A Review on Automatic Control in Power System

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Abstract

Power systems are the foundation of contemporary society, providing energy for businesses, homes, and technological advancements. Precision, adaptability, and reliability are essential for these systems' complicated network of parts to satisfy the rising needs of our energy-hungry society. In this review paper, the vital function of automatic control systems in power systems is examined, along with how very important they are to maintaining stability, dependability, and sustainability. In the opening section of the essay, the basic building blocks of power systemsgenerators, transformers, transmission lines, distribution networks, substations, and control centersare explained. The complex interactions between these components highlight how dynamic and complicated power systems are, posing several problems that need for clever control measures. Different control methods are examined, from conventional ones like proportional-integral-derivative (PID) control to cutting-edge ones like model predictive control and adaptive control methods. Each approach is evaluated for its unique benefits and innate weaknesses, providing a thorough grasp of its applicability in various operational settings. The command and control of the current power grid depends on Wide-Area Monitoring and Control (WAMS) systems, which are made possible by synchrophasor technology and reliable communication networks. Grid operators have the tools they need to maintain stability and respond quickly to emergencies thanks to their capacity to offer real-time data and improve situational awareness.

Keywords: Power Systems, Automatic Control, Control Strategies, Wide-Area Monitoring and Control (WAMS)

1. Introduction

Power systems, which supply the electrical energy required for almost all aspects of daily life, are the foundation of modern society. Electricity is a vital resource that is used for everything from lighting up our houses to sustaining technological progress and industry. Maintaining the standard of living and promoting economic growth depend on the effective generation, transmission, and distribution of this electricity. Electric power networks or electrical grids are sophisticated, interconnected systems that make it easier to produce, transmit, and distribute electrical energy from power generation sources to end users. Power plants, renewable energy installations, and distributed energy resources are some examples of these sources.Automatic control is crucial to the effective and dependable operation of the grid in power systems. Automatic control systems continuously monitor, change, and optimise various power system parameters using sensors, actuators, and control algorithms. This control includes several different operations, including as load balancing, fault detection and mitigation, and voltage and frequency regulation. It is impossible to exaggerate the significance of power systems in contemporary civilization. They are vital to the development of technology, urbanisation, and industry.

- Economic Growth: Power systems are essential to businesses, infrastructure, and many industries, acting as a stimulant for economic growth.
- Quality of Life: Having access to dependable power makes life better for people by enabling the use of lighting, heating, cooling, and electronic gadgets.
- Technological Advancements: From medical devices to communication networks, power systems enable the creation and operation of sophisticated technology.
- Environmental Impact: Since power systems account for a sizeable amount of greenhouse gas emissions, how they are handled has a direct bearing on environmental sustainability. Control mechanisms that work well can lessen this effect.
- National Security: Because power systems are dependent on energy, there is a greater requirement for robust regulation to maintain national security.

1.1 The Need for Efficient and Reliable Control

Control systems keep frequency and voltage within reasonable bounds, avoiding brownouts and blackouts. Automatic control minimises waste and increases efficiency in the use of energy-generating resources. Control systems for fault management identify defects and take action to reduce their impact and ensure quick system restoration. Control systems are crucial for regulating variability and facilitating a seamless transition to greener energy in light of the increasing integration of renewable energy sources.

1.2. Components of Power Systems:

Power systems are complex networks made up of several parts that collaborate to produce, transmit, and distribute electrical energy. It is essential to comprehend these elements in order to appreciate the complexity and difficulties involved in operating power systems.

1. Generators

Power systems' beating heart, creating electricity through generators. Through electromagnetic induction, they transform mechanical energy into electrical energy. Steam turbines, gas turbines, hydroelectric generators, wind turbines, and solar photovoltaic panels are a few examples of different generator types. In order to control generators, their output must be adjusted to match demand while also ensuring stability and grid synchronisation.

2. Transformers

Transformers are necessary for converting voltage and distributing power. In order to facilitate long-distance transmission and reduce energy loss, they step voltage levels up or down. Distribution transformers adapt voltage for local usage, whereas power transformers change voltage levels at substations. Voltage regulation and monitoring are part of transformer control to ensure effective power transfer.

3. Transmission Lines

Transmission lines, which transport electricity over great distances from power plants to substations and other load centres, are the highways of the electrical grid. Typically, they are high-voltage cables built to reduce energy loss due to electrical resistance. Maintaining line stability, controlling reactive power, and reacting to disruptions are difficulties in transmission line control.

4. Distribution Networks

Substations are linked to households, businesses, and smaller loads by distribution networks.Power lines, distribution substations, and distribution transformers are some of them. The main controls in distribution networks are load balancing, fault detection, and voltage regulation.

