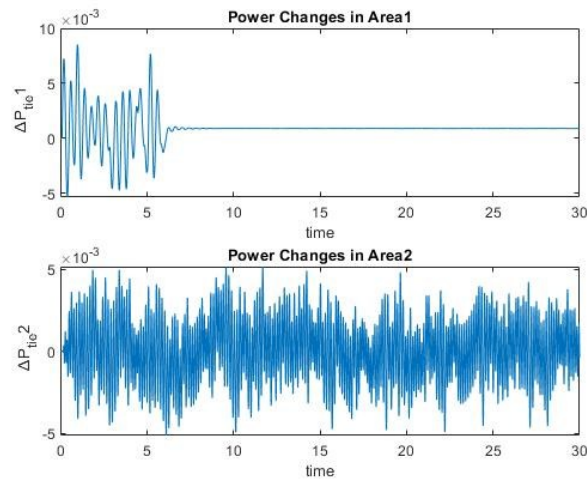


Figure 13. Results pf The ACE of the first and second areas after applying SMC-BHO

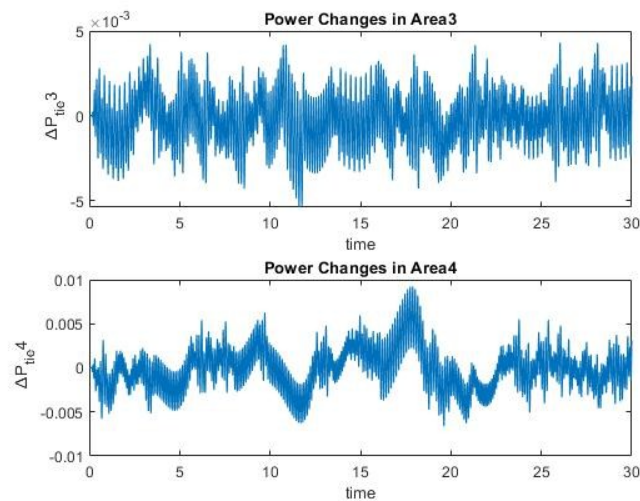


Figure 14. Rate The ACE of the third and fourth areas after applying SMC-BHO

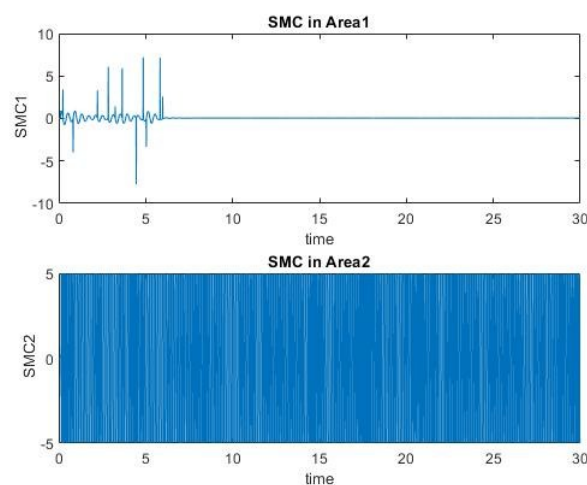


Figure 15. Estimate The control actions of the first and second areas after applying SMC-BHO

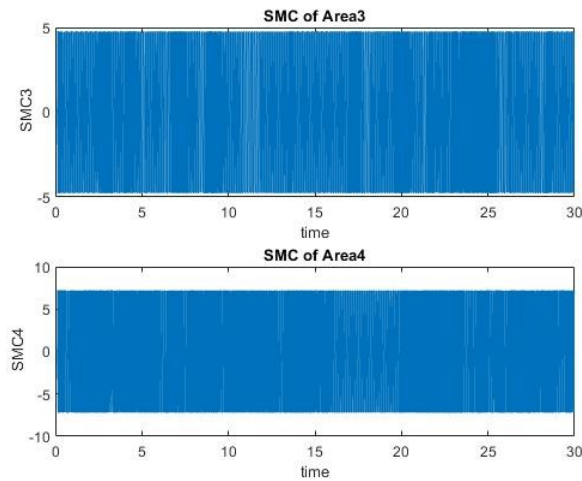


Figure 16. Results The control actions of the third and fourth areas after applying SMC-BHO

