Modern Temperature Control of Electric Furnace in Industrial Applications Based on Modified Optimization Technique

Mahmoud M. Hussein 1, Salem Alkhalaf 2, Tarek Hassan Mohamed 1, Dina S. Osheba 3, Mahrous Ahmed 4, Ashraf Hemeida 1,* and Ammar M. Hassan 5

1 Department of Electrical Engineering, Faculty of Energy Engineering, Aswan University, Aswan 81528, Egypt
2 Department of Computer, College of Science and Arts in Ar-Rass, Qassim University, Ar Rass 52571, Saudi Arabia
3 Department of Electrical Engineering, Faculty of Engineering, Menoufia University, Shebin El Kom 32511, Egypt
4 Department of Electrical Engineering, College of Engineering, Taif University, Taif 21944, Saudi Arabia
5 Arab Academy for Science, Technology and Maritime Transport, Aswan 81516, Egypt
* Correspondence: ashraf@asu.edu.eg; Tel.: +20-106-032-2000

Abstract: In this paper, an enhanced version of whale optimization algorithm (EWOA) is presented to be applied in adaptive control techniques as a parameter tuner. One weakness point in this control scheme is the low efficiency of its objective function. Balloon effect (BE) is a modification introduced to increase the efficiency of the objective function of the optimization method and the ability of the controller to deal with system problems increase consequently. Controlling of the temperature of electric furnaces is considered as one of the important issues in several industrial applications. Conventional controllers such as PID controller cannot deal efficiently with the problem of parameters variations and step disturbance. This paper proposes an adaptive controller, in which the gain of the temperature controller is tuned online using EWOA supported by balloon effect. System responses obtained by the proposed adaptive control scheme using EWOA + BE have been compared with an electric furnace temperature control (EFTC) scheme response using both the PID controller-based modified flower pollination algorithm (MoFPA) and PID-accelerated PIDA-based MoFPA. From the results, it can be observed that the proposed controller tuned by the EWOA + BE method improves the time performance compared with the other techniques (PID and PIDA-based MoFPA) in case of EFTC application.

Keywords: modern control methods; temperature control; electric furnace; industrial applications

1. Introduction

The electric furnaces are the most widely used in the industry. They convert electrical energy to heat energy. Temperature in electric furnaces is one of the pressing factors that needs accurate and fast control in this industrial process [1]. The physical properties of the resulting material may differ from the physical properties of the required material if the electric furnace temperature is not precisely controlled. Therefore, it needs accurate and rapid control as much as possible.

The electric furnace temperature control (EFTC) system is considered as one of the real-world second-order systems plus time delay (SOSPD) [2] that are broadly utilized in numerous industrial production operations [2,3]. There are many electric furnace temperature control approaches in industry. From these approaches, proportional-integral-derivative (PID) control system, sliding mode control (SMC), predictive control, and internal model control (IMC). However, about 90% of the industry uses the PID controller due to its ease of use, obvious functionality, and its applicability [4].

Ziegler–Nicholes (ZN) and Cohen–Coons (CC) techniques are considered the most widely used for tuning the traditional PID method [5]. Tuning the PID is an arduous
duty for the researchers as a result of the non-linear properties of the electric furnace system. Moreover, the system parameters might vary with time. Therefore, an intelligent and adaptive controlling technique can be a superior decision for tuning the PID. Currently, intelligent computing approaches such as fuzzy logic (FL) [6], genetic algorithm (GA) [7,8], and neural network (NN) [9] are effectively implemented to resolve difficult and complicated problems [10].

Conventional PID system controllers are linear and need the experience of operators to regulate the coefficient, which is considered a time-consuming procedure [11]. Therefore, it necessitates the evolution of an optimum tuning technique for the PID control system.

The genetic algorithm (GA) technique is an optimization method that depends on the evolution operation. It was proposed first by Holland, 1975 [12,13]. It is a robust optimization technique console design [5]. It might be exploited to optimize diverse error functions to achieve PID parameters.

