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Review

A Review of the Research on the Wide-Band Oscillation Analysis and Suppression of Renewable Energy Grid-Connected Systems

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Abstract: With the continuous expansion of the scale of power generated by grid-connected renewable energy, the form and operation characteristics of power grids have undergone significant changes, and the power electronic characteristics of power systems are prominent, resulting in the frequent occurrence of wide-band oscillation problems when renewable energy power generation equipment is connected to a power grid. Oscillation has the characteristics of nonlinearity and has an oscillation frequency ranging from a few hertz to several thousand hertz or more, which seriously threatens the stable operation of power grids. This paper summarizes the wide-band oscillation events that occur worldwide under the background of renewable energy access to power grids, classifies the wide-band oscillation events according to the distribution of oscillation frequency bands, and sorts out the characteristics of various oscillations. From the perspectives of the source side and network side, the existing oscillation suppression measures are classified and prospected.

Keywords: renewable energy; wide-band oscillation; oscillation characteristics; analytical method; oscillation suppression

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1. Introduction

As the foundation of modern social civilization, electric energy has played an indispensable role in the development of industry and the economy. In the traditional power industry, non-renewable fossil energy such as that obtained from coal mining is used to generate electricity, which exacerbates the problem of energy shortage, and the damage to the environment cannot be ignored. Under the dual pressure of energy demand and environmental protection, more research resources have been invested in the field of distributed generation technology of renewable energy. Many countries and regions have put forward adaptive development plans for renewable energy power generation [1–4]. The EU Ministry of Energy plans to achieve 80% of renewable energy power generation by 2050; China is building large-scale photovoltaic power plants and wind farms to achieve carbon neutrality by 2060.

An important support for the rapid development of renewable energy power generation is the large number of applications of power electronic devices; the development of fast semiconductor switches and the use of real-time control algorithms make it possible to generate grid-friendly and economical electricity through renewable energy [5–7]. In addition to the high penetration of renewable energy power generation at the power generation end, on the load side, users are also increasingly relying on power electronic equipment with higher auxiliary control performance; power electronic loads such as inverter-driven motors and electric vehicle charging piles are widely accessed, and the load characteristics have also changed significantly. In general, the power side of the current power system has a high proportion of renewable energy access, and the grid side and the load side also have access to a high proportion of power electronic equipment, thus constituting a new type of power system, the structure of which is shown in Figure 1. Some researchers call this power system a "double-high" power system, presenting a "double-high" characteristic (a high proportion of renewable energy and a high proportion of power electronic equipment) [8]. The large-scale access of power electronic equipment has made the operation mode and dynamic characteristics of the power system change significantly, represented by the converter interface of renewable energy power generation; there is nonlinear strong coupling between the control system and the traditional electromagnetic equipment, and there is also a cross-coupling phenomenon between multiple converters. When there is a disturbance in the double-high power system, the mode evolution and response process of the system have complex spatio-temporal interaction coupling characteristics, and the disturbance of the power system presents amplitude–frequency time variation and wide frequency domain characteristics, which researchers in the field of electric power summarize as wide-band oscillation.

