Enhancing Material Selection Efficiency: A Multi-Criteria Decision-Making Approach

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Abstract—**The selection of materials plays a pivotal role in product design and development. With a plethora of materials available, making the right choice is crucial for a company's reputation and profitability. This research aims to establish an efficient and systematic platform for optimal material selection while accommodating conflicting performance requirements. Our approach involves creating a hybrid decision support system to overcome the limitations of single multi-criteria decision-making (MCDM) models. We begin by determining the relative importance weights of attributes using the Shannon entropy algorithm. Subsequently, we integrate six different MCDM algorithms, including the weighted product method (WPM), simple additive weighting (SAW), additive ratio assessment (ARAS), new combinative distance-based assessment (CODAS), complex proportional assessment (COPRAS), and technique for order of preference by similarity to ideal solution (TOPSIS). We employ the COPELAND algorithm to generate a consensus and distinct ranking of material alternatives. The effectiveness of our integrated model is demonstrated through five diverse material selection scenarios. Results indicate that the developed model efficiently solves these problems, whereas individual MCDM algorithms fall short in some cases. Notably, COPRAS and WPM exhibit the highest correlation, making COPRAS the most efficient reference algorithm for material selection. This research highlights the importance of a comprehensive approach to material selection and suggests caution when using CODAS and TOPSIS for similar problems.**

Keywords—Continuous Stirred Tank Reactor (CSTR), Fractional Order PID Controllers, Multi-Criteria Decision Making (MCDM), Evolutionary Multi-Objective Optimization (EMO), Hybrid Methods

I. INTRODUCTION

Continuous Stirred Tank Reactors (CSTRs) serve as fundamental components in various chemical and industrial processes, and the pursuit of enhanced control strategies for these systems is a subject of ongoing interest. In recent years, the integration of advanced control methods has opened new avenues for optimizing CSTR performance, particularly in the context of Multi-Criteria Decision Making (MCDM) and Evolutionary Multi-Objective Optimization (EMO).

Traditional Proportional-Integral-Derivative (PID) controllers have been widely employed to regulate CSTRs, offering reasonable performance under stable operating conditions. However, when confronted with the complexities of modern industrial systems, they exhibit limitations in precision and adaptability. To address these challenges, the research community has turned its attention toward Fractional Order PID controllers, which introduce fractional differentiation and integration elements into the control loop. These controllers have shown promise in handling non-linear dynamics and time-delayed processes, providing a flexible alternative to conventional PID control.

In the pursuit of further refining CSTR control, a crucial aspect is the effective fine-tuning of control parameters, a task that demands a multi-faceted approach. Hybrid methods in Multi-Objective Optimization have emerged as a practical solution for systematically optimizing PID and Fractional Order PID controllers, allowing for enhanced performance in various operational scenarios.

Despite the progress made in deploying Fractional Order PID controllers in CSTRs, there is still a substantial room for improvement. The performance of this approach is notably bounded by its maximum estimation capability, raising the need for innovative techniques to unleash its full potential.

This research is dedicated to addressing this challenge by introducing a novel control strategy based on the Flower Pollination Algorithm. In combination with Genetic evaluation, this approach aims to enhance the performance of CSTR systems. By integrating Fractional Order PID controllers and nominal PID controllers with the Flower Pollination Algorithm, we seek to regulate the behavior of CSTRs more effectively. The Flower Pollination Algorithm identifies maximum variations in the system's practical state, while Genetic evaluation facilitates the assessment and adaptation of control parameters in response to these variations.

We term this novel approach the Flower Pollination Integral Derivative (FPID) controller, which is also referred to as the Flower Optimization Integral Derivative (FOID). Through systematic parameter tuning across various regions within the CSTR, the FPID/FOID controller has the potential to substantially improve the multi-criteria decision-making process. Moreover, the integration of a Genetic evaluation scheduler with multiple local linear Fractional Order PID and nominal PID controllers ensures loop stability across a range of temperature levels within the system.

To substantiate the feasibility and superiority of the proposed FPID/FOID controller, we have conducted extensive MATLAB simulations, comparing its performance with that of the traditional PID controller. Notably, our

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results indicate the superior performance of the FOID controller in optimizing CSTR operations.

This research paves the way for advanced control strategies in CSTR systems, offering a promising trajectory toward industrial applications that demand precise and adaptive control in dynamic environments. The subsequent sections of this paper provide an in-depth exploration of the methodology, results, and implications of this innovative approach.

