Efficient Power Management System of Electrical and Control System- A Review

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Abstract: In the quest for sustainable and efficient energy utilization, the development of advanced power management systems (PMS) has become paramount in both electrical and control systems. This review paper explores the contemporary strategies and technologies employed in efficient power management, with a focus on optimizing energy usage, enhancing system reliability, and reducing operational costs. The study delves into various components of power management, including smart grids, renewable energy integration, demand-side management, and advanced control algorithms. Emphasis is placed on the role of intelligent systems and IoT in enabling real-time monitoring and adaptive control, which are critical for achieving energy efficiency. Furthermore, the review addresses the challenges and future prospects in the field, highlighting the need for innovative solutions to meet the growing energy demands while minimizing environmental impact. Through an extensive examination of recent advancements and case studies, this paper aims to provide a comprehensive understanding of the efficient power management systems and their pivotal role in modern electrical and control systems.

1. INTRODUCTION

Bioinspired algorithms have emerged as powerful tools for solving complex optimization and control problems in various fields, including electrical power systems. These algorithms draw inspiration from natural processes and phenomena, mimicking the behavior of biological organisms and ecosystems to tackle challenging problems in power generation, transmission, distribution, and utilization [1]. By leveraging the principles of evolution, swarm intelligence, neural networks, and other biological concepts, bioinspired algorithms offer unique solutions that can enhance the efficiency, reliability, and sustainability of electrical power systems [2].

In recent years, the applications of bioinspired algorithms in electrical power systems have gained considerable attention. These algorithms provide innovative approaches to address complex optimization problems, decision-making processes, and control strategies that are inherent in power system operation and management. They offer advantages such as adaptability, robustness, and the ability to handle uncertainties and dynamic environments [3].

The applications of bioinspired algorithms in electrical power systems are diverse and cover a wide range of areas [4]. In power generation, these algorithms are utilized to optimize the scheduling and operation of power plants, improve the integration of renewable energy sources, enhance fuel efficiency, and reduce emissions. They can assist in determining the optimal mix of energy resources, load forecasting, and power plant maintenance scheduling [5]. In power transmission and distribution, bioinspired algorithms play a crucial role in optimizing power flow routing, load balancing, and voltage control [6]. They contribute to the efficient utilization of transmission and distribution infrastructure, improve fault detection and diagnosis, enhance grid stability and security, and support the integration of distributed energy resources [7].

Overall, the applications of bioinspired algorithms in electrical power systems offer significant potential for optimizing and improving the performance of power generation, transmission, distribution, and utilization [10]. By harnessing the principles derived from nature, these algorithms provide novel solutions that can tackle the complex and dynamic nature of power systems [11]. With further research and development, bioinspired algorithms are expected to play a vital role in shaping the future of electrical power systems toward a more efficient, reliable, and sustainable energy landscape as shown in figure 1 [12].

2. ELECTRICAL POWER SYSTEM

Power generation, transmission, distribution, and utilization are essential components of the electrical power system [13]. Here is a detailed review of each aspect:

1. Power Generation: Power generation involves converting various energy sources into electrical energy. It encompasses a range of technologies, including fossil fuel power plants, nuclear power plants, renewable energy sources (such as solar, wind, hydro, and geothermal), and emerging technologies like tidal and wave power [14]. Each technology has its own advantages and challenges in terms of cost, environmental impact, reliability, and scalability. The choice of power generation technology depends on factors like resource availability, location, energy demand, and sustainability goals [15].

2. Power Transmission: Power transmission is the process of transporting electrical energy from power generation facilities to substations or load centers [16]. High-voltage transmission lines, typically operating at voltages above 100 kV, are used to transmit electricity over long distances with minimal losses [17]. Transmission systems employ transformers to step up the voltage for efficient transmission and step it down at substations near load centers [18]. Transmission networks require careful planning and optimization to ensure grid stability, reliability, and efficient power flow [19].