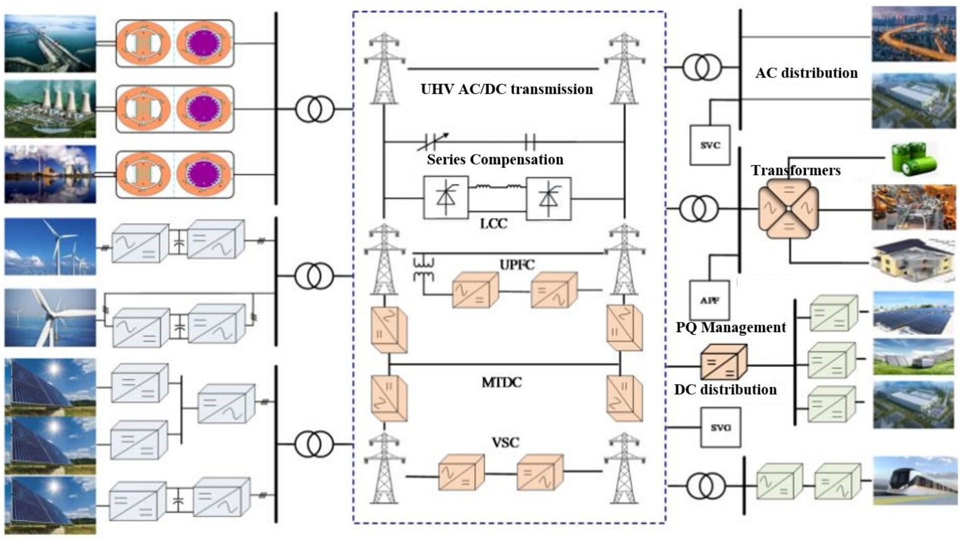


Figure 1. Schematic diagram of power electronics-dominated power systems.

The trend of renewable energy generation and mass grid integration has become unstoppable, but the current research on the oscillation phenomenon of a "double-high" power grid is not enough to support the development speed of power grid electronics. The oscillation of renewable energy generation has brought huge losses to the power industry and residents' lives. In the face of frequent wide-band oscillation accidents, it is necessary to carry out a unified mechanism analysis and summary of oscillation suppression methods.

This paper first summarizes the oscillation accidents caused by the integration of renewable energy into the grid around the world and analyzes and classifies them. Then, the current researchers' methods of researching the mechanism of wide-band oscillation are summarized, and the advantages and limitations of various analysis methods are summarized. This paper comprehensively summarizes some wide-band oscillation suppression methods proposed or used by academia and industry. Finally, the research status of wide-band oscillation is summarized, and the future research trend is proposed, which the authors hope will be helpful to future researchers in this field.

2. Analysis of Wide-Band Oscillation Phenomena and Characteristics

The AC power grid is essentially an electric energy system that is forced to work at the power frequency, but when studying its oscillation problem, it often focuses on the energy exchange of frequencies other than the power frequency carried in the power system, which includes three categories, mechanical, electromagnetic, or mechanical and electromagnetic coupling, which will generally cause power quality problems and endanger the safe and stable operation of the power system in serious cases. In recent years, power system oscillation events have occurred in different frequency bands all over the world, and the oscillation frequency range is 2 Hz–2 kHz [9]. The wide-band oscillation caused by the grid connection of renewable energy generation with a power electronic interface is mainly concentrated in the sub-synchronous frequency band, accompanied by sub/hypersynchronous interweaving and high-frequency oscillation, which is different from the ultra-low-frequency oscillation caused by traditional generator sets. This section collects, analyzes, and classifies wide-band oscillation events from around the world.

2.1. Wide-Band Oscillation Events

Renewable energy power generation is restricted by wind and solar resources, and power generation bases are mostly distributed in remote areas such as grasslands, mountains, and deserts. Under such conditions, power grids lack the support of synchronous motors, the inertia of the power system is small, and the short-circuit ratio of renewable energy access points is also small. According to the IEEE std 1204-1997 [10], a grid with an SCR of less than 3 is called a weak grid, where the impedance of a long-distance transmission line is not negligible [11]. When the penetration rate of renewable energy with power electronic grid-connected interfaces continues to increase, and the characteristics of an AC power grid become weaker, the power grid cannot be regarded as an ideal power grid, and the problem of wide-band oscillation arises. The participants are no longer only synchronous generators, but also power electronic equipment and various controllers, renewable energy units, AC and DC dynamics, transmission lines, and synchronous generators. Because power electronic equipment is different from traditional equipment in terms of hardware structure, control mode, response characteristics, interactive coupling, etc., it has a profound impact on the dynamic behavior of the power grid [12,13]. Table 1 summarizes the wide-band oscillation events of power systems that occur around the world [14–24].