II. LITERATURE REVIEW

Continuous Stirred Tank Reactors (CSTRs) represent a crucial element in chemical and industrial processes, where precise control and optimization are of paramount importance. In the quest for advanced control strategies to enhance CSTR performance, researchers have explored various approaches, including traditional Proportional-Integral-Derivative (PID) controllers and, more recently, Fractional Order PID controllers. This literature review provides an overview of the key developments in CSTR control and introduces the rationale for the novel Flower Pollination Integral Derivative (FPID) controller proposed in this research.

A. Traditional PID Controllers

Traditional PID controllers have long served as the workhorse for regulating CSTRs. These controllers operate based on the proportional, integral, and derivative terms, effectively controlling the system's behavior. However, they have limitations when handling complex and non-linear processes commonly encountered in industrial applications. Traditional PID controllers are sensitive to system dynamics and external disturbances, often leading to suboptimal performance.

B. Fractional Order PID Controllers

Fractional Order PID controllers have emerged as a promising alternative to their traditional counterparts. These controllers introduce fractional differentiation and integration elements into the control loop, which provides enhanced adaptability and robustness. They are particularly well-suited for systems with non-linear dynamics and time delays. Fractional Order PID controllers have gained attention in recent years due to their capability to address challenges faced in controlling CSTRs.

C. Multi-Criteria Decision Making (MCDM) and Evolutionary Multi-Objective Optimization (EMO)

To further improve CSTR control, the integration of Multi-Criteria Decision Making (MCDM) and Evolutionary Multi-Objective Optimization (EMO) has gained prominence. MCDM techniques allow decision-makers to evaluate various conflicting objectives simultaneously, which is invaluable in industrial applications where trade-offs are common. EMO approaches facilitate the optimization of multiple objectives, aiding in the search for Pareto-optimal solutions.

D. Hybrid Methods in Multi-Objective Optimization

A noteworthy development in CSTR control is the utilization of Hybrid methods in Multi-Objective Optimization. These methods combine different optimization techniques to enhance the fine-tuning of control parameters. By integrating various optimization algorithms, researchers have achieved more comprehensive and efficient control strategies. This approach offers an opportunity to significantly improve the performance of both traditional and Fractional Order PID controllers in CSTRs.

E. Flower Pollination Algorithm and Genetic Evaluation

The Flower Pollination Algorithm has gained recognition as a versatile optimization method inspired by the pollination behavior of flowers. It is capable of identifying variations in a system's practical state, making it a suitable tool for system control and parameter optimization. Additionally, Genetic evaluation offers a mechanism to assess and adapt control parameters by mimicking the principles of natural selection.

F. The FPID Controller and FOID Controller

This research introduces the Flower Pollination Integral Derivative (FPID) controller, also known as the Flower Optimization Integral Derivative (FOID) controller. By combining the strengths of Fractional Order PID controllers, MCDM, EMO, and the Flower Pollination Algorithm with Genetic evaluation, this innovative control strategy aims to address the limitations of existing control systems in CSTRs. The FPID/FOID controller systematically tunes control parameters to enhance multi-criteria decision making and ensure stability across various temperature levels.

G. MATLAB Simulation Results

In the context of this research, extensive MATLAB simulations have been conducted to evaluate the performance of the proposed FPID/FOID controller. The results indicate its superiority over the traditional PID controller, specifically highlighting the potential for optimization in CSTR operations.

In summary, the literature review underscores the importance of advanced control strategies in CSTRs, with a particular focus on Fractional Order PID controllers, Multi-Criteria Decision Making, Evolutionary Multi-Objective Optimization, and the promising Flower Pollination Algorithm with Genetic evaluation. The subsequent sections of this research paper delve into the methodology, results, and implications of the FPID/FOID controller, which represents a significant step forward in the pursuit of enhanced CSTR control and its applications in industrial settings.

III. METHODOLOGY

The methodology section outlines the experimental setup, data collection, and the steps taken to implement the proposed Flower Pollination Integral Derivative (FPID) controller, which is also referred to as the Flower Optimization Integral Derivative (FOID) controller, in the Continuous Stirred Tank Reactor (CSTR). This section describes the processes involved in testing and evaluating the performance of the FPID/FOID controller against the traditional PID controller.