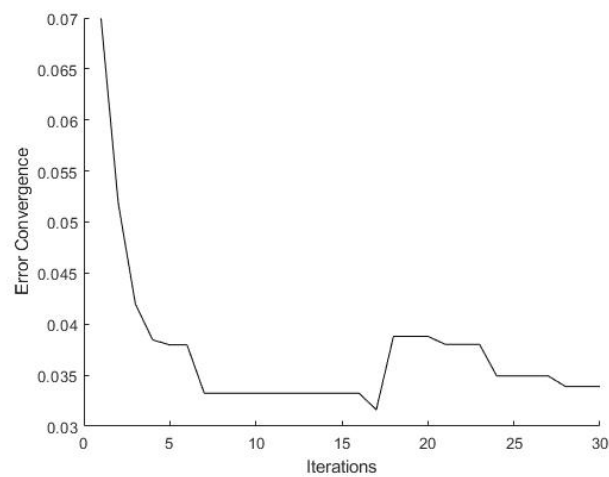


Figure 17. Outcome of the error convergence of SMC and BHO

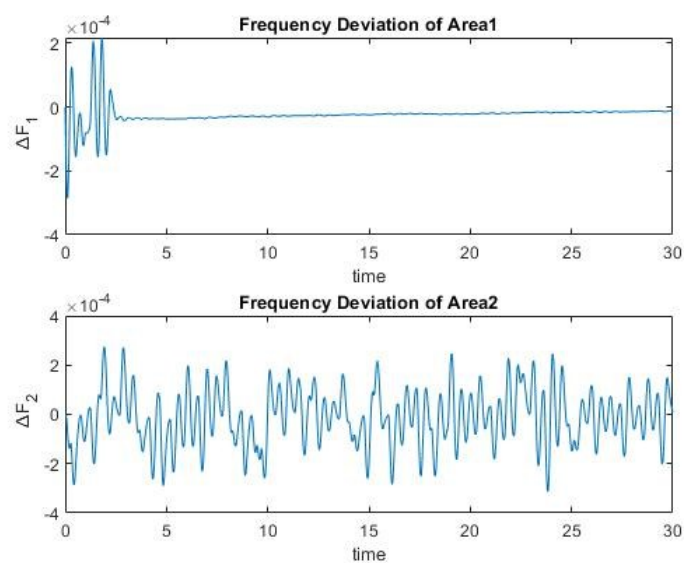


Figure 18. Results of The frequency changes of the first and second areas after applying PID-BHO

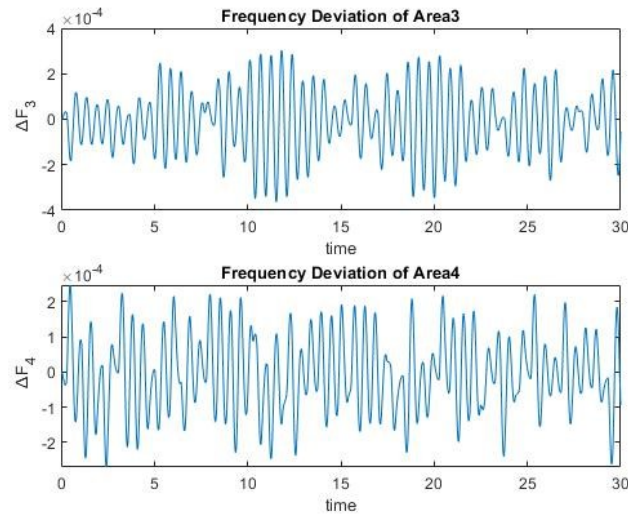


Figure 19. Rate of The frequency changes of the third and fourth areas after applying SMC-BHO

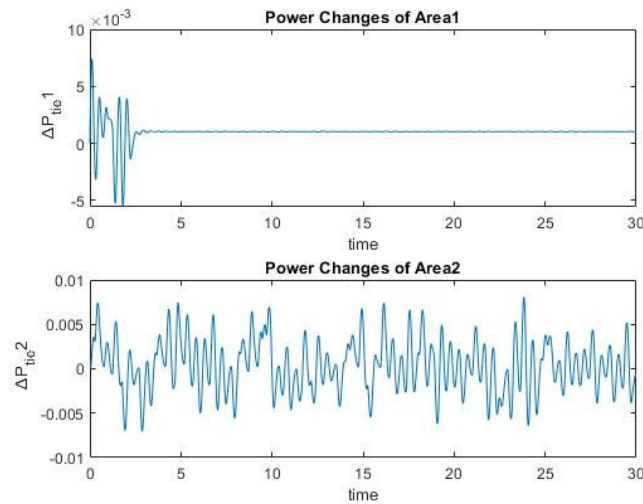


Figure 20. Assessment The ACE of the first and second areas after applying PID-BHO