The authors in [14] exploited the Nelder Mead (NM) technique for tuning the PID utilizing the integral of absolute error (IAE) as a cost function. They demonstrated that their suggested technique is more efficient than Ziegler–Nicholes (ZN), Cohen–Coon (CC), and direct synthesis (DS) techniques. In [15], the authors implemented a fuzzy logic for tuning the PID for controlling the electrical furnace temperature as a first order system. They indicated that the proposed control method is better than the conventional PID controller system. The authors in [12] implemented GA for optimizing the gains of PID controller utilizing a weighted combination of integral square error (ISE), integral absolute error (IAE), and integral time multiple absolute errors (ITMAE) to improve the system performance. They acquire a more stable controller by implementing GA method through improving the settling time, peak time, and rise time (transient and steady state response). In [16] the authors proposed and tested an enhanced method of extended non-minimal state space fractional order model predictive control (EnMSSFMP) on the model of temperature for an electric heating furnace. They compared their suggested approach with an extended non-minimal state space model predictive control (EnMSS MPC) and model predictive control (MPC) and they noticed the effectiveness of their proposed approach. The authors in [17] presented a genetic algorithm (GA)-based PID control system for tuning the PID to overcome the problems of the conventional PID, exploiting IAE as a cost function. They observed that their proposed technique is more effective than the traditional PID. In [18], the authors presented a relative study between the fuzzy self-tuned PID control system and GA-PID control system for controlling the position of DC motor. The authors in [19] designed a self-learning fuzzy controller for tuning the PID control parameters and they found that it has effective performance. In [20], the authors designed the PID, GA-PID, and GA-IMC control systems for controlling the heat exchanger temperature. They indicated that the GA-IMC control system has a better performance than the others. The authors in [21] presented an improved form of the original flower pollination algorithm (FPA) named the modified flower pollination algorithm (MoFPA) to enhance the performance of searching. The suggested MoFPA is implemented for designing the proportional-integral-derivative-accelerated (PIDA) control system to adjust the temperature of the electric heating furnace. The authors found that the proposed control system is efficient compared with the PID control system.

A poor temperature control method in electric furnace means increasing power losses. So, a robust temperature control is considered as a way to minimize the total energy consumed by a furnace.

Optimization techniques such as whale optimization algorithm (WOA) have been used to tune gains of conventional controllers in an adaptive manner in many industrial applications [22]. Moreover, an enhanced version of the whale optimization algorithm (EWOA) was presented to increase the efficiency of classical WOA [23]. The authors in [24] proposed an effective whale optimization algorithm for solving optimal power flow problems (EWOA-OPF). On the other hand, one of the disadvantages of implementing classical techniques such as (WOA, EWOA) in the adaptive control approach is applying
nominal parameters in designing the objective function considering zero-load disturbance. However, this assumption may lead to poor performance especially at the moment of disturbance and parameters changes. Therefore, this study proposed a balloon effect (BE) modification \[25\] to the optimization algorithm as a solution of this problem, to support its sensitivity to both of disturbances and parameters changes. The main contributions of this study can be summed up as the following:

- The (EWOA + BE) optimization algorithm is implemented for tuning the gains of the temperature controller of an electric furnace;
- The results and performance of the proposed adaptive technique based on (EWOA + BE) is compared with the recent and efficient algorithms suggested in the literature;
- The results prove that the adaptive temperature control based on (EWOA + BE) technique has more accurate results with the best overshoot, rise time, and settling time compared with the other recent schemes.

The remainder of this paper is organized as follows: Electric furnace temperature system is provided in Section 2. Enhanced whale optimization algorithm is discussed in Section 3. Balloon effect is presented in Section 4. The proposed control system is presented in Section 5. Simulation results are investigated in Section 6. Conclusions are presented in Section 7.

2. Electric Furnace Temperature System

Figure 1 illustrates the block diagram of the used application system \[26\]. It contains four parts: electrical furnace, thermocouple, heater, and controller. The parameters can be illustrated as follows:

- \( r \) represents the input voltage;
- \( U \) represents the controller’s output voltage;
- \( Y \) represents the thermocouple’s output voltage and;
- \( R \) represents the armature resistance.