3. Power Distribution: Power distribution involves the delivery of electricity from substations to end-users, such as residential, commercial, and industrial customers [20]. Distribution systems operate at lower voltages than transmission systems and consist of distribution substations, transformers, and an extensive network of power lines. Distribution networks face challenges related to load balancing, voltage regulation, fault detection, and power quality management [21].

2.1. Power Generation

Power generation is the process of converting various energy sources into electrical energy. It plays a crucial role in meeting the increasing demand for electricity worldwide [2]. Power generation technologies can be broadly categorized into conventional (fossil fuel-based and nuclear) and renewable energy sources [18]. Here is an overview of different power generation methods:

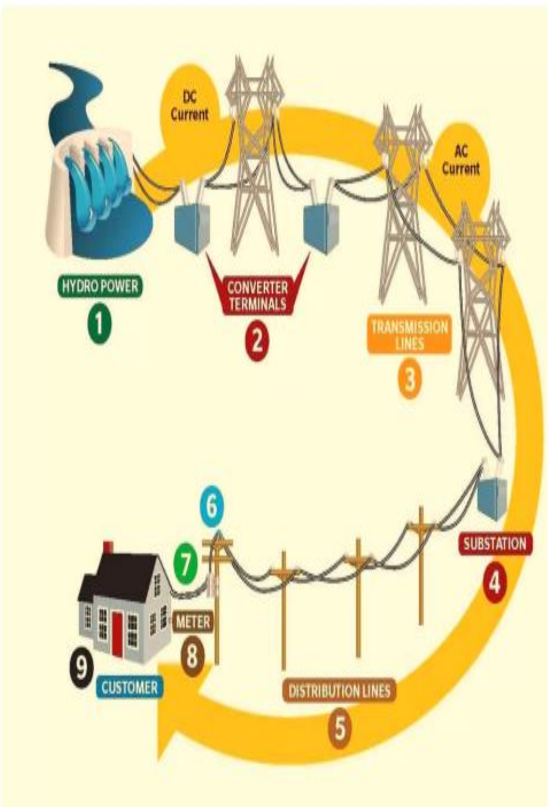
1. Fossil Fuel-Based Power Generation: Fossil fuel-based power generation involves the combustion of coal, natural gas, or oil to produce heat, which is then used to generate steam. The steam drives a turbine connected to a generator, converting mechanical energy into electrical energy.
2. Nuclear Power Generation: Nuclear power plants utilize nuclear fission to generate heat. The process involves splitting the nuclei of radioactive materials, such as uranium or plutonium, in a controlled manner [3]. The heat produced is used to generate steam, which drives a turbine and generates electricity.
3. Renewable Energy Sources: Renewable energy sources are gaining significant attention due to their environmental benefits and long-term sustainability [4]. Several renewable energy technologies are used for power generation.

2.2. Power Transmission

Power transmission is an essential component of the electrical power system that enables the efficient transfer of electricity from power generation sources to end consumers. It involves the transport of electrical energy at high voltages over long distances, minimizing losses and ensuring reliable and safe delivery of electricity [13]. Here is an overview of power transmission.

1. High Voltage Transmission: Electrical power is typically transmitted at high voltages to reduce the losses that occur during transmission.

FIGURE 1. Stages in electric power flow [5]



1. Transmission Lines: Power is transmitted through a network of overhead or underground transmission lines. Overhead transmission lines are commonly used and consist of conductors mounted on towers or poles. These lines can span vast distances and carry large amounts of electrical power [15].
2 Substations: Substations play a crucial role in the power transmission system. They act as intermediate points between power generation stations and the distribution network. Substations facilitate voltage transformation, switching, and protection functions, ensuring efficient power flow and control [6].
2. Environmental Considerations: Power transmission infrastructure may have environmental impacts, particularly for overhead transmission lines. Mitigation measures, such as proper route planning, insulation, and noise reduction techniques, are implemented to minimize these impacts [5].