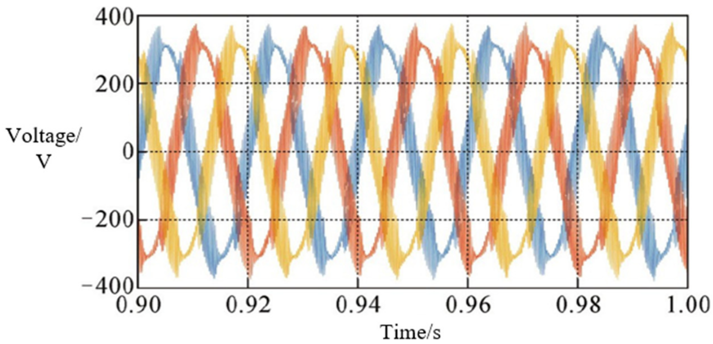
Table 1. The accidents of wide-band oscillation in a power system integrated with renewable energy.

Accident Time	Scenes	Band/Hz	Consequences
2007	The wind farm in Minnesota, USA, is connected to a series of lines that cause oscillation	10–13	Wind turbine damage
2008	The harmonic content of the wind turbines in the Saihanba Wind Farm in Inner Mongolia exceeded the standard	1000, 1050	Wind turbines trip frequently, some units are shut down
2009	A transmission line trip at a wind farm in Texas, USA causes system oscillations	20–30	Damages series capacitors and wind turbines
2011	A wind farm in Oregon, USA causes oscillations in windy weather	5–14	Generates large reactive power harmonics
2012–2013	The doubly fed wind turbines of the Guyuan Wind Farm in Hebei Province interact with the series compensation power grid	3–12	In severe cases, it will lead to the disconnection of large-scale wind turbines
2013	The Ningxia Wuzhong direct-drive wind farm protection action triggers oscillation	95	Causes large-scale wind turbines to go off the grid
2014	The increase in the output of the South Australian wind power flexible and direct transmission system leads to sub-synchronous oscillation	30	The flexible direct transmission system is suspended

Table 1. *Cont.*

Accident Time	Scenes	Band/Hz	Consequences
2014–2015	Direct-drive wind farms in the Hami area of Xinjiang undergo sub/hypersynchronous oscillations	20–80	The thermal power unit trips and the frequency of the power grid decrease
2015	The power fluctuation in the Jilin photovoltaic power station causes oscillation	1000	Currents fluctuate greatly
2015	The feeder of the Ontario photovoltaic power station in Canada is put into the shunt capacitor to cause oscillation	20–80	Protection action, unit tripping
2015–2019	Oscillations are caused by weak power grids and converters in the West Murray area of Australia	7	Voltage oscillations occur
2018–2019	Oscillation of wind turbines and photovoltaic units in Ontario, Canada	3.5	Protection action, unit tripping
2019	Load shedding and offline at the Howth offshore wind farm in the UK	9	System delisting, massive power outages
2020	Wind turbines in West Murray District, Australia, have sub-synchronous frequency oscillations	15–20	Feeder line trip protection action
2021	Sub-synchronous oscillations were detected for voltage fluctuations at a PV plant in Virginia, USA	22, 38, 82	Causes voltage oscillations
2021	A high proportion of wind power in Scotland in the UK is oscillating	8	Causes voltage oscillations

Among the above-mentioned accidents, high-frequency oscillations occur at the grid-connected points when large-scale photovoltaic power stations are connected to the grid; the reason for this is generally due to the negative resistance at the resonant frequency, and the dominant factor is the voltage feedforward filter [25]. Figure 2 records the waveforms of the current and voltage oscillations at a typical PV grid-connected point. Sub-synchronous oscillation will occur in the process of power transmission of doubly fed wind farms through long-distance series compensation lines. As early as 1970, sub-synchronous oscillations occurred at the Mohave wind farm in the United States [26]. Since 2012, a similar phenomenon has occurred in Guyuan Wind Farm in Hebei Province, China [9], where the oscillation frequency is distributed within 5~10 Hz with the change in the number of wind turbines in operation, and the oscillation will quickly subside if the series capacitor is removed, as shown in Figure 3. The recording of this accident shows that the wind power grid-connected interface will interact with the series line to cause divergent oscillation.