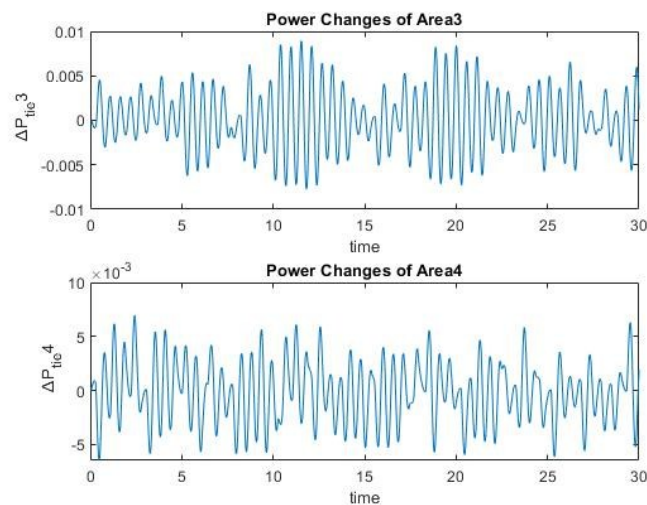


Figure 21. Assessment The ACE of the third and fourth areas after applying SMC-BHO

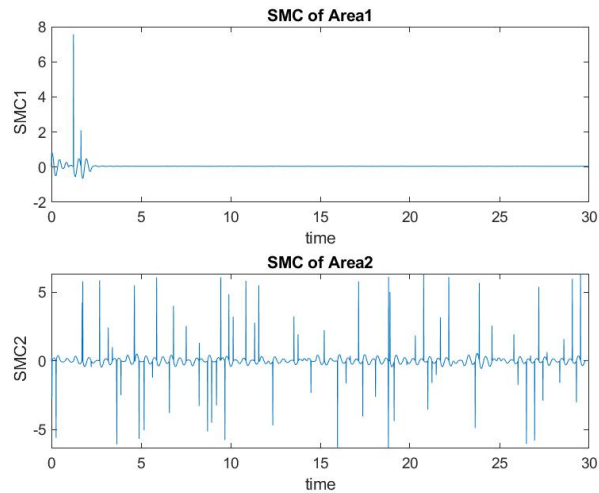


Figure 22. Outcomes The control actions of the first and second areas after applying PID-BHO

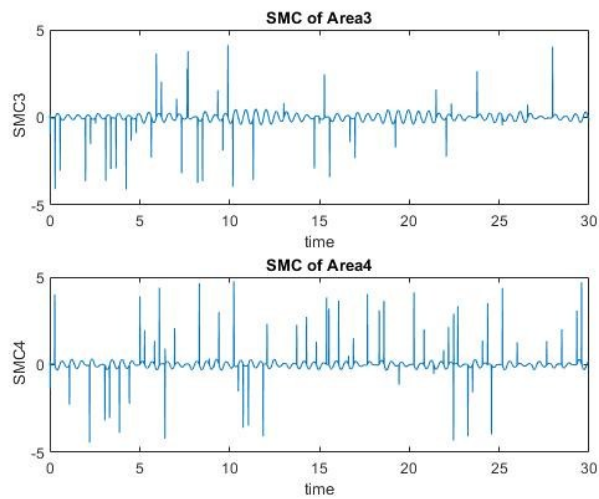


Figure 23. Rate of The control actions of the third and fourth areas after applying SMC-BHO