2.3 Power Distribution

Power distribution is the final stage in the delivery of electricity from power generation sources to end consumers. It involves the division of electrical energy into lower voltage levels for safe and reliable distribution to homes, businesses, and other facilities. Power distribution networks are responsible for delivering electricity to individual customers and ensuring a consistent and efficient power supply [13]. Here is an overview of power distribution:

1. Substations: Power from the transmission system is received at substations, which act as interface points between the transmission and distribution systems. Substations step down the high voltage received from the transmission lines to lower voltages suitable for distribution [10].

2. Distribution Networks: Distribution networks consist of a network of overhead or underground power lines that transport electricity from substations to individual customers. These lines are designed to carry lower voltage levels to ensure safety and reduce electrical losses during distribution [17].

3. BIOINSPIRED ALGORITHMS

Biologically inspired algorithms, also known as natureinspired algorithms or bio-inspired algorithms, are computational techniques that draw inspiration from biological systems to solve complex problems [11]. These algorithms mimic the behavior, processes, and principles observed in nature, such as evolutionary processes, swarm behavior.

4. BIOINSPIRED ALGORITHMS IN ELECTRICAL POWER SYSTEMS

Biologically inspired algorithms, also known as natureinspired algorithms or bio-inspired algorithms, are computational techniques that draw inspiration from biological systems to solve complex problems. These algorithms have been successfully applied in various domains, including power generation, transmission, distribution, and utilization as shown in figure 2[17]. Here are some applications of biologically inspired algorithms in these areas:

Power Generation Optimization: Biologically inspired algorithms such as genetic algorithms, particle swarm optimization, and ant colony optimization have been used to optimize the design and operation of power generation systems.

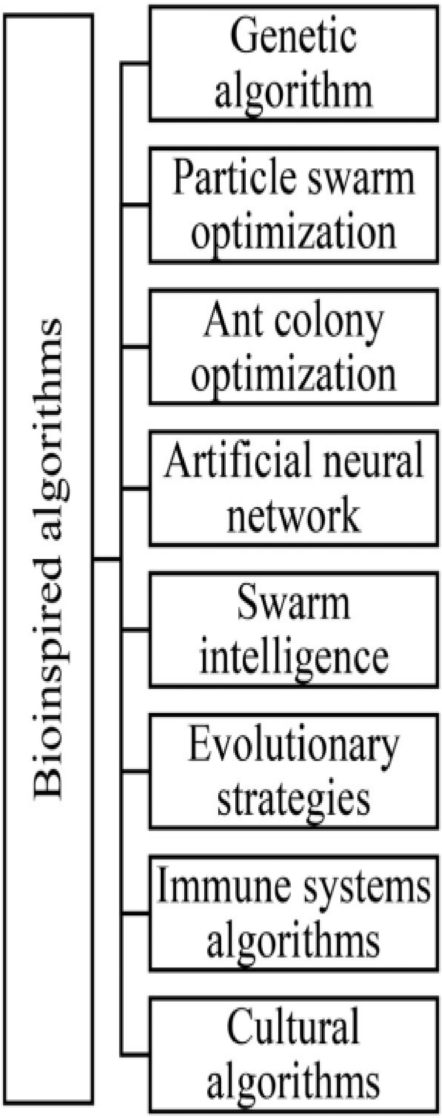


FIGURE 2. Types of bioinspired algorithms[10]

1. Renewable Energy Integration: With the increasing integration of renewable energy sources into power grids, biologically inspired algorithms can help address the challenges associated with intermittent generation and grid stability.
2. 3. Power System Planning and Expansion: Biologically inspired algorithms can assist in long-term power system planning and expansion.
3. 4. Fault Detection and Diagnosis: In power transmission and distribution systems, the early detection and diagnosis of faults are crucial for maintaining system reliability as shown in figure 3.