![Block diagram of the electric furnace](image)

The transfer function of the proposed temperature control system can be expressed in SOSP as \[26\]:

\[
G_p(s) = \frac{0.15}{s^2 + 1.1s + 0.2} \tag{1}
\]

Considering the time delay, the total transfer function is:

\[
G_p(s) = \frac{0.15}{s^2 + 1.1s + 0.2} e^{-1.5s} \tag{2}
\]

3. Enhanced Whale Optimization Algorithm

The idea of whale optimization algorithm (WOA) \[23–27\] is built on studying the social behavior of humpback whales to simulate it. It can be considered as a bubble net...
hunting strategy. In this strategy, bubbles make a ‘9-shaped path’ around the prey using the whale. It dives about 10 to 16 m, then sends a spiral shape of bubbles around the prey and moves in the direction of the prey to capture it as illustrated in Figure 2.

![Figure 2. Humpback whale bubble net hunting strategy.](image)

According to the WOA, the current location of the prey is the best solution. The equation of general prey is represented after the past whale action by:

\[
\vec{D} = \left| \vec{C} \cdot \vec{X}^*(t) - \vec{X}(t) \right| \tag{3}
\]

\[
\vec{X}(t + 1) = \vec{X}^*(t) - \vec{D} \cdot \vec{A} \tag{4}
\]

where
- \( \vec{A} \) and \( \vec{C} \) represent vectors of coefficients;
- \( \vec{X}^* \) represents the best position (updated every iteration if there is another best solution);
- \( \vec{X} \) represents the vector of the position; and
- \(|.|\) represents the absolute value.

The best position is modified by time to reach the best location. The vectors \( \vec{C} \) and \( \vec{A} \) can be calculated by

\[
\vec{A} = 2 \cdot \vec{a} \cdot \vec{r} - \vec{a} \tag{5}
\]

\[
\vec{C} = 2 \cdot \vec{r} \tag{6}
\]

where
- \( \vec{r} \) represents a random vector in the interval [0, 1];
- \( \vec{a} \) decreases linearly from 2 to 0 over the iterations.

There are two paths for catching prey that can be explained and mathematically presented as follows:

In this method, if \( t \) is the current number of iteration and \( t_{\text{max}} \) is the maximum iteration number, the shrinking encircling approach is executed by linearly decreasing the value of \( \vec{a} \) using the following equation:

\[
\vec{a} = 2 - \frac{2t}{t_{\text{max}}} \tag{7}
\]

In this path, a helix-shape describes the position of the prey and the whale, then the movement can be expressed as:

\[
\vec{X}(t + 1) = \vec{D} \cdot e^{i\lambda} \times \cos(2\pi t) + \vec{X}^*(t) \tag{8}
\]
The enclosed phase mode can be described by:

\[
\vec{X}(t+1) = \begin{cases} 
\vec{X}^*(t) - \vec{D} \cdot \vec{A} & \text{if } p < 0.50 \\
\vec{D} \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.50 
\end{cases}
\]  

(9)

where

- \( b \) is a constant to define the shape of the logarithmic spiral;
- \( l \) is a random number within the interval \([-1, 1]\) and;
- \( p \) represents a probability number inside \([0, 1]\).

At the end, there is an exploration phase. In this phase, humpback whales search for their prey randomly using the anisotropy of the exploration vector \(|\vec{A}|\).

\[
\vec{D} = |\vec{C} \cdot \vec{X}_{\text{random}} - \vec{X}(t)|
\]  

(10)

\[
\vec{X}(t+1) = \vec{X}_{\text{random}} - \vec{D} \cdot \vec{A}
\]  

(11)

A modified WOA is presented in [23] by enhancing the searching operation using addition of an inertia weight \( \omega \) (where \( \omega \in [0, 1] \)) to the technique. The location vector of WOA can be adjusted to a modified one as:

\[
\vec{X}^*(t) \rightarrow \omega \vec{X}^*(t)
\]  

(12)

Pseudo-code of the enhanced whale optimization algorithm (EWOA) is presented in Appendix A.

4. Balloon Effect

Balloon effect (BE) is presented to solve the issue of updating the cost function of the optimization method to increase its sensitivity to system problems such parameters variations and system disturbance. BE is applied in many systems as in a [28–31].

