A Review of Research Methods for Developing Grid Security and Stability Control Strategies for New Type Power Systems

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Abstract. In the accelerating wave of global energy transition, the new type power system is gradually becoming the core structure of the future energy system. With the large-scale integration of wind and other renewable energy sources to the power grid, the structural complexity of the power system increased significantly, and the security and stability issues, as core elements restricting the efficient operation of the system, become more and more significant. In this context, the stability control system, as the second line of defense in the security system for power grid, plays an irreplaceable role in ensuring the power angle stability, voltage stability and frequency stability of large scale power system. This paper aims to expounds the role of the power grid security and stability control system, as well as the challenges and potential opportunities brought by the new type power systems, and systematically discusses the evolution of the strategic development method of the power grid security and stability control system under the background of the acceleration of the global energy transition, and its future development trend.

Keywords: New type power systems, stability control strategy, voltage stabilization, frequency stabilization.

1. Introduction

In the construction and development of the new type power system, the distributed access and large-scale grid integration of renewable, intermittent energy sources have become the norm. This transformation not only drives the structural upgrading of the power system but also poses heightened challenges and demands on its safe and stable operation [1, 2]. As a pivotal component within the security defense architecture of the power system, the stability control system primarily functions to swiftly identify system states when the power system encounters significant disturbances. By implementing preset control strategies, it effectively dampens system oscillations and prevents the occurrence of widespread blackouts, thereby ensuring the dynamic stability and continuous power supply capacity of the power system [3, 4].

The rational formulation of control strategies for stability control systems serves as a vital foundation for their precise and efficient operation. This process necessitates a profound comprehension of the dynamic behavior of power systems, encompassing high-precision modeling of system models, comprehensive analysis of fault scenarios, and optimized selection of control measures. The formulation of these control strategies must strike a balance between system security, economy, and flexibility, ensuring that while safeguarding stable system operation, the impact on power supply to users is minimized, and the strategies are adaptable to future changes in power system structures and the uncertainties posed by renewable energy integration [5].

2. Performance Analysis of Stability Control System under The Framework of New Type Power Systems

2.1. Angle Stability Maintenance

Angle stability focus on after major disturbances in power system, the generator rotor Angle can quickly return to running status and maintain the synchronization. Under the background of new energy on a large scale grid, power of the volatility significantly changed the trend of the distribution power system, which pose a challenge [6] to Angle stability. Specifically, the new energy power generation device is connected to the grid through a power electronic converter, and its inertia is very little or nearly no inertia. When the system fault disturbance, such as short circuit caused by voltage sag, the new energy device can not like a traditional synchronous generator inertia that provide the necessary support, cause the system Angle change rate rising, is not conducive to Angle to maintain stability. As slow Angle stability analysis, the inertia Angle rate of change of the key factors, is vital for stability control the time margin.

The security and stability control system can accurately predict and evaluate the dynamic behavior of the power system by collecting the operation data of the power system in real time and using algorithms and models. Once detected Angle instability risk, the system can real-time trigger preset control strategy, such as the removal of part of the generator or load, adjustment of reactive power compensation device, etc., effectively restrain swing Angle and prevent column system solutions, to ensure the synchronicity and stability of the power network.

2.2. Voltage Stability Assurance

Voltage stability means that after the power system is disturbed, the voltage of each node can be maintained within the allowable range to avoid voltage collapse. The intermittent and fluctuating characteristics of new energy sources (such as wind power and photovoltaic) cause changes in the transmission power of the grid when a large number of grid connections, resulting in node voltage fluctuations. The new energy power generation device is mainly connected to the power grid through power electronic converters, and its reactive power regulation ability is relatively weak. When facing load peak or voltage drop caused by system failure, the new energy power supply may not provide enough reactive power support to maintain voltage stability. In addition, the low voltage crossing capacity of some new energy power generation devices is limited, and a large number of off-grid failures will further worsen the voltage condition of the grid.

By monitoring the voltage level of each node of the power system, the safety and stability control system can evaluate the voltage stability in real time by combining information such as load change and reactive power distribution [7]. When the voltage drop trend is detected, the system can automatically adjust the generator excitation current, switching capacitors and reactors and other reactive power compensation equipment, or adjust the transformer tap to improve the reactive power balance of the system, enhance the voltage support ability, prevent the occurrence of voltage collapse accidents, and ensure the voltage quality and stable operation of the power system.

2.3. Frequency Stability Enhancement

Frequency stability means that the power system can maintain the current frequency fluctuation within the allowable range after experiencing serious disturbance to avoid frequency collapse. The inertia of new energy power generation equipment is very small, resulting in the overall equivalent inertia of the power system is reduced. When the active power disturbance occurs in the system, such as tripping of large thermal power units, the frequency of the system changes rapidly due to the lack of sufficient inertial support, which increases the risk of frequency instability. The intermittency and volatility of the output power of new energy generation, such as wind power fluctuations caused by changes in wind speed and photovoltaic power fluctuations caused by changes in light intensity, will exacerbate frequency fluctuations. In addition, the response characteristics of the power electronic control system of the new energy power generation device are significantly different from that of the traditional synchronous generator control system, and there may be a delay in processing signals related to frequency fluctuations, which affects its ability to support frequency stability and even aggravates frequency fluctuations in some cases [8].