(**a**)

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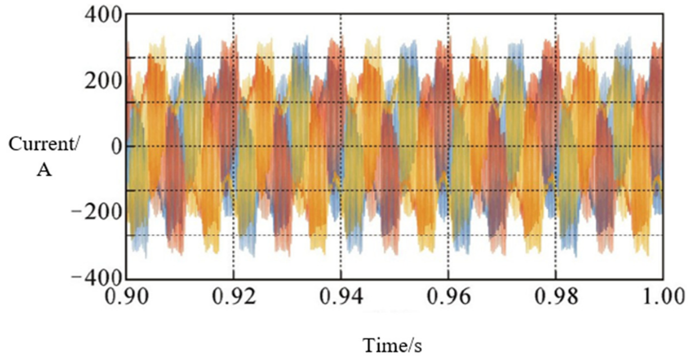

(**b**)

Figure 2. Photovoltaic grid-connected high-frequency oscillation waveform. (**a**) PCC point voltage oscillation waveform. (**b**) PCC point current oscillation waveform.

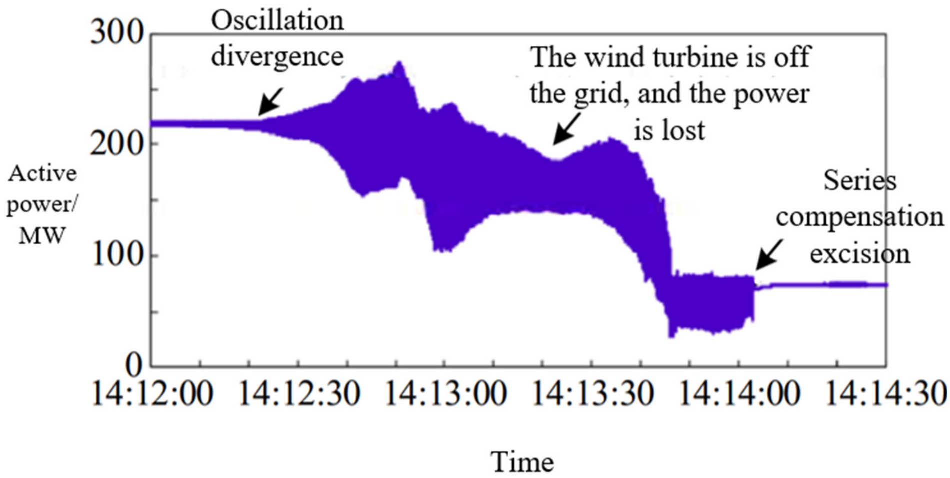

Figure 3. The output power of a wind farm in Guyuan, Hebei, China.

2.2. Wide-Band Oscillation Characteristic Analysis

The main difference between the "double-high" power system and the traditional power system lies in the power electronification of the power generation side, the transmission network, and the distribution network side, and the essence of the wide-band oscillation problem lies in the interaction of the dynamic behavior between the three. Compared with the oscillation problem of the traditional power system, the wide-band oscillation problem of the "double-high" power system has obvious changes in three aspects: the participating object, the oscillation form, and the scope of influence, which are mainly manifested in the following:

(1) Participants: For a traditional power system, the main participants of oscillation are synchronous generator sets, such as the oscillation of the excitation control system, the oscillation of the prime mover speed regulation system, and the torsional vibration of the shafting of the thermal power unit. The wide-band oscillation of the "double-high" power system is determined by the power electronic equipment and its control system, the traditional electrical equipment, and the transmission network. For example, the interaction between the power electronic converter of a wind turbine and the series compensation device of the transmission line will cause a new type of sub-synchronous oscillation.

(2) Oscillation form: The oscillation form of the traditional power system mainly includes low-frequency oscillation (0.1~2.5 Hz) caused by the excitation device and control system, ultra-low-frequency oscillation (less than 0.01 Hz) caused by the unreasonable parameter setting of the governor of the hydro turbine unit, and sub-synchronous

oscillation caused by the coupling of the rotor shafting system of the steam turbine unit and the line series compensation device. The oscillations of "double-high" power systems are usually caused by power electronics and their control systems, and their oscillation often begins with small-signal negative damping instability, followed by divergent continuous oscillation over a wide frequency range (a few Hz to several kHz).