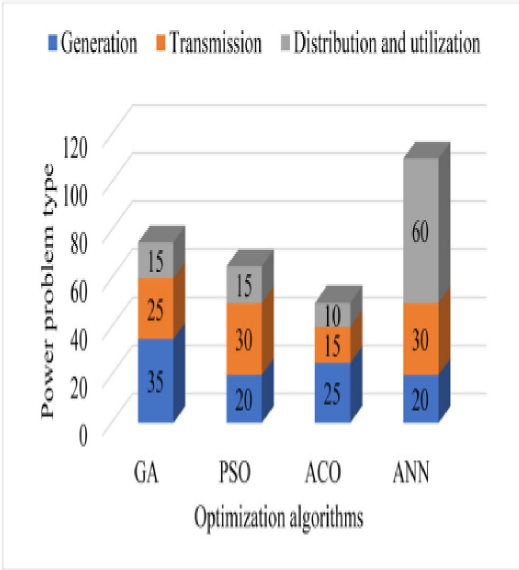


FIGURE 3. Percentage distribution of bioinspired algorithms across different power system optimization problems[14].

4. CHALLENGES AND FUTURE PROSPECTIVES

Bioinspired algorithms have demonstrated their effectiveness in electrical power systems, offering potential benefits for planning and operation. However, it is important to acknowledge the limitations and challenges associated with bioinspired algorithms, including their computational complexity, parameter tuning, and scalability issues [19]. Further research is needed to address these challenges and develop hybrid algorithms that combine the strengths of different bioinspired techniques [20]. In the future, the integration of bioinspired algorithms with emerging technologies such as machine learning and big data analytics holds promise for advancing the capabilities of power systems. This integration can enable smarter decision-making, real-time optimization, and improved system resilience [11]. One promising direction for future work involves exploring the hybridization of bioinspired algorithms with machine learning techniques. Integrating the adaptability of genetic algorithms with the learning capabilities of neural networks, for instance, could lead to more robust and efficient optimization strategies.

5. CONCLUSION

In conclusion, this concise review has provided an overview of the applications of bioinspired algorithms in electrical power systems. The integration of bioinspired algorithms into power systems has shown great potential in addressing complex optimization and control problems, leading to improved system performance, energy efficiency, and cost savings. The review highlighted the use of bioinspired algorithms in various aspects of power systems, including power generation, transmission, distribution, and utilization. In power generation, these algorithms have been applied to optimize the operation and scheduling of power plants, maximize renewable energy integration, and improve overall efficiency. In power transmission and distribution, bioinspired algorithms have been utilized to optimize power flow routing and scheduling, enhance fault.

REFERENCES

[1] V. Sharma and A. K. Tripathi, “A systematic review of metaheuristic algorithms in IoT based application,” Array, vol. 14, pp. 100164, 2022. DOI: 10.1016/j.array.2022.100164.

[2] M. G. M. Abdolrasol, et al., “Artificial neural networks based optimization techniques: a review,” Electronics, vol. 10, no. 21, pp. 2689, 2021. DOI: 10.3390/electronics10212689.

[3] A. K. Kar, “Bio inspired computing–a review of algorithms and scope of applications,” Expert Syst. Appl., vol. 59, pp. 20–32, 2016. DOI: 10.1016/j.eswa.2016.04.018.

[4] R. Shankar, S. R. Pradhan, K. Chatterjee and R. Mandal, “A comprehensive state of the art literature survey on LFC mechanism for power system,” Renew. Sustain. Energy Rev., vol. 76, pp. 1185–1207, 2017. DOI: 10.1016/j.rser.2017.02.064.

[5] M. Thirunavukkarasu, Y. Sawle and H. Lala, “A comprehensive review on optimization of hybrid renewable energy systems using various optimization techniques,” Renew. Sustain. Energy Rev., vol. 176, pp. 113192, 2023. DOI: 10. 1016/j.rser.2023.113192.

[6] R. Kumar, S. K. Khatri and M. J. Divan, “Optimization of power consumption in data centers using machine learning based approaches: a review,” IJECE, vol. 12, no. 3, pp. 3192, 2022. DOI: 10.11591/ijece.v12i3.pp3192-3203.

[7] T. Strasser, et al., “A review of architectures and concepts for intelligence in future electric energy systems,” IEEE Trans. Ind. Electron., vol. 62, no. 4, pp. 2424–2438, 2015. DOI: 10.1109/TIE.2014.2361486.