The safety and stability control system evaluates the frequency stability by monitoring the frequency change of power system in real time and analyzing the active power balance. When the frequency deviates from the normal range, the system can quickly adjust the active power output of the generator, or cut off part of the non-critical load, in order to restore the power balance of the system, prevent the frequency collapse, and ensure the frequency quality and stable operation of the power system. At the same time, the safety and stability control system can also work with other control equipment of the power system (such as automatic generation control AGC, automatic voltage control AVC, etc.) to jointly maintain the frequency stability of the power system.

3. Evolution of Strategy Formulation Methods for Stable Control Systems under The Framework of New Type Power Systems

Stability control system is the core technology component to ensure the safe and stable operation of power system, the scientific and effective method of its control strategy formulation plays a crucial role in maintaining the overall safety and reliability of power system. With the continuous development of power system and the emergence of new technologies, the strategy formulation method of stability control system is undergoing profound changes and progress.

3.1. Power Grid Stability Control Strategy Based on Logical Operation

At present, the formulation of power grid stability control strategy generally relies on off-line analysis. According to a variety of typical power network operating conditions, the power research institutions have carried out the stability analysis of the power network under potential fault scenarios in advance. On this basis, the network configuration and major fault types that need to implement stability control measures are identified, and the corresponding control requirements are calculated accurately. Through comprehensive analysis of the correlation between the control requirements of the same fault under different operation modes and the characteristic parameters of the power grid, the stability control strategy table is constructed [9, 10]. In order to ensure that the stability control strategy table can be effectively integrated into the power grid regulation system and reduce the complexity of calculation, it is particularly important to formulate a power grid security and stability control strategy table suitable for various operating states of the control equipment. The policy table should contain the trigger event (the specific grid state change that triggers the control action), the mode description (detailing the implementation path of the control policy), the operating state (clearly defining the current mode of operation of the grid or equipment), and the control action (the specific regulation policy taken in response to the triggering event and the operating state). Among them, the trigger event, mode description and operation state together constitute the start logic framework of the control strategy, and the control measure is the concrete response action plan to these logical frameworks. As the core basis to guide the safe and stable operation of power grid, the stability control strategy table plays a key role in power grid regulation. According to the content of the policy table, the equipment manufacturer converts the policy into a specific control instruction that can be directly applied to the power grid stability control device and embedded in the device. In the actual operation of the power system, the power electronic control module implements the corresponding stability control measures strictly according to the preset control logic in the policy table to ensure the reliable operation of the power grid.

Up to now, many researches have deeply explored the method of building stability control strategy based on logical operation, aiming at effectively dealing with complex problems in actual power grid operation. Literature [11] summarizes the preliminary analysis work in the process of formulating the stability control strategy table. Based on the structure of Turpan power grid in 2022, in order to solve the dynamic stability problem of local power grid caused by the fault of main transformer, this paper studies the influence of damping ratio on the impact characteristics of power grid under different working conditions and the optimal stability control strategy when the isolation network is operated, and proposes the scheme of adding 750kV substation in Turpan area. Literature [12] applies the method of formulating stability control strategies based on logical operations to the field of stability control of new energy power grids. Through in-depth research on the operating state equation of new energy power grids, this paper proposes and validates a control strategy method that analyzes the control strategy into start-up conditions, control measures and control logic, and describes it through logical operation expressions. By using the new energy grid security and stability control strategy table constructed according to the method, power operation managers can efficiently calculate the control strategy according to the state of the grid and the type of fault, so as to ensure the safe and stable operation of the new energy grid. Literature [13] focuses on the optic-aluminum coupling control and the formulation of control cutting machine strategy. Based on the measured data of the large power grid, the stability characteristics of the power grid after the failure of the same tower double loop and bus, and the influence of the start-up of thermal power units and new energy output on the stability of the power grid are simulated and analyzed in this paper. Therefore, a comprehensive dispatching control scheme and load transfer strategy are proposed. At the same time, the concept of load real cutting coefficient of electrolytic aluminum rectifier transformer is introduced, which has positive significance to improve the accuracy of stability control system.

3.2. Power Grid Stability Control Strategy Based on Artificial Intelligence

Traditionally, the formulation of power grid stability control strategy is highly dependent on the expert's experience judgment and professional knowledge of power system. Although strict calculation analysis and simulation verification process can basically establish a strategy scheme to meet the safe and stable operation standards of the power system, with the increasing complexity of the power system, especially the new challenges brought by large-scale grid connection of new energy, the traditional control strategy gradually shows the limitations of insufficient flexibility and delayed response when dealing with the rapid change of the state of the power system.