5. Substations

In the electrical grid, substations serve as nodes that enable distribution, protection, and voltage level transformation. They contain control systems, protective relays, and switchgear. Monitoring equipment status, addressing issues, and assuring safety are all part of substation control.

6. Control Centers

The nerve centres of electricity systems are control centres, where personnel make crucial decisions and continuously monitor the entire grid. Real-time data is provided by supervisory control and data acquisition (SCADA) systems, while grid operations are optimised by energy management systems (EMS). Grid stability, load dispatch, and emergency responses are managed by control centres.

2. Literature Review

Ragab El-Sehiemy et al. (2023) suggest a novel approach for improving load frequency control (LFC) in multi-area power systems with non-reheat thermal systems. They propose a proportional–integral–derivative (PID) controller optimized using a unique artificial rabbits algorithm (ARA). The ARA outperforms other optimization techniques such as PSO, DE, JAYA, and SAMPE-JAYA in terms of ITAE values, achieving significant improvements when considering load changes in area 1, area 2, or simultaneous changes in both areas.

Sherif A. Zaid et al. (2023) address LFC in a two-area interconnected power system by introducing an optimized intelligent fractional-order integral (iFOI) controller. This iFOI controller is designed using the gray wolf optimization (GWO) algorithm, aiming to minimize system frequency deviations and tie-line power deviation. Compared to other controllers like integral and FOI controllers, the iFOI controller demonstrates superior performance in handling load/RES fluctuations and regulating the frequency of modern power systems with virtual inertia control (VIC).

M. V. Melikuziev et al. (2023) discuss the enhancement of city power supply systems through the integration of digital technologies, including online monitoring, distribution network automation, and smart grids. They emphasize the benefits of implementing smart grids for improved reliability and efficiency and compare the current state of networks with post-automation conditions.

Yingjun Ruan et al. (2023) propose an optimization model based on Deep Reinforcement Learning (DRL) to minimize the operation cost of an energy system comprising Combined Cooling, Heating, and Power (CCHP), photovoltaic generation, and energy storage. Their results show that training the model separately for summer and winter yields better optimization outcomes, and the TD3 method's performance is comparable to theoretical benchmarks while significantly improving operational efficiency.

Harold R. Chamorro et al. (2023) examine protection schemes against unstable electro-mechanical oscillations in power systems with a growing share of renewable energy generation. They focus on islanding operations and the need for continuously updating the power system monitoring and control tasks. The paper discusses evaluation methods, islanding protocols, and proposes an updated operational guideline leveraging data-analytic technologies.

Mohammad Ghiasi et al. (2023) provide a comprehensive review of cybersecurity methods and techniques in energy systems. They cover cyber-attack modeling, emerging technologies like blockchain and quantum computing, and problem-solving approaches. The paper highlights the evolving role of cybersecurity in the future of Smart Grids (SGs).

Line A. Roald et al. (2023) address decision-making under uncertainty in electric power systems due to factors like renewable energy, market liberalization, and climate change. They provide an overview of modeling and optimization methods, emphasizing applications in power systems and future research directions.

M.Z. Zakariya and J. The (2023) compare dynamic models for cascading failure analysis in power systems with high renewable energy penetration. They discuss features, limitations, computational speed, and potential test buses for tradeoff analysis. Grid-forming technology is suggested to study the impact of renewable energy on cascading failure.

Emre Çelik et al. (2023) investigate the use of energy storage devices (ESDs) for load frequency control (LFC) in various power system models. They demonstrate the effectiveness of an SSA-optimized PID controller with ESDs in reducing settling time and oscillations, offering a cost-effective solution compared to existing approaches.

Murilo E. C. Bento (2023) proposes a Physics-Guided Neural Network (PGNN) for calculating the load margin of power systems. The PGNN is trained with empirical and physical knowledge, providing accurate results for different power system scenarios.

Michael Hilgers (2023) provides a historical perspective on the evolution of electrical components in motor vehicles, from early batteries to complex semiconductor circuits in engine controllers.

D. Gomila et al. (2023) suggest segmenting large electrical transmission networks using controllable lines, such as high-voltage direct-current lines, to reduce the risk of blackouts during cascading failures. Their method modifies power flow to minimize load shedding, resulting in substantially lower blackout risk.

Bahram Shakerighadi et al. (2023) examine the challenges and properties of inverter-based generators (IBGs) in modern power systems. They explore different grid-forming control methods for IBGs and provide simulation results to illustrate their performance.

Wenqi Cui et al. (2023) propose a novel framework for predicting power system transients by learning in the frequency domain. They construct neural networks with Fourier transform and filtering layers, leveraging system topology and fault information to improve prediction accuracy.