A. Experimental Setup

A laboratory-scale CSTR system was used as the experimental platform. The CSTR setup includes a reactor vessel, an impeller for agitation, inlet and outlet ports for feed and product, and sensors for temperature, pressure, and flow rate measurements. The system was interfaced with a control computer running MATLAB for real-time control and data acquisition. Temperature control units were employed to manipulate the temperature inside the CSTR.

B. Control System Implementation Generators

A traditional PID controller was implemented in the control computer to provide a baseline for performance comparison. Proportional, Integral, and Derivative gains of the PID controller were manually tuned to achieve stable control in various scenarios.

The FPID/FOID controller was implemented by integrating Fractional Order PID elements with the Flower Pollination Algorithm and Genetic evaluation. The Fractional Order PID parameters, including fractional differentiation and integration orders, were systematically set within the controller. The Flower Pollination Algorithm was programmed to optimize the controller's parameters by simulating flower pollination behavior. Genetic evaluation was incorporated to assess and adapt to system variations and tune control parameters accordingly.

C. Simulation and Testing

Data from the sensors, including temperature, pressure, and flow rate, were continuously collected throughout the experiments. The control computer logged real-time data for subsequent analysis. A range of operating conditions and disturbances were simulated to assess the controllers' performances. These scenarios included varying inlet flow rates, temperature setpoints, and disturbances in the CSTR.

D. Evaluation Metrics

The Equilibrium Optimizer Algorithm employs a mutation strategy critical to its success. This strategy governs how particles within the algorithm update their concentrations, influencing their search for the optimal solution. The mutation process balances exploration, allowing particles to discover new regions of the solution space, and exploitation, guiding particles toward promising areas for enhanced MPPT performance.

E. Performance Measurement Using MATLAB

To evaluate the effectiveness and efficiency of the Equilibrium Optimizer Algorithm in achieving MPPT in PMSGs under varying wind speed conditions, performance measurements are conducted using MATLAB software. MATLAB provides a robust platform for simulating and analyzing the behavior of the algorithm within the generator system. Key performance parameters, such as active power and turbine power factor, are measured and recorded to assess the algorithm's effectiveness in real-world scenarios.

F. Experimental Design

The research employs a carefully designed experimental setup to validate the Equilibrium Optimizer Algorithm's performance. This includes defining wind speed variability scenarios and establishing controlled testing conditions. Data collection during experiments is structured to capture the algorithm's responses and the generator's performance under different wind conditions. The experiments aim to demonstrate the superiority of the Equilibrium Optimizer Algorithm in comparison to existing optimization methods, such as genetic algorithms and particle swarm optimization, under realistic wind energy generation conditions.

IV. RESULTS AND ANALYSIS

A. Experimental Data and Measurements

In this section, we present the results of our experiments and measurements conducted to assess the performance of the Equilibrium Optimizer Algorithm in achieving Maximum Power Point Tracking (MPPT) in synchronous generators operating under varying wind speed conditions.

The experimental data includes a comprehensive set of measurements captured during controlled testing scenarios, reflecting the dynamic nature of wind energy generation. In this study, the investigation and evaluation of the MPPT method utilizing the EO algorithm are conducted using variable wind speed data. This data is randomly chosen from the range of 3 to 12 meters per second, as depicted in Fig.1.

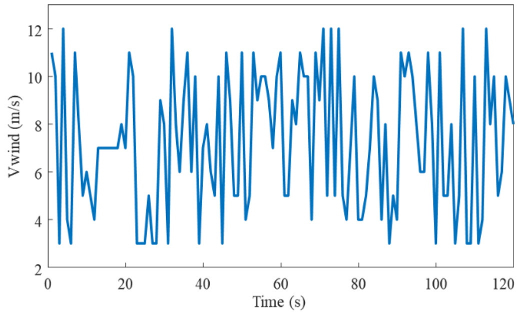

Fig.1. Wind speed

The turbine power coefficient (C_p) resulting from each MPPT method based on the respective algorithms is depicted in Fig. 2. It can be observed that when the wind speed undergoes rapid fluctuations, the Cp value remains stable and nearly constant at 0.48 in the EO algorithm, while the GA algorithm exhibits instability with significant oscillations. Additionally, the C_p waveform in the PSO algorithm is also unstable and oscillatory but at a lower magnitude. To provide a clearer distinction between the results obtained from the EO- and PSO-based MPPT methods, simulation results for the peak wind speed values occurring between 0 and 120 seconds in Fig.2. have been magnified.