Facing this situation, the rapid development of artificial intelligence technology and its wide application in new type power systems have opened up a new research perspective and frontier exploration direction for the strategy formulation of stability control systems. Specifically, artificial intelligence technology is integrated into the process of formulating stability control strategies, and advanced technologies such as machine learning and deep learning are used to conduct in-depth mining and intelligent analysis of power system operation data, aiming to achieve accurate prediction and intelligent regulation of power system status [14-16]. This method not only significantly improves the accuracy and real-time response ability of the stability control strategy, but also gives it the ability to make adaptive adjustment and optimization according to the real-time operating state of the power system, thus effectively enhancing the stability and reliability of the power system.

In the academic research and engineering practice of power system security and stability control, in order to meet the challenges of various scenarios, some scholars have integrated machine learning technology into the strategy establishment method. These methods not only broaden the boundaries of traditional control methods, but also significantly improve the adaptability and stability of the power grid in the complex and changeable environment of the power system, and inject new vitality into the future development of the power system. Literature [17] proposes a voltage stability emergency control strategy based on CNN-LSTM network. This strategy trains the model through the sample set generated offline, quantifies the sensitivity of the control measures, and then builds an optimization model to solve the cutting machine and load cutting strategy, realizing high-precision voltage stability prediction, and ensuring that the AC/DC hybrid power grid can quickly restore voltage stability under large disturbance. Literature [18] proposes a voltage security and stability control strategy for new energy grid based on time-series convolutional residual network and Pelican optimization algorithm. By constructing prediction model and control model, this strategy not only improves the accuracy of voltage stability prediction, but also obtains the best cutting load measure successfully. Simulation results show that the proposed method can significantly improve the safety and stability of power grid after failure. In terms of transient power Angle stability control, literature [19] modeled it as a sequential decision problem, and introduced constrained Markov model and reinforcement learning agent for iterative interactive optimization of cutting decision-making. In order to improve the agent's understanding of the transient stability trend of power grid, the strategy adopts the spatio-temporal feature sensing network layer of GCN and LSTM cascade, and introduces the security reinforcement learning technology to ensure the rationality and security of the action. Aiming at the problem of emergency load cutting decision, literature [20] adopts the "safety constraint over-limit punishment method" and "safety check method" to construct the decision model. The former designs the constraint conditions on the basis of the traditional Markov decision process, and uses the proximity strategy optimization algorithm to guide the intelligent system to determine the security policy. The latter trains the security evaluator network based on historical data, and combines SAC and DDPG algorithms to enhance the agent's exploration capability and optimize the repair strategy. The simulation results show that these two methods can not only ensure the safety of the power grid, but also optimize the cutting load, and the latter has better performance in frequency stability and strategy optimization. Aiming at the high frequency problem of the "double-high" transmitter system under large power surplus accidents such as DC lock, a frequency emergency control model based on multi-type resource coordination was proposed in literature [21]. By integrating resources such as synchronous power supply, new energy, extraction storage, DC modulation and stable control cutter, the model effectively improves the frequency transient process, restrains the new energy off-grid, and realizes the goal of the lowest emergency control cost, thus improving the transient frequency stability of the transmitter system. These studies not only provide new ideas and methods for the stability control of power system, but also lay a solid foundation for the safe and stable operation of power system in the future.

4. Conclusion

With the acceleration of global energy transformation and the construction of new type power systems, the security and stability of power systems are becoming increasingly significant. As the core part of power system security defense architecture, stability control system and technologies are becoming more and more important.

First of all, the power grid security and stability control system play a key role in maintaining the stability of the power system, ensuring the power Angle stability, voltage and frequency stability of the power system, and laying a solid theoretical and technical foundation for the safe, reliable and efficient operation of the electric power system.

Secondly, the global energy transformation has put forward great challenges and new requirements for the stability control system. The access of intermittent new energy increases the complexity of the power system, reduces the inertia of the system, and puts forward higher requirements for information processing capacity and system economic cost control. However, the development of artificial intelligence has also brought unprecedented opportunities for the development of stability control systems.

Moreover, the strategy formulation method of stability control system is undergoing continuous evolution. The traditional method of formulating control strategy based on logical operation has gradually changed to the power grid stability control strategy based on Artificial Intelligence. In particular, the stability control strategy formulation method combining machine learning and deep learning has become a hot topic in current research. These methods not only improve the accuracy and real-time performance of the strategy, but also make adaptive adjustment and optimization according to the real-time operation state of the power system, showing great application potential.

In summary, the evolution of the strategy formulation method of the stability control system is a process of continuous exploration, innovation and improvement. In the future, with the continuous development of the power system and the continuous emergence of new technologies, the strategy formulation method of the stability control system will continue to develop in the direction of intelligence, self-adaptation, coordination and standardization, providing a more solid guarantee for the safe and stable operation of the power system.

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