Figure 3 describes the idea of the balloon effect. According to Figure 4, at any iteration \((i)\) the optimizer is fed by both of the system output \(Y_i(s)\) and the system input \(U_i(s)\) to compute the transfer function of the proposed system:

\[
G_i(s) = \frac{Y_i(s)}{U_i(s)}
\]  

(13)
\[ G_i(s) = (A L_i) (G_{i-1}(s)) \quad (14) \]

while \( G_{i-1}(s) \) can be calculated using the nominal value as:

\[ G_{i-1}(s) = (\rho_i) (G_o(s)) \quad (15) \]

and

\[ \rho_i = \prod_{n=1}^{i-1} A L_n \]

### 5. Proposed Control Technique

The dependence of the objective function on nominal values of the system transfer function is considered as a foible in the adaptive control design using conventional EWOA, but the presence of BE beside EWOA deals with this disadvantage, where the objective function depends on the updated value of the transfer function at any moment. In this study, EWOA + BE is applied inside a temperature-adaptive controller of the electric furnace. For simplification, Equation (1) is used as a plant transfer function and to make the total closed loop transfer function in the form of the second-order system the following lag compensator is applied:

\[ G_c(s) = \frac{K_i(s + 0.24)}{s} \quad (16) \]

So

\[ T.F = \frac{\omega_n^2}{s^2 + 2\zeta\omega_ns + \omega_n^2} \quad (17) \]

Now the job of the optimizer is to make online tuning of \( K_i \) as shown in Figure 5, noting that:

In case of EWOA,

\[ \omega_n = \sqrt{K_i} \text{ and } 2\zeta\omega_n = 0.82 \]

where

\[ T_{r0} = \frac{\pi - \sqrt{(1 - \zeta^2)}}{\omega_n \sqrt{(1 - \zeta^2)}}, \quad T_{s0} = \frac{4}{\omega_n\zeta} \quad \text{and} \quad M_{P0} = e^{\left(\frac{-n^2}{\omega_n^2}\right)} \]

So the object function

\[ j = \min \sum T_{r0} + T_{s0} + M_{P0} = f(K_i, G_o(s)) \quad (18) \]

According to Equation (18) the system variations affect the modified value of \( K_i \).

In the case of EWOA + BE, \( \omega_n = \sqrt{K_i} \) and \( 2\zeta\omega_n = 0.82 \) the object function

\[ J = \min \sum T_{rj} + T_{sj} + M_{Pj} = f(K_i, G_i(s)) \quad (19) \]
According to Equation (19) the system variations affect strongly the modified value of $K_i$.

Figure 5. Temperature control system using three control techniques.

6. Results and Discussion

This section discusses the dynamic performance performed by the electric furnace with the proposed temperature control scheme.

The MATLAB/Simulink environment is utilized to model and simulate the suggested system. Three scenarios have been used to test the efficiency of applying the adaptive temperature control techniques shown in Figure 5 to the electric furnace as follows:

6.1. First Scenario

In this scenario a constant temperature desired value is applied to the proposed system. Moreover, a system with an adaptive temperature controller with (EWOA + BE) is compared with the adaptive controller with classical EWOA and both recent controllers presented in [21] (MoFPA-based PIDA and MoFPA-based PID). Figure 6 illustrates the result of this case study. From this figure, it is clear that adaptive controllers with (EWOA + BE) and (classical EWOA) provide good dynamic responses comparing with controllers in [21], where there is no overshoot and a small settling time but a large rise time in the accepted range. In addition, the system with MoFPA-based PID has poor start dynamics through the first two seconds. Moreover, the system with EWOA + BE has the smallest settling time (about 13 s) and the detailed comparison is listed in Table 1.