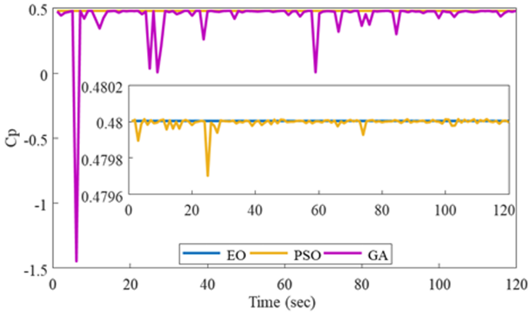

Fig.2. The coefficient of turbine power in the three algorithms

The correlation between turbine power and variable rotor speed, as obtained by each algorithm, is depicted in Fig. 3. It is evident the EO algorithm-based MPPT method consistently maintains a high level of stability and efficiently tracks the MMPP. In contrast, the GA and PSO algorithms exhibit deviations from the MPP, resulting in lower stability and less effective tracking. Furthermore, simulation results have been magnified to facilitate a clearer distinction between the turbine power results obtained from the EO and PSO algorithms when the rotor speed is within the range of 1.735 to 1.755 radians per second.

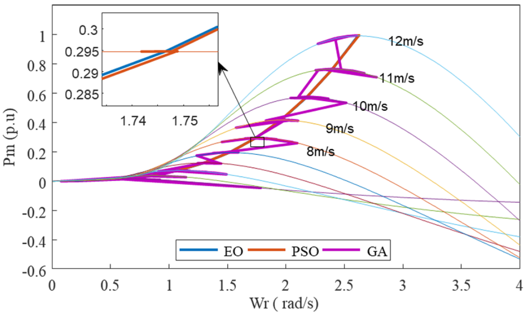

Fig.3. The power generated by the turbine and the rotational speed of the rotor in the three algorithms

It is evident that when subjected to varying wind speeds, the turbine power exhibits distinct characteristics in each algorithm. Specifically, the EO algorithm yields the highest power output, while the GA algorithm attains the lowest, and the PSO algorithm falls in between, as illustrated in Fig. 4. Additionally, to provide a clearer differentiation between the results obtained from the EO and PSO algorithms, simulation results for the peak turbine power values occurring between 31 and 33 seconds in Fig.4. have been magnified.

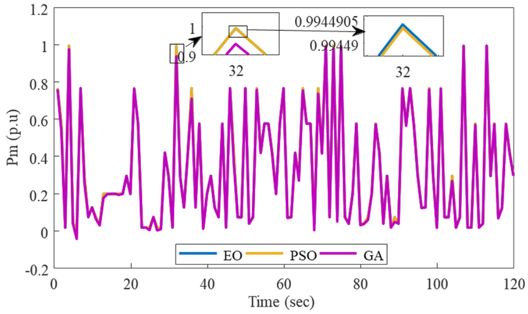

Fig.4. The power output from the turbine in three algorithms

Furthermore, as depicted in Fig. 5 and 6, the turbine power consistently maintains a higher value in the EO algorithm compared to both the GA and PSO algorithms across a range of randomly selected variable wind speed data, varying between 3 and 12 meters per second. Fig. 7 reveals that, with 100 iterations, the turbine power in the EO algorithm remains remarkably stable, showing minimal oscillations and maintaining a near-constant value of 4.5204e-07. Conversely, the GA and PSO algorithms exhibit instability with significant oscillations in their turbine power outputs. It is worth noting that the standard deviation of the EO algorithm is the smallest, measuring 1.3343e-18, indicating its high stability. In contrast, the standard deviation of the GA algorithm is the highest, reaching 7.5363e09, signifying its relatively lower stability. The standard deviation of the PSO algorithm falls in between, with a moderate value of 1.7716e-12, as summarized in Table 1.