(3) Scope of influence: Traditional electromagnetic oscillation caused by the resonant circuit in the power system is often a local oscillation of a single oscillation mode. The wide-band oscillation of the "double-high" power system involves multi-unit and multi-electrical equipment in multiple regions, and the oscillation frequency will change with the change in the topology of the power electronic equipment, showing multi-modal characteristics. For modes with low oscillation frequencies, the oscillation energy is large, and the influence range is wide [5]. This is mainly because the interaction of a single mode of oscillation with the power electronics may excite a new oscillation mode, resulting in oscillation energy.

It can propagate in a wide range of power grids so that the oscillation develops from local to global, and the wide-band oscillation shows the characteristics of spatiotemporal distribution. Wide-band oscillation involves multi-region and multi-electrical equipment, mainly due to the divergent oscillation caused by negative damping, and it is no longer a single-mode local oscillation but a multi-modal global complex problem, which has become an important problem affecting the safe and stable operation of electrical equipment and power systems.

2.3. Classification of Wide-Band Oscillations

According to the above accidents, the oscillation frequency can be divided into low-frequency oscillation, sub/super synchronous oscillation, and medium/high-frequency oscillation [27]. According to the oscillation participants, it can be divided into four types: renewable energy units and AC transmission lines, renewable energy units and DC transmission lines, renewable energy units and energy storage devices or flexible alternative current transmission systems (FACTS), and different renewable energy units. According to the difference in the response characteristics of each device and the bandwidth of the control link, the following classifications are made:

(1) In the low-frequency band of 0.1–2.5 Hz, "electromechanical-like" low-frequency oscillations may occur due to the improper control parameters of the virtual synchronous control of renewable energy units or the control parameters of phase-locked loops on the electromechanical time scale [28–31].

(2) In the sub/hypersynchronous frequency bands of several Hz to two times the power frequency, the resonance of the doubly fed rotor side converter and the series compensation capacitor may occur [32,33]. There are also cases where the grid-side converter of the direct-drive fan interacts with the weak AC grid to cause oscillation [34–36]. There are also direct-drive fans, doubly fed fans, or photovoltaic grid-side converters that interact with HVDC transmission equipment, such as VSC-HVDC [37,38] or LCC-HVDC [39], to cause oscillations. In addition, it is also common for sub-synchronous control interactions [40] to occur between converters in multi-energy units to trigger oscillations. For example, based on the similarity transformation theory, ref. [34] reveals that there are inter-machine and machine–network oscillation modes between multiple direct-drive fans or between direct-drive fans and VSC-HVDC in sub-synchronous frequency bands. On this basis, ref. [41] analyzed that the inter-machine oscillation mode is mainly affected by the DC voltage control link of the grid-side converter of the direct-drive fan, while the machine-grid oscillation mode is mainly affected by the constant DC voltage control link of the grid-side converter of the direct-drive fan and the constant d-axis AC voltage control of the VSC-HVDC transmitter. Ref. [42] further reveals that there are similar sub-synchronous oscillation modes in the direct-drive wind farms connected to the grid

through a flexible direct transmission system under similar operating conditions. In addition, due to the asymmetry of the DQ axis control structure and parameters of renewable energy units or flexible DC transmission equipment, there are still corresponding hypersynchronous components in the voltage and current signals [43]. In summary, the interactions in the above sub-synchronous bands are classified as sub-synchronous/hypersynchronous oscillations.

(3) In the medium and high frequency bands from 100 Hz to more than 1000 Hz, there is a dynamic interaction between the renewable energy station and the modular multilevel converter high-voltage direct-current transmission (MMC-HVDC) [44], and between the weak AC grid and the MMC-HVDC in the medium and high frequency bands, and medium and high frequency oscillations may occur.

Depending on the generation mechanism of wide-band oscillation (whether there is inductive capacitance LC circuit resonance) and the participating equipment (whether the power electronic equipment controller has a significant influence on the oscillation), there are two types of wideband oscillation in the power system, namely resonance (there is LC circuit resonance) and control oscillation (there is no LC circuit resonance, and the controller has a significant influence on the oscillation), as shown in Figure 4.