Figure 6. System dynamic performance of the first scenario.
### Table 1. Performance specification due to first case.

|                | Controller with EWOA + BE | Controller with EWOA | MoFPA-Based PIDA | MoFPA-Based PID |
|----------------|---------------------------|----------------------|------------------|-----------------|
| $M_p$          | 0.5%                      | 1%                   | 3.5%             | 18%             |
| $T_r$          | 6.3 s                     | 6.1 s                | 6 s              | 4.4 s           |
| $T_s$          | 12.5 s                    | 12.5 s               | 20 s             | 20 s            |

### 6.2. Second Scenario

A case of step change in desired temperature is tested in this scenario, a step change with value of 0.5 is supplied at $t = 30$ s and results in this case are shown in Figure 7. The responses illustrated in this figure support the same notes obtained from the first scenario where both of the adaptive controllers are efficient in the step change in the system input, and the system with (EWOA + BE) can provide the best dynamic performance compared with the controller with MoFPA-based PIDA. Table 2 indicates the performance in this case. In addition, Figure 8 illustrates the optimizer output in the case of classical EWOA and EWOA + BE.

### Table 2. Performance specification due to second case.

|                | Controller with EWOA + BE | Controller with EWOA | MoFPA-Based PIDA |
|----------------|---------------------------|----------------------|------------------|
| $M_p$          | 85%                       | 1%                   |                  |
| $T_r$          | 4.3 s                     | 4.6 s                | 6 s              |
| $T_s$          | 13 s                      | 13 s                 | 14 s             |

![Figure 7. System dynamic performance of the second scenario.](image-url)

![Figure 8. Output gain of EWOA and EWOA + BE.](image-url)
6.3. Third Scenario

In this scenario, the effect of a step load disturbance is studied. The system was exposed to step load disturbance shown in Figure 9. Figure 10 shows the dynamic responses in such a case. From this figure, we can note that: good settling time and overshoot can be obtained using EWOA + BE, while the system with classical EWOA can provide poor performance.

![Figure 9. Step disturbance.](image1)

![Figure 10. System dynamic performance of the third scenario.](image2)

6.4. Fourth Scenario

In this scenario, a random reference temperature was applied to the system as shown in Figure 11, the dynamic performance of this scenario is illustrated in Figure 12. From this figure, it is clear that the proposed controller with EWOA+BE provided the best performance compared with other controllers.
In this scenario, a random reference temperature was applied to the system as shown.

Data Availability Statement: Data sharing is not applicable.

Acknowledgments:

Author Contributions: Conceptualization, M.M.H., T.H.M. and A.M.H.; methodology, M.M.H., T.H.M., A.M.H., S.A. and A.H.; software, D.S.O., A.M.H., M.M.H. and M.A.; validation, T.H.M., S.A. and A.H.; investigation, A.H., D.S.O. and M.A.; resources, S.A. and T.H.M.; data curation, A.H., A.M.H. and M.M.H.; formal analysis, M.M.H. and T.H.M.; visualization, D.S.O., M.A. and M.M.H.; writing—original draft, M.M.H. and T.H.M.; writing—review and editing, S.A., D.S.O., M.A. and A.M.H.; supervision, A.H., T.H.M. and A.M.H.; funding acquisition, S.A. and M.A.; project administration, T.H.M. and A.H.; All authors have read and agreed to the published version of the manuscript.

Funding: The financial support received from Taif University Researchers Supporting Project Number (TURSP-2020/146), Taif University, Taif, Saudi Arabia.

Data Availability Statement: Data sharing is not applicable.

Conflicts of Interest: The authors declare no conflict of interest.
Appendix A Pseudo-Code of the EWOA

Algorithm A1: Enhanced Whale Optimization Algorithm (EWOA)

Initialize the whales population \( \vec{X}, I (i = 1, 2, \ldots, n) \)
Calculate the fitness of each search agent
Identify the best search agent = \( \vec{X}^* \)
While (\( t < \) maximum number of iterations)
    For each search agent, update \( \vec{a}, \vec{A}, \vec{C}, I \) and \( p \)
        If \( 1 (p < 0.5) \)
            Update the position of the current search agent by Equation (3) as a function of inertia weight \( W \) [replace \( \vec{X}(t) \rightarrow w. \vec{X}(t) \)]
        else if \( 2 (|\vec{A}| \geq 1) \)
            Modernize the position of the current search agent by Equation (10)
        end if 2
    else if \( 1 (p \geq 0.5) \)
        Modernize the position by Equation (8) as a function of weight (W)
    end if 1
    end for
Check if any search agent goes beyond the search space and amend it
Calculate the fitness of the search agent
Update \( \vec{X}^* \) if there is a better solution
\( t = t + 1 \)
End while