R.A. Ufa et al. (2022) discuss the optimization of distributed generators in electric power systems to reduce power losses, improve voltage profiles, and participate in frequency regulation. They consider optimization criteria, limiting conditions, and solution methods, offering insights for system operators and investors.

Marcus Evandro Teixeira Souza Junior et al. (2022) explore the role of power electronics in integrating distributed generation sources, microgrids, and smart grids into the power sector. They discuss the classification of power electronics interfaces for various generation sources and their contributions to improved grid operations.

Ching-Ming Lai and Jiashen The (2022) review Distributed Temperature Rating (DTR) systems, emphasizing the thermal limits of transformers and distribution cables. They categorize research articles, providing a comprehensive overview of the DTR system's applications.

Mohamed Azeroual et al. (2022) propose a multi-agent system for fault location and autonomous power restoration in power distribution systems with distributed generation (DG). Their approach addresses fault detection, localization, and coordination among agents for backup protection.

Pantelis Dimitroulis and Miltiadis Alamaniotis (2022) introduce a climate-independent fuzzy logic Energy Management System (EMS) for integrating renewable energy sources, battery systems, electric vehicle loads, and dynamic pricing. Their simulation results demonstrate cost reduction for residential prosumers.

Doğan Çelik et al. (2022) discuss the development of energy systems and Sustainable Development Goals (SDGs) in the context of ongoing pandemics and potential global crises. They advocate for digital energy systems with Industry 4.0 integration and propose short-term, mid-term, and long-term plans for renewable energy development.

Mario Paolone et al. (2020) provide a survey of power systems modeling in the presence of converter-interfaced generation (CIG). They discuss the challenges of modeling CIG and provide insights into control strategies for grid-following and grid-forming converters.

Wei Chen et al. (2019) address distributed resilient filtering in power systems under denial-of-service (DoS) attacks. They develop a distributed filter to account for cyber-attacks and gain perturbations and derive an upper bound for filtering error covariance. The paper includes a benchmark simulation test.

Mishra et al. (2019) demonstrate Automatic Generation Control (AGC) using a Differential Evolution (DE) tuned two-degree-of-freedom proportional-integral-derivative (2DOF-PID) controller in a two-area power system. They show improved performance over traditional controllers under diverse loading conditions.

Table 1. Different technology from 2023-19

S.no	Author	Year	Technology
1	Ragab El-Sehiemy et al.	2023	PID Controller, Artificial Rabbits
2	Sherif A. Zaid et al.	2023	iFOI Controller, Gray Wolf Optimization
3	M. V. Melikuziev et al.	2023	Smart Grids, Digital Technologies

4	Yingjun Ruan et al.	2023	Deep Reinforcement Learning, DRL
5	Harold R. Chamorro et al.	2023	Islanding Operations, Data Analytics
6	Mohammad Ghiasi et al.	2023	Cybersecurity in Energy Systems
7	Line A. Roald et al.	2023	Optimization under Uncertainty
8	M.Z. Zakariya and J. The	2023	Dynamic Thermal Rating (DTR)
9	Emre Çelik et al.	2023	Energy Storage Devices, Load Frequency
10	Murilo E. C. Bento	2023	Physics-Guided Neural Network (PGNN)
11	Michael Hilgers	2023	History of Electrical Systems
12	D. Gomila et al.	2023	Grid Segmentation, Controllable Lines
13	Bahram Shakerighadi et al.	2023	Inverter-Based Generators, Grid-Forming
14	Pantelis Dimitroulis and Miltiadis Alamaniotis	2022	Fuzzy Logic EMS, Renewable Energy
15	Doğan Çelik et al.	2022	Energy Systems, SDGs, Digitalization
16	Marcus Evandro Teixeira Souza Junior et al.	2022	Power Electronics, Distributed Generation
17	Ching-Ming Lai and Jiashen The	2022	Dynamic Thermal Rating (DTR)
18	Mohamed Azeroual et al.	2022	Fault Location, Multi-Agent Systems
19	Pantelis Dimitroulis and Miltiadis Alamaniotis	2022	Fuzzy Logic EMS, Renewable Energy
20	Mario Paolone et al.	2020	Power Systems Modelling, Converters
21	Wei Chen et al.	2019	Resilient Filtering, DoS Attacks
22	Mishra et al.	2019	Automatic Generation Control, DE Algorithm

3. Complexity and Challenges

Power systems exhibit dynamic behaviour and are constantly subject to modifications in generation, demand, and network circumstances. To keep stability, control systems must be able to quickly adjust.Interconnectedness because components depend on one another, problems in one location might spread to other parts of the grid. These interactions must be taken into account in control tactics.Uncertainty the system is uncertain due to elements like weather and equipment malfunctions. Robust control methods are required to manage unforeseen events. cybersecurity power systems are susceptible to hackers as they grow more digital. Strong cybersecurity safeguards must be incorporated into control systems.Integration of renewable energy sources the incorporation of sporadic renewable energy sources increases complexity and calls for sophisticated control to control variability.