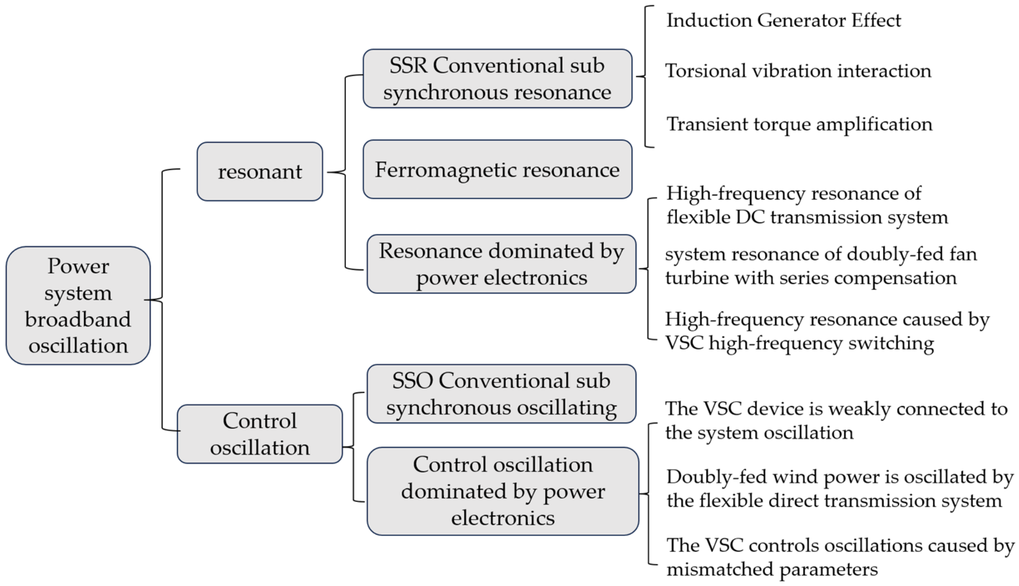

Figure 4. Power system wide-frequency oscillation of resonance and controlled oscillation.

3. Analysis Method for Wide-Band Oscillation

Table 2 shows that the various analysis methods for wide-band oscillation have their own application scenarios and application scopes.

Table 2. Summary of stability analysis of power system.

Analytical Methods	Description of the Oscillation Mechanism	Advantage	Disadvantage
Eigenvalue analysis [45]	The state matrix has a right hemi planar eigenvalue	The theory is rigorous, the accuracy is high, and the matrix factorization can provide engagement and sensitivity metrics	The modeling process is heavily dependent on the structure and parameters of the system, which is difficult to model, large in computation, and poor in scalability

Table 2. *Cont.*

Analytical Methods	Description of the Oscillation Mechanism	Advantage	Disadvantage
Impedance analysis [46]	The interactive system exhibits negative damping characteristics at the same frequency of impedance amplitude	The frequency characteristics of the impedance are intuitively displayed from the perspective of RLC circuits, the impedance of the device can be obtained through measurement, and the model is highly scalable	The physical significance of the coupling impedance is not clear, the frequency coupling aggravates the complexity of the analysis, and it is difficult to divide the source carrier subsystem into the multi-feed system
Time domain simulation/frequency domain scanning [47]	The convergence results of numerical calculations are displayed graphically	It is intuitive and has a wide range of applications, which can analyze the time/frequency characteristics of various complex equipment and verify the correctness of the derivation of various modeling theories	It can only provide the results of system operation, which is greatly affected by the system scale, simulation step size, and solution algorithm, and it is difficult to carry out a further analysis of the oscillation mechanism
Extended complex torque coefficient analysis [48]	Subsystems A and B have a pair of similar open-loop oscillation modes	It can reveal the instability mechanism of the small interference oscillation of the system from the perspective of dynamic interaction of components, which is flexible and diverse	The mathematical theory is not rigorous enough, and can only provide an estimate of the oscillation mode rather than an accurate value, and there is a certain stability judgment error
Amplitude and phase analysis [5]	As the interface between the grid-connected equipment and the electrical network, the amplitude and phase of the internal electric potential reflect the dynamic response of the equipment to the network	The theory is novel, the physical concept is clear, and the dynamic process of the communication system is understood from the energy connotation	The modeling process is relatively complex, there is a complex coupling relationship between the amplitude and phase of the electric potential in the equipment, and the application in complex systems needs to be further verified
Generalized short-circuit ratio [49]	Quantify system strength, performance, and stability margins from the perspective of short-circuit ratio	It can characterize the relative strength of the AC power grid to the access equipment and intuitively reflect the dynamic voltage response performance or system strength of the system	Although it is a generalization of the conventional short-circuit ratio, it contains more physical concepts and is relatively abstract, so it needs to be further studied and applied