References

1. Li, J.W.; Yan, C.F.; Liu, J. Design of temperature control system based on fuzzy PID. In Advanced Materials Research; Trans Tech Publications Ltd.: Wollerau, Switzerland, 2012; Volume 418, pp. 1756–1759.
2. O’Dwyer, A. Handbook of PI and PID Controller Tuning Rules, 3rd ed.; Imperial College Press: London, UK, 2009.
3. Liptak, B.G. Instrumentation Engineer’s Handbook Volume Two, Process Control and Optimization, 4th ed.; CRC Press: Boca Raton, FL, USA, 2005.
4. Jayachitra, A.; Vinodha, R. Genetic algorithm based PID controller tuning approach for continuous stirred tank reactor. Adv. Artif. Intell. 2014, 2014, 791230. [CrossRef]
5. Banu, U.S.; Uma, G. ANFIS gain scheduled CSTR with genetic algorithm based PID minimizing integral square error. In Proceedings of the IET-UK International Conference on Information and Communication Technology in Electrical Sciences (ICTES) 2007, Tamil Nadu, India, 20–22 December 2007; pp. 57–62.
6. Omarov, B.; Anarbayev, A.; Turyskulov, U.; Orazbayev, E.; Erdenov, M.; Ibrayev, A.; Kendzhaeva, B. Fuzzy-PID Based Self-Adjusted Indoor Temperature Control for Ensuring Thermal Comfort in Sport Complexes. J. Theor. Appl. Inf. Technol. 2020, 98, 1877–1888.
7. Sain, D.; Swain, S.; Mishra, S.; Dutta, S. Robust Set-Point Weighted PID Controller Design Using Genetic Algorithm for Electric Furnace Temperature Control System. Int. J. Control. Theory Appl. 2016, 9, 29–36.
8. Rajarathinam, K.; Gomm, J.B.; Yu, D.-L.; Abdelhadi, A.S. PID Controller Tuning for a Multivariable Glass Furnace Process by Genetic Algorithm. Int. J. Auton. Comput. 2016, 13, 64–72. [CrossRef]
9. Hosseini, S.A.; Shirani, A.S.; Lotfi, M.; Menhaj, M.B. Design and application of supervisory control based on neural network PID controllers for pressurizer system. Prog. Nucl. Energy 2020, 130, 103570. [CrossRef]
10. Rahmat, M.F.; Yazdani, A.M.; Movahed, M.A.; Mahmoudzadeh, S. Temperature control of a continuous stirred tank reactor by means of two different intelligent strategies. Int. J. Smart Sens. Intell. Syst. 2011, 4, 149–153. [CrossRef]
11. Bhushan, Y.; Singh, K.Y. PID Control of Heat Exchanger System. Int. J. Comput. Appl. 2010, 8, 22–27.
12. Khuwaja, K.; Lighari, N.-U.; Tarca, I.C.; Tarca, R.C. PID Controller Tuning Optimization with Genetic Algorithms for a Quadcopter. Recent Innov. Mechatron. 2018, 5, 1–7. [CrossRef]
13. Perng, J.-W.; Hsieh, S.-C.; Ma, L.-S.; Chen, G.-Y. Design of robust PI control systems based on sensitivity analysis and genetic algorithms. Neural Comput. Appl. 2016, 29, 913–923. [CrossRef]
14. Sinlapakun, V.; Assawinchaichote, W. Optimized PID controller design for electric furnace temperature systems with Nelder Mead Algorithm. In Proceedings of the 12th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology, Hua Hin, Thailand, 24–27 June 2015; pp. 1–4.
15. Jiang, W.; Jiang, X. Design of an intelligent temperature control system based on the fuzzy self-tuning PID. Procedia Eng. 2012, 43, 307–311. [CrossRef]
16. Zhang, R.; Zoua, Q.; Caob, Z.; Gao, F. Design of fractional order modeling based extended non-minimal state space MPC for temperature in an industrial electric heating furnace. *J. Process Control*. 2017, 56, 13–22. [CrossRef]