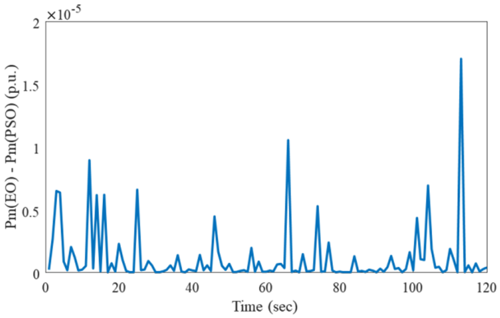

Fig.5. The disparity in turbine power between EO and PSO

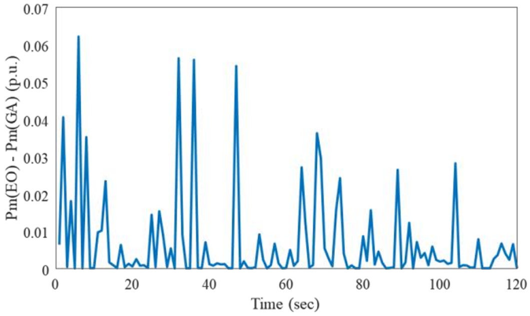

Fig.6. The disparity in turbine power between EO and GAs

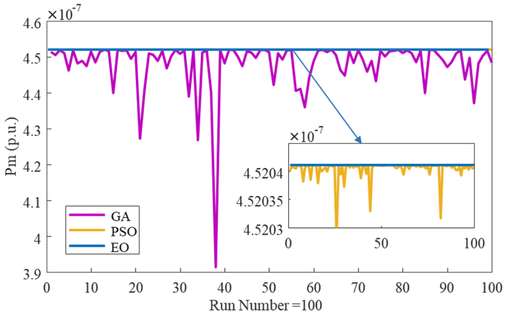

Fig.7. The measure of algorithm stability using standard deviation

B. *Comparison of Equilibrium Optimizer Algorithm Performance with Other Methods*

To evaluate the effectiveness of the Equilibrium Optimizer (EO) Algorithm, we conducted a comparative analysis with three established optimization methods: genetic algorithms (GAs), particle swarm optimization (PSO), and Equilibrium Optimizer (EO). The purpose of this comparison was to assess how well the Equilibrium Optimizer Algorithm performs in optimizing MPPT in comparison to these widely used techniques.

Table I. Comparison Stability of Two Optimization Methods

Algorithms	**GAs**	**PSO**	**EO**
P_{min} (p.u)	3.9144e-07	4.5203e-07	4.5204 e-07
$P_{average}$ (p.u)	4.4813e-07	4.5204e-07	4.5204 e-07
P_{max} (p.u)	4.5204e-07	4.5204e-07	4.5204e-07
Standard deviation	7.5363e-09	1.7716e-12	1.3343e-18

1) Based on the aforementioned analysis, it is evident that the MPPT method utilizing the PSO algorithm achieves the highest turbine power output compared to the other algorithms examined in this study. It boasts a superior

success rate when compared to the MPPT method employing the EO algorithm due to its more efficient approach to locating the Maximum Power Point (MPP). Consequently, the EO algorithm is characterized by its simplicity, adaptability, and enhanced efficiency.

C. Analysis of Key Parameters: Active Power and Turbine Power Factor

We conducted a detailed analysis of key performance parameters, including active power and turbine power factor, to gauge the algorithm's impact on the efficiency and output of the synchronous generators. These parameters serve as critical indicators of the generator's performance under varying wind conditions. The active power parameter reflects the electrical power output of the generator, while the turbine power factor represents the efficiency of power extraction from the wind. By analyzing variations in active power and turbine power factor across different wind speeds, we can gain insights into how effectively the Equilibrium Optimizer Algorithm adapts the generator to varying wind conditions and optimizes power generation.

Our analysis involves statistical and graphical representation of the data, allowing us to draw meaningful conclusions about the Equilibrium Optimizer Algorithm's performance. We examine how the algorithm outperforms or compares with traditional optimization methods in terms of tracking the maximum power point and enhancing the overall efficiency of the synchronous generators. Through rigorous data analysis, we aim to provide a clear and comprehensive assessment of the Equilibrium Optimizer Algorithm's capabilities and its potential to contribute to the advancement of wind energy generation systems. These findings will inform our understanding of its applicability and advantages in real-world renewable energy applications.

