Exploration of Safety, Stability, and Power Quality Issues in New Energy Power Generation

Feng Zhou

Anhui Urban Construction Design Institute CORP.,Ltd., Hefei, Anhui, 230000, China

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Abstract: The continuous development of new energy power generation, including wind and solar energy, is propelled by the the gradual transition to clean low carbon sources in global energy structure. Nonetheless, the intermittent, variable, and low-inertia property of new energy power generation is distinct from the controlling means of the traditional generation system with synchronous generators as the mainstay; thus making safety and stability problems as well as poor power quality. This paper analyzes the basic requirements of new energy power generation safety and stability, discusses the problem of related power quality, points out the main contradictions in grid-connected operation of new energy, and gives targeted countermeasures. It serves as a reference for the reliable operation of power systems with high penetration of new energy integration, and supports the safe and efficient development of new energy power generation in the process of energy transformation.

1. Introduction

Under the impetus of "dual carbon" goals, new energy power generation is a key direction for optimizing the energy structure in China, and since then, the installed capacity of wind and photovoltaic power generation has been continuously growing. Traditional power system with the help of synchronous generators rotating inertia and a mature operating mechanism, has strong anti-disturbance capabilities to maintain frequency and voltage stability. Nonetheless, with the basic characteristics of the inherent intermittency and low-inertia properties such as wind power generation (WPG) and solar power generation (SPG), which have been increasingly widespread in global energy systems, its simple implementation is becoming apparent, resulting in further disruption to the traditional power balance model and stable operation mode. Based on the above background, it is of great practical significance to carry out an in-depth analysis of the operational problems caused by new energy power generation in power systems, organize their influence mechanism and explore its solution methods to promote the sustainable and healthy development of new energy power generation and ensure the clean, low-carbon, safe and reliable supply of electricity for power systems.

2. Core Factors Influencing the Safety and Stability of New Energy Power Generation

2.1 Inherent Intermittency and Fluctuation of New Energy Power Generation

Due to the direct dependence on natural environmental conditions, the output of new energy power generation is unstable and uncontrollable as compared with traditional synchronous generators, which has great intermittency and fluctuation characteristics. Facing the energy conversion process, whether solar irradiance for photovoltaic power generation or wind speed for wind power generation, are continuously changed by natural conditions resulting in real-time output of new energy units to be time-varying. Such fluctuations not only break the traditional balance state of power systems, but also bring challenges to the dispatch and operation mode of each system. Traditional power systems are fundamentally based upon the lesson of "generation following load," keeping a balance in energy flow across an electrical network by enhancing or reducing the output of synchronous generators. However, new energy output is unstable, and it leads to the need of

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constantly adjusting reserve resources to respond ED fluctuations. When the adjustment capacity of reserve resources cannot respond to the fluctuation amplitude in time or the delay is large, it will break the original rigid balance of power and lead to problems such as frequency deviation.

2.2 Low Inertia and Converter Control Characteristics of New Energy Units

Inertia plays an important role to keep the frequency of power systems. Synchronous generators in conventional power systems built inertia, which is generated by the kinetic energy of their rotating components. If power in the system is imbalanced, they can decelerate the rate of frequency change by discharging their kinetic energy to buy time for further frequency regulation equipment to respond and maintain frequency stability. On the contrary, power electronic converters are used to realize energy conversion and grid-connection processes for new energy units. They do not have rotating parts that can develop inertia such as the inertia format created by synchronous generators, and therefore these units constitute a typical low-inertia power supply. With the increasing penetration level of new energy units in power system, the total inertia of system will be continuously reduced, which leads to continuous decline of system mechanical properties against disturbance and makes the rate of change on frequency exceed traditional systems allowed range, resulting in higher possibility of frequency instability. Moreover, the stability of power systems are highly related to control strategies of converters. Existing studies on control of new energy units are mainly concentrated on maximum power output, with the consideration of power-generation efficiency. They do not have a very strong capacity to regulate voltage on the grid and cannot provide effective support response when the grid voltage fluctuates. When a grid fault occurs, converters may respond by activating the protection mechanism to turn off its output to prevent damage in own components which causes more imbalance on the power supply and of course the voltage drop made greater influence on voltages stability of system [1].

2.3 Insufficient Synergy and Adaptation between New Energy Grid Connection and Traditional Power Systems

Traditional power systems are all designed according to the operation characteristic of synchronous generator, including the design logic, grid structure and dispatch mechanism. However, the operational characteristics of new energy power generation are very different from that of synchronous generators; there is a lack of effective synergy and adaptation between large-scale grid connection and traditional power system on several levels. This problem has emerged to be a keynote factor aggravating the safety and steadiness risks of the system. From the perspective of grid structure, most areas rich in new energy resources are physically distant from load centers. Transmission of new energy power through long-distance transmission lines to load centers. Nevertheless, because long-distance transmission lines have smaller transient stability margins and the output of new energy in geographical units is not constant, power oscillations along the line can easily occur, increasing the hazards of line failure or at least increasing instability of power transfer over such long distances, raising dangers for safe operation. For dispatch mechanism level, traditional dispatch modes are calculated based on deterministic generation plans, but new energy output has a strong randomness and cannot be forecasted deterministically, so the calculating methodology for output forecasting is changing its way to probabilistics. However, the accuracy of new energy output forecasting is far from sufficient, leading to more difficulty for dispatch system departments in reasonably formulating power balance plans and coordinating new energy output with load demand.