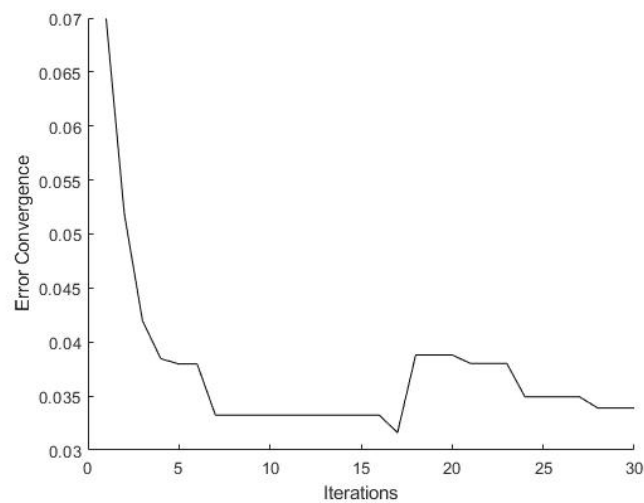


Figure 24. Results of the error convergence of SMC and BHO

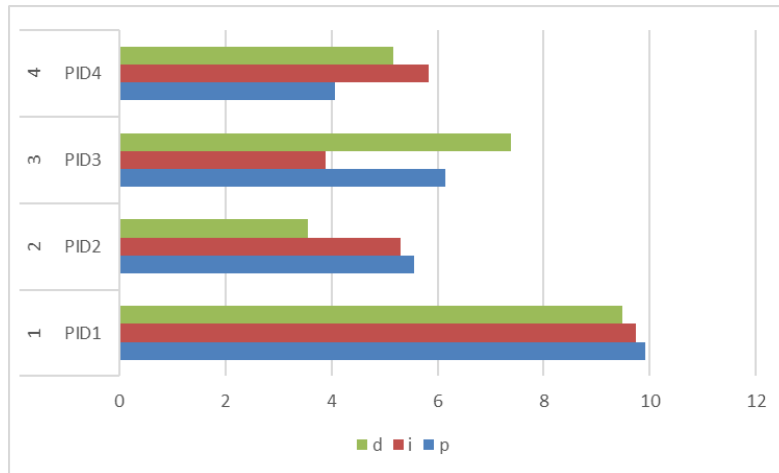


Figure 25. Outcomes of study according to The parameters of PIDs using BHO

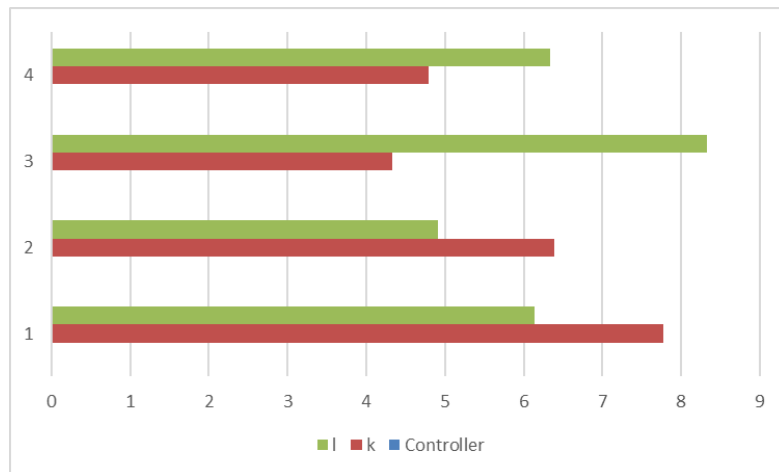


Figure 26. Outcomes of study according to The parameters of SMCs with sign using BHO

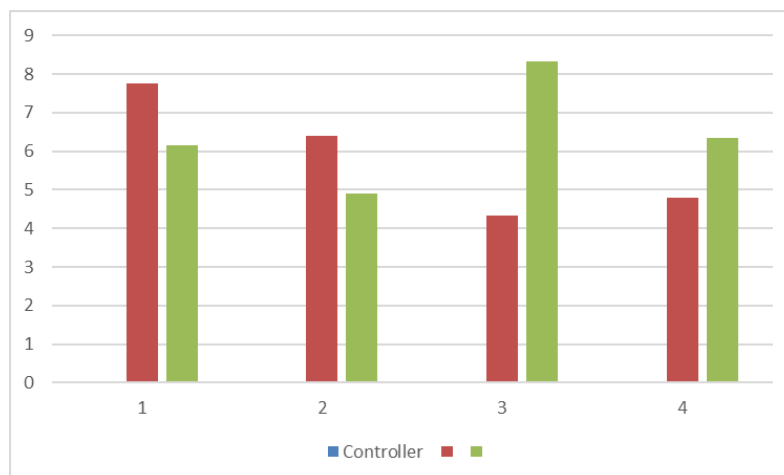


Figure 27. Outcomes of study according to The parameters of SMCs with tanh using BHO