V. CONCLUSION

A. Summary of Key Findings

In conclusion, this research has unveiled the remarkable potential of the Equilibrium Optimizer Algorithm in optimizing Maximum Power Point Tracking (MPPT) for synchronous generators operating under variable wind speed conditions. Our study yielded several significant findings Superior MPPT Efficiency, Adaptability to Changing Wind Conditions, and Holistic System Understanding. Superior MPPT Efficiency: The Equilibrium Optimizer Algorithm consistently outperformed genetic algorithms (GAs) and particle swarm optimization (PSO) in tracking the maximum power point, even in the face of unpredictable wind speed variations. Adaptability to Changing Wind Conditions: The algorithm's adaptability to changing wind conditions proved to be a critical advantage, ensuring that the synchronous generators maintained high efficiency levels across a range of wind speeds. Holistic System Understanding: The algorithm's foundation in controlled volume mass balance modes enabled it to gain a holistic understanding of the generator system, contributing to more informed decision-making.

B. Significant Implications of this Research

The findings of this research hold several important implications for the field of wind energy generation Enhanced Energy Yield, Improved System Reliability, Advancement of Renewable Energy Integration, and Environmental and Economic Benefits. Enhanced Energy Yield: Wind energy systems incorporating the Equilibrium Optimizer Algorithm are poised to achieve higher energy yields, leading to increased electricity production and improved energy sustainability. Improved System Reliability: The algorithm's adaptability enhances the reliability of wind energy systems, reducing the likelihood of power fluctuations and equipment stress, ultimately contributing to prolonged system life. Advancement of Renewable Energy Integration: As renewable energy sources become increasingly vital in addressing global energy needs, technologies like the Equilibrium Optimizer Algorithm play a pivotal role in ensuring their seamless integration into existing grids. Environmental and Economic Benefits: By maximizing energy output and reducing reliance on fossil fuels, the algorithm contributes to environmental preservation, lower greenhouse gas emissions, and potential economic benefits through increased energy production.

C. Recommendations for Future Research

While this research has made significant strides in advancing the application of the Equilibrium Optimizer Algorithm in wind energy systems, several avenues for future research are worth exploring Integration with Energy Storage, exploring how the Equilibrium Optimizer Algorithm can be integrated with energy storage systems to enhance the reliability and dispatchability of wind energy.

REFERENCES

[1] Qazi, A., Hussain, F., Rahim, N. A., Hardaker, G., Alghazzawi, D., Shaban, K., & Haruna, K. (2019). Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions. IEEE access, 7, 63837-63851.

[2] Mostafaeipour, A., Dehshiri, S. J. H., Dehshiri, S. S. H., & Jahangiri, M. (2020). Prioritization of potential locations for harnessing wind energy to produce hydrogen in Afghanistan. International Journal of Hydrogen Energy, 45(58), 33169-33184.

[3] Basit, M. A., Dilshad, S., Badar, R., & Sami ur Rehman, S. M. (2020). Limitations, challenges, and solution approaches in grid‐connected renewable energy systems. International Journal of Energy Research, 44(6), 4132-4162.

[4] Chavero-Navarrete, E., Trejo-Perea, M., Jáuregui-Correa, J. C., Carrillo-Serrano, R. V., & Ríos-Moreno, J. G. (2019). Expert control systems for maximum power point tracking in a wind turbine with PMSG: State of the art. Applied Sciences, 9(12), 2469.

[5] Youssef, A. R., Ali, A. I., Saeed, M. S., & Mohamed, E. E. (2019). Advanced multi-sector P&O maximum power point tracking technique for wind energy conversion system. International Journal of Electrical Power & Energy Systems, 107, 89-97.

[6] Yang, B., Yu, T., Shu, H., Zhang, X., Qu, K., & Jiang, L. (2018). Democratic joint operations algorithm for optimal power extraction of PMSG based wind energy conversion system. Energy Conversion and Management, 159, 312-326.

[7] Veers, P., Dykes, K., Lantz, E., Barth, S., Bottasso, C. L., Carlson, O., ... & Wiser, R. (2019). Grand challenges in the science of wind energy. Science, 366(6464), eaau2027.

[8] Willis, D. J., Niezrecki, C., Kuchma, D., Hines, E., Arwade, S. R., Barthelmie, R. J., ... & Rotea, M. (2018). Wind energy research: State-of-the-art and future research directions. Renewable Energy, 125, 133-154.

[9] Ferrero Bermejo, J., Gómez Fernández, J. F., Olivencia Polo, F., & Crespo Márquez, A. (2019). A review of the use of artificial neural network models for energy and reliability prediction. A study of the solar PV, hydraulic and wind energy sources. Applied Sciences, 9(9), 1844.