3. Power Quality Issues in New Energy Power Generation

3.1 Voltage Fluctuation and Flicker

The characteristics in connecting new energy power generation systems to grid directly result in voltage fluctuation and flicker issues. Since the output of wind and photovoltaic power generation relies on natural conditions, it adjusts in real time according to the changes in wind speed and light intensity. Because of this dynamic nature of the output, power into the grid becomes a variable where net output is perforated through the connection to the generated. The instant of electricity reduces through the grid weight which is converting as popular power, so this has due to instantaneous voltage variations at that grid connection point and surrounding region which results of working of voltage fluctuations. Unlike traditional power generation, the new energy output fluctuates more frequently and the amplitude change is less predictable. This is especially true in areas where new energy installed capacity accounts for a high proportion, the output fluctuations of individual or multiple new energy units will further superimpose leading to an expansion and intensification of voltage fluctuation range.

Voltage flicker is the direct effect of voltage variation on its electrical equipment. When the frequency of voltage fluctuations is just in the interval where the human eye is sensitive to changes of light intensity, it makes the illumination level of lighting equipment circling and then people see a flicker in their vision. This is not only related to the visual comfort of residents in daily life, but also interferes with industrial production processes that rely on a high degree of stability of the power supply, such as precision manufacturing and electronic processing. This can result in lowering the operating precision of production equipment, quality fluctuations of products, or even malfunctioning faults of the equipment, threatening to disrupt the continuity and stability of industrial production. Meanwhile, also the continuous voltage fluctuation will lead to faster aging of power equipment such that it shortens the service period of transformers, motors and other equipment as well. In turn, this causes an increase in operation & maintenance costs for power systems.

3.2 Harmonic Pollution

The large scale utilization of power electronic converters in novel energy generation systems is the primary cause of harmonic pollution. From pitch control of wind power, maximum power point tracking of photovoltaic, to the AC-DC conversion of new energy power before grid-connected, a series of energy conversion and control based on DC electronic converters can not be separated from intelligent control. They control the amplitude and frequency of output power during the converters operation by periodically turning on and off switching devices. This process too, creates significant non-sinusoidal components of the current called harmonic currents. Harmonic currents are injected into the grid and will generate voltage drop in grid impedance, distorting the grid voltage waveform and producing harmonic voltages which can affect other equipment or loads in the grid [2].

3.3 Three-Phase Imbalance

New energy power generation systems connected to the grid can easily cause three-phase imbalance problems in the grid, mainly due to the single-unit operational characteristics and grid connection methods of new energy units. Some small new energy units usually employ a single-phase grid connected method, that is the output of this unit only injects into one phase grid directly destroying the power balance between three phases of the grid and leading the three-phase voltage and current to significantly deviate from each other. Even for large new energy power stations that adopt three-phase grid connection, factors such as slight difference of the element parameters in each phase inside units or unbalanced light distribution in photovoltaic array, and also the wind turbine output inconsistency among different turbines may change the three-phase power output by the power station, and ultimately affect onsthe balance state of the grid.

4. Optimization Strategies for Safety, Stability, and Power Quality Issues in New Energy Power Generation

4.1 Strengthening Inertia Support and Voltage Regulation Capabilities of New Energy Units

The low inertia and weak voltage support ability of new energy units is an important technical barrier that must be overcome to realize the deep integration of new energy and the grid, so it is necessary to optimize unit control strategies from a technical perspective. Virtual inertia control technology can be incorporated into the control systems of new energy units to simulate the inertia characteristics of synchronous generators on one hand. This technology detects the frequency change of the grid, thus automatically and timely releasing or absorbing power with the objective of allowing for slower rate of frequency change to buy some time for system frequency regulation when frequent fluctuation occurs; therefore, it makes up for mechanical inertia deficiency inherently existing in new energy units. In this process, droop control strategies should be integrated to turn the new energy units into units similar to synchronous generators in frequency response characteristics, increase their ability to participate in system frequency regulation and ultimately improve the level of system frequency stability.

However, the control logic of voltage regulation of new energy units should be optimized. Add a voltage support module to converter control strategy. If the grid voltage is varying, instead of seeking maximum powers, we try to maintain a stable voltage. In this way, the converter's reactive power output is dynamically adjusted in real time according to grid connection voltage for quickly compensating the existing reactive power deficit of the grid and suppressing voltage fluctuation, further improving the absorptive ability of the integrated photovoltaic station over voltages on surrounding grid side as well as reducing flicker problems due to voltage fluctuations.