[8] S. N. Fallah, R. C. Deo, M. Shojafar, M. Conti and S. Shamshirband, “Computational intelligence approaches for energy load forecasting in smart energy management grids: state of the art, future challenges, and research directions,” Energies, vol. 11, no. 3, pp. 596, 2018. DOI: 10.3390/ en11030596.

[9] T. Nasir, et al., “Recent challenges and methodologies in smart grid demand side management: state-of-the-art literature review,” Math. Problems Eng., vol. 2021, pp. 1– 16, 2021. DOI: 10.1155/2021/5821301.

[10] Z. Liu, et al., “Artificial intelligence powered large-scale renewable integrations in multi-energy systems for carbon neutrality transition: challenges and future perspectives,” Energy AI, vol. 10, pp. 100195, 2022. DOI: 10.1016/j. egyai.2022.100195.

[11] T. H. Nguyen, L. V. Nguyen, J. J. Jung, I. E. Agbehadji, S. O. Frimpong and R. C. Millham, “Bio-inspired approaches for smart energy management: state of the art and challenges,” Sustainability, vol. 12, no. 20, pp. 8495, 2020. DOI: 10.3390/su12208495.

[12] B. Dasu, S. Mangipudi and S. Rayapudi, “Small signal stability enhancement of a large scale power system using a bio-inspired whale optimization algorithm,” Prot. Control. Mod. Power. Syst., vol. 6, no. 1, pp. 1–17, 2021. DOI: 10. 1186/s41601-021-00215-w.

[13] S. M. Nosratabadi, R. A. Hooshmand and E. Gholipour, “A comprehensive review on microgrid and virtual power plant concepts employed for distributed energy resources scheduling in power systems,” Renew. Sustain. Energy Rev., vol. 67, pp. 341–363, 2017. DOI: 10.1016/j.rser. 2016.09.025. [14] X. Luo, J. Wang, M. Dooner and J. Clarke, “Overview of

current development in electrical energy storage technologies and the application potential in power system operation," Appl. Energy, vol. 137, pp. 511–536, 2015. DOI: 10.1016/j.apenergy.2014.09.081.

[15] L. Mehigan, J. P. Deane, B. O. Gallach oir and V. Bertsch, "A review of the role of distributed generation (DG) in future electricity systems," Energy, vol. 163, pp. 822–836, 2018. DOI: 10.1016/j.energy.2018.08.022.

[16] C. Kavuma, D. Sandoval and H. K. J. de Dieu, African Centre of Excellence in Energy for Sustainable Development, University of Rwanda Kigali, Rwanda., "Analysis of power generating plants and substations for increased Uganda's electricity grid access," AIMS Energy, vol. 9, no. 1, pp. 178–192, 2021. DOI: 10.3934/energy. 2021010.

[17] H. Kim and P. Holme, "Network theory integrated life cycle assessment for an electric power system," Sustainability, vol. 7, no. 8, pp. 10961–10975, 2015. DOI: 10.3390/su70810961.

[18] S. Pal, A. Biswas, S. Kumar, S. Sarkar, P. Mandal and M. Sarkar, 2019. November). The Analysis of the Modern Power System with Distributed Network. In Proceedings of JIS University National Conference on Multidisciplinary Research 2019, pp. 44.

[19] H. Abdi, S. D. Beigvand and M. La Scala, "A review of optimal power flow studies applied to smart grids and microgrids," Renew. Sustain. Energy Rev., vol. 71, pp. 742–766, 2017. DOI: 10.1016/j.rser.2016.12.102.

[20] J. Liu, Z. Huang, M. Fan, J. Yang, J. Xiao and Y. Wang, "Future energy infrastructure, energy platform and energy storage," Nano Energy, vol. 104, pp. 107915, 2022. DOI: 10.1016/j.nanoen.2022.107915.

[21] W. H. Kersting, 2017, Distribution System Modeling and Analysis. Boca Raton: CRC press.