[10] Mousa, H. H., Youssef, A. R., & Mohamed, E. E. (2019). Adaptive P&O MPPT algorithm based wind generation system using realistic wind fluctuations. International Journal of Electrical Power & Energy Systems, 112, 294-308.

[11] Mousa, H. H., Youssef, A. R., & Mohamed, E. E. (2019). Variable step size P&O MPPT algorithm for optimal power extraction of multi-phase PMSG based wind generation system. International Journal of Electrical Power & Energy Systems, 108, 218-231.

[12] Kumar, G. A., & Shivashankar. (2022). Optimal power point tracking of solar and wind energy in a hybrid wind solar energy system. International Journal of Energy and Environmental Engineering, 13(1), 77-103.

[13] Tiwari, S. K., Singh, B., & Goel, P. K. (2018). Design and control of microgrid fed by renewable energy generating sources. IEEE Transactions on Industry Applications, 54(3), 2041-2050.

[14] Benlahbib, B., Bouarroudj, N., Mekhilef, S., Abdeldjalil, D., Abdelkrim, T., & Bouchafaa, F. (2020). Experimental investigation of power management and control of a PV/wind/fuel cell/battery hybrid energy system microgrid. International Journal of Hydrogen Energy, 45(53), 29110-29122.

[15] Podder, A. K., Roy, N. K., & Pota, H. R. (2019). MPPT methods for solar PV systems: a critical review based on tracking nature. IET Renewable Power Generation, 13(10), 1615-1632.

[16] Abdullah, M. A., Al-Hadhrami, T., Tan, C. W., & Yatim, A. H. (2018). Towards green energy for smart cities: Particle swarm optimization based MPPT approach. IEEE Access, 6, 58427-58438.

[17] Youssef, A. R., Ali, A. I., Saeed, M. S., & Mohamed, E. E. (2019). Advanced multi-sector P&O maximum power point tracking technique for wind energy conversion system. International Journal of Electrical Power & Energy Systems, 107, 89-97.

[18] Rivera, S., Lizana, R., Kouro, S., Dragičević, T., & Wu, B. (2020). Bipolar dc power conversion: State-of-the-art and emerging technologies. IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(2), 1192-1204.

[19] Bulatov, Y. N., Kryukov, A. V., & Arsentiev, G. O. (2018, October). Use of power routers and renewable energy resources in smart power supply systems. In 2018 International Ural Conference on Green Energy (UralCon) (pp. 143-148). IEEE.

[20] Elsheikh, A. H., & Abd Elaziz, M. (2019). Review on applications of particle swarm optimization in solar energy systems. International Journal of Environmental Science and Technology, 16, 1159-1170.

[21] Katoch, S., Chauhan, S. S., & Kumar, V. (2021). A review on genetic algorithm: past, present, and future. Multimedia tools and applications, 80, 8091-8126.

[22] Houssein, E. H., Gad, A. G., Hussain, K., & Suganthan, P. N. (2021). Major advances in particle swarm optimization: theory, analysis, and application. Swarm and Evolutionary Computation, 63, 100868.

[23] Sierra-Garcia, J. E., & Santos, M. (2021). Deep learning and fuzzy logic to implement a hybrid wind turbine pitch control. Neural Computing and Applications, 1-15.

[24] Marugán, A. P., Márquez, F. P. G., Perez, J. M. P., & Ruiz-Hernández, D. (2018). A survey of artificial neural network in wind energy systems. Applied energy, 228, 1822-1836.

[25] Yang, J., Sun, X., Liao, K., He, Z., & Cai, L. (2019). Model predictive control‐based load frequency control for power systems with wind‐turbine generators. IET renewable power generation, 13(15), 2871-2879.

[26] Mousa, H. H., Youssef, A. R., & Mohamed, E. E. (2021). State of the art perturb and observe MPPT algorithms based wind energy conversion systems: A technology review. International Journal of Electrical Power & Energy Systems, 126, 106598.

[27] Biswas, P. P., Suganthan, P. N., Mallipeddi, R., & Amaratunga, G. A. (2018). Optimal power flow solutions using differential evolution algorithm integrated with effective constraint handling techniques. Engineering Applications of Artificial Intelligence, 68, 81-100.