4.2 Optimizing the Structure and Operation Dispatch of New Energy Grid Connection Systems

From the aspects of grid structure and dispatch mechanism, the synergy and accommodation of new energy and traditional power system should be improved so as to alleviate the influence of grid connection on system stability. For grid structure optimization, based on the separation of new energy resources and load centers, it should be promoted that distributed and centralized new energy develop coordinately. Second, distributed photovoltaic (PV) and scattered wind power projects should be deployed near load centres to alleviate long-distance transmission needs and improve the stability of power between two line towers. Regarding centralized new energy bases, we should strengthen the construction of supporting transmission channels to a greater extent, and actively adopt flexible HVDC transmission technologies to enhance the transient stability margins and power regulation capabilities of transmissions system, suppress power oscillations in lines, and guarantee the safety of long-distance transmission.

For dispatch optimization, we need to build a flexible dispatch mechanism in accordance with new energy randomness. Introduce high-precision new energy output forecasting technology, through the fusion of meteorological data and historical operation data based on artificial intelligence algorithm to strengthen the accuracy of short-term and ultra-short-term output prediction, and lay a reliable basis for dispatch plan formulation. Based on this, a new energy + energy storage coordination management mode should be constructed from the aspects of coordinating scheduling and characteristics of energy storage devices to smooth out the fluctuations brought by the output of new energy. Energy is stored on output peaks and released on output troughs to keep power balance in the system. Thirdly, dispatch rules should be improved: newly-added energy units must enter the reserve resource system of the grid or some other platform of participating in auxiliary services such as frequency and voltage regulation logic, and elaborate compensation mechanisms to enhance enthusiasm for new energy units to participate in system regulation should be further established; Finally, inertia and reactive power support deficiencies of the systems could be compensated.

4.3 Strengthening Power Quality Monitoring and Harmonic Control

Construct full-chain monitoring on new energy power generation and take targeted control measures can efficiently control the power quality problems caused by it. A dual strategy of "source suppression + end treatment" should be adopted in harmonic control. For the source suppression,,the topology structure and control algorithms of converters in new energy units needs to be studied. Open access is an initiative that aims to make scientific research freely other Multi-level converters and the pulse at source width modulation optimization technologies are also included harmonics so as to cut down harmonic components in converters working while fundamentally lowering the source of harmonic pollution. Monitoring data will outperform the planning level and identify regions where harmonic pollution is serious, and thus configure flat devices such as active power filters or passive power filters that receive actual end treatment every day. For a new energy power station, large capacity active power filters central to the grid connection point, real-time harmonic current compensation in the grid. Small harmonic control devices should be installed at the load entrance on sensitive loads on the user side to shield the user electrical equipment from harmonic interference and form a harmonic control system covering all aspects of power generation, transmission, and consumption [3].

4.4 Improving the Standard System for Safety, Stability, and Power Quality of New Energy Power Generation

The standard specification and technical requirements and management norms for the safe operation of new energy power generation systems need to be clarified, so as to provide guarantees accordingly. At the level of technical standard formulation, the grid connection technical requirements for new energy units should be refined, and stricter and more detailed standard parameters should be proposed in key indicators such as frequency response, voltage regulation, inertia support and harmonic suppression to ensure that the unit has enough system friendliness. We should improve the design and construction standards of new energy power stations, reasonably configure the requirements for energy storage equipment, reactive power compensation equipment and monitoring equipment in system configuration, standardize technical processes such as selection, installation, commissioning of main electrical equipment in power stations and operation and maintenance of new energy devices to better guarantee the construction source level to ensure that power stations have safety stable operation and passable electric quality level. As for the improvement of management standards, it is necessary to formulate operation and maintenance procedures for new energy power stations to regulate the work processes of unit inspections, equipment maintenance and fault handling, and reduce safety, stability and power quality problems caused by improper operation and maintenance. According to this, a coordinated management mechanism among departments should be established, so as to strengthen the exchange and cooperation between grid enterprises, new energy power generation enterprises and equipment manufacturing enterprises, form a standard implementation and supervision system in one step together, promote the implementation of standards effectively and provide institutional guarantee for the safe and efficient development of new energy power generation.

5. Conclusion

New energy power generation has always been a key problem which the large-scale development of the industry because it is the core force in promoting global clean energy transition, with respect to safe and stable operation and control of power quality. At present, new energy power generation is still in a process of high-proportion grid connection, facing dual challenges of technological iteration and system adaptation, and the practical effect of existing optimization strategies needs to be verified and adjusted according to the characteristics of different regional grids and new energy installation scale. There will be further improvements in new energy power generation systems on simulation accuracy of inertia, output prediction accuracy, and electricity quality control efficiency driven by deep integration of power electronics technology, energy storage technology and artificial intelligence algorithms.Continuous incrementing on the common share with new energy power generation can be powered ahead through this way under global carbon neutrality goals achieved.

References

[1] Liang Lele. Discussion on Safety, Stability, and Power Quality Issues in New Energy Power Generation [J]. Smart Building & Smart City, 2024(10): 97-99.

[2] Jiang Qirong. Discussion on Safety, Stability, and Power Quality Issues in New Energy Power

Generation [J]. Electrical Age, 2014(4): 40-43.

[3] Yang Fan. Interview with Professor Jiang Qirong from the Department of Electrical Engineering and Applied Electronic Technology, Tsinghua University on Safety, Stability, and Power Quality Issues in New Energy Power Generation [J]. Electrical Applications, 2014, 33(3): 6-8.