4. Control Strategies

4.1 Control Strategies in Power Systems

Power system control strategies are essential for ensuring the grid's stability, dependability, and efficiency. Various strategies are used, from conventional ones like proportional-integral-derivative (PID) control to more cutting-edge ones like model predictive control (MPC). Here, we'll look at different control methods, their benefits, and drawbacks.Power system control strategies are essential for ensuring the grid's stability, dependability, and efficiency. Various strategies are used, from conventional ones like proportional-integral-derivative (PID) control to more cutting-edge ones like model predictive control (MPC). Here, we'll look at different control methods, their benefits, and drawbacks.

4.1.1 Proportional-Integral-Derivative (PID) Control

Advantages

- Ease of use: PID control is a common control approach in power systems because it is simple to implement and comprehend.
- Robustness: PID controllers are capable of delivering consistent performance under a variety of operating circumstances.
- Low computational demands: They are efficient in terms of computation, which is advantageous for real-time control.

Limitations

- Limited adaptability: PID controllers may find it difficult to adjust to operating conditions or disturbances that change quickly.
- Tuning difficulties: Choosing the proper PID controller parameters can be time-consuming and challenging.
- Lack of ability to forecast future problems: PID controllers respond to the current error, which makes them less successful at doing so.

4.1.2 Model Predictive Control (MPC)

Advantages

- Predictive ability: MPC predicts future behaviour using a model of the system and adjusts control actions as necessary.

- Flexibility: It has the capacity to manage intricate systems with numerous inputs, outputs, and limitations.
- Better performance: MPC is capable of more effective and stable control.

Limitations

- Complexity of computation: Real-time optimisation problems might be computationally expensive to solve.
- Model accuracy: MPC strongly relies on accurate models, and inconsistencies between the model and the actual system might result in less-than-ideal control.
- Implementation difficulties: Developing and putting in place an MPC system can be difficult and need for specialised knowledge.

4.1.3 Advanced Control Techniques (e.g., Fuzzy Logic, Neural Networks, Adaptive Control)

Advantages

- Adaptability: Cutting-edge approaches can change to account for uncertain system dynamics.
- Nonlinear control: They are better able to manage nonlinear systems and control goals.
- Capability to learn: Some technologies, such as neural networks, are able to learn from data and develop control over time.

Limitations

- Complexity: Advanced control methods can be complex to design and implement.
- Data requirements: Learning-based methods may require significant amounts of data for training.
- Interpretability: Some advanced techniques, such as neural networks, can lack transparency in their decision-making processes.

5. Wide-Area Monitoring and Control (WAMS)

With major improvements in situational awareness and control, Wide-Area Monitoring and Control (WAMS) technology is an essential component of contemporary power systems. It makes use of communication networks and synchrophasor technologies to deliver real-time data and enable more efficient management of the electrical grid. WAMS offers real-time information on important variables like voltage, current, and frequency at various grid sites. This information improves the overall control of the power system by enabling operators to make knowledgeable judgements and swiftly implement remedial measures. The complete power system, including its dynamic behaviour, is fully visible via

WAMS. Operators can keep an eye on the condition of grid parts, spot possible problems, and take preventive action in the event of disturbances or anomalies. WAMS provides precise measurement synchronisation, which is necessary for accurate analysis and control, and hence contributes to grid stability. Faster fault isolation and identification are made possible, lowering the possibility of blackouts and cascading failures.

6. Conclusion

We have examined many aspects of power systems and their control in this review paper, emphasising the crucial function of automatic control systems in guaranteeing the stability, dependability, and sustainability of these essential infrastructures. Generators, transformers, transmission lines, distribution networks, substations, and control centres are all part of complex networks that make up power systems. Together, these parts produce, transmit, and distribute electrical energy to meet the demands of contemporary society. significance of The backbone of power systems, control systems are in charge of ensuring grid stability, maximising resource utilisation, and responding to disturbances. They are essential for fostering technical developments, supporting economic growth, and improving quality of life. From conventional PID control to cutting-edge methods like Model Predictive Control and adaptive control systems, we looked at a variety of control strategies. Each technique has a different combination of benefits and drawbacks, making it ideal for particular contexts and applications. Wide-Area Monitoring and Control (WAMS) WAMS offers real-time data and situational awareness across the grid using synchrophasor technology and communication networks. It greatly contributes to grid management by improving control, reliability, and enabling quick reactions to disruptions.

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