17. Gani, M.M.; Islam, M.S.; Ullah, M.A. Optimal PID tuning for controlling the temperature of electric furnace by genetic algorithm. *SN Appl. Sci.* 2019, 1, 880. [CrossRef]

18. Morán, E.F.; Pazmiño, W.Y.; Monteses, J.B. Genetic algorithm and fuzzy self-tuning PID for DC motor position controllers. In Proceedings of the 19th International Carpathian Control Conference (ICCC), Szilvasvarad, Hungary, 28–31 May 2018; pp. 162–168.

19. Deng, C.; Wang, Z. Self-learning fuzzy algorithm optimized temperature control and efficiency monitoring of heat exchanger. In Proceedings of the 37th Chinese Control Conference (CCC), Wuhan, China, 25–27 July 2018; pp. 3394–3399.

20. Valarmathi, R.; Theerthagiri, P.; Kumar, R.; Gomathi, V. Design of genetic algorithm based internal model controller for a heat exchanger. In Proceedings of the International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), Chennai, India, 28–29 March 2018; pp. 489–495.

21. Pringsakul, N.; Puangdownreong, D. MOFPA-Based PIDA Controller Design Optimization for Electric Furnace Temperature Control System. *Int. J. Innov. Comput. Inf. Control*. 2020, 16, 1863–1876.

22. Mirjalili, S.; Lewis, A. The Whale Optimization Algorithm. *Adv. Eng. Softw.* 2016, 95, 51–67. [CrossRef]

23. Kanagasabai, L. Enhanced whale optimization algorithm for active power loss diminution. *Int. J. Inform. Commun. Technol.* 2020, 9, 19–23.

24. Nadimi-Shahraki, M.H.; Taghian, S.; Mirjalili, S.; Abualigah, L.; Elaziz, M.A.; Oliva, D. EWOA-OPF: Effective Whale Optimization Algorithm to Solve Optimal Power Flow Problem. *Electronics* 2021, 10, 2975. [CrossRef]

25. Petrović, M.; Miljković, Z.; Jokić, A. A novel methodology for optimal single mobile robot scheduling using whale optimization algorithm. *Appl. Soft Comput.* J. 2019, 81, 1–25.

26. Aljarah, I.; Faris, H.; Mirjalili, S. Optimizing connection weights in neural networks using the whale optimization algorithm. Optimizing connection weights in neural networks using the whale optimization algorithm. *Soft Comput.* 2018, 22, 1–15. [CrossRef]

27. Mohammed, H.M.; Umar, S.U.; Rashid, T.A. A Systematic and Meta-Analysis Survey of Whale Optimization Algorithm: A Systematic and Meta-Analysis Survey of Whale Optimization Algorithm. *Comput. Intell. Neurosci.* 2019, 2019, 1–25. [CrossRef]

28. Dahab, Y.A.; Abubakr, H.; Mohamed, T.H. Adaptive Load Frequency Control of Power Systems Using Electro-Search Optimization Supported by the Balloon Effect. *IEEE Access* 2020, 8, 7408–7422. [CrossRef]

29. Abubakr, H.; Mohamed, T.H.; Hussein, M.M.; Guerrero, J.M.; Agundis-Tinajero, G. Adaptive frequency regulation strategy in multi-area microgrids including renewable energy and electric vehicles supported by virtual inertia. *Int. J. Electr. Power Energy Syst.* 2021, 129, 106814. [CrossRef]

30. Mohamed, T.H.; Alamin, M.A.M.; Hassan, A.M. Adaptive position control of a cart moved by a DC motor using integral controller tuned by Jaya optimization with Balloon effect. *Comput. Electr. Eng.* 2020, 87, 106786. [CrossRef]

31. Mohamed, T.H.; Abubakr, H.; Alamin, M.A.M.; Hassan, A.M. Modified WCA based Adaptive Control Approach Using Balloon Effect: Electrical Systems Applications. *IEEE Access* 2020, 8, 60877–60889. [CrossRef]