Although the physical concepts and analysis processes of each analysis method are different, they are all linearized analysis methods based on steady-state operating points (or steady-state trajectories), and there is no difference in nature. Mathematically, any system can be described by differential-algebra-difference equations [50], and the equivalent transformations of these characteristic equations from different perspectives form the existing small-signal analysis system. Therefore, there is no need to stick to a specific analysis perspective and method when choosing, and it is the basic direction and criterion of future stability analysis method research to ignore the secondary factors and choose the appropriate analysis angle according to the key problem of concern.

4. Suppression Measures for Wide-Band Oscillations

The existing wide-band oscillation suppression strategy can be divided into the source side and the grid side from the control object; the suppression strategy on the source side includes adjusting the parameters and control structure of the generator set and adding damping control and branch compensation; the relevant electrical quantity can be directly extracted by oscillation suppression on the source side; and the control effect is better when it is close to the target unit. On the grid side, the flexible AC transmission system (FACTS) and the additional control of DC lines can intuitively eliminate and protect the resonance of the lines that are prone to oscillation.

4.1. Source-Side Oscillation Suppression

According to the design method of the control strategy, the strategy of suppressing the wide-band oscillation from the source side can be divided into the following: adjusting the controller parameters and controller structure, additional damping control, and control branch compensation. To adjust the parameters of the controller, it is necessary to first screen the dominant factors that affect the oscillation, and based on the dominant factors, the safety and stability domain of the parameter adjustment is obtained [51]. Based on the key controller parameters, the parameters can be optimized to improve the stability of the system. Ref. [35] proposes an impedance sensitivity index to measure the sensitivity of parameters, which can determine the magnitude of the controller's influence on SSO characteristics. Ref. [52] considers the stability of wind power flexibility and direct grid connection to the parameter optimization design, and the results show that the parameter optimization considering only a single controller cannot meet the stability of the interconnection system. The limitation of adjusting the parameters to suppress the wide-band oscillation is that some key parameters cannot be adjusted in the actual operation [53], so they can only have certain reference significance for the early planning and design stages. The design method of adjusting the controller structure to suppress wide-band oscillation is carried out by using a nonlinear controller to replace the existing PI control, such as H∞ control, sliding mode control, etc., but due to the complex control structure and large amount of calculation, it is difficult to realize in the actual power grid, and it is still in the theoretical stage. In general, the additional damping control is based on the state space model or impedance model of the system, and the optimal additional positions of the key feedback signal and output signal are selected to design the damping controller of the system [54]. The additional damping based on the state-space model can configure the eigen root of the system to achieve oscillation suppression. However, the additional damping control based on the impedance model reshapes the impedance through the transfer function design, changes the position of the resonant point, or increases the phase margin of the system to suppress the generation of oscillations [55].

The performance of the additional damping controller is determined by the feedback function of the design, and the robustness and suppression performances of different additional damping controllers are compared in ref. [56]; the analysis shows that the performance of the additional controller is mainly determined by the input signal, the position of the output signal, and the control structure. The additional damping controller is mainly composed of several filtering links, the proportional gain link, the phase shifting link, and the limiting link. The filtering link eliminates the noise of other frequency bands, the proportional gain loop amplifies the control signal, the phase-shifting link realizes phase compensation, and the limiting link ensures that the output signal is within the effective range [57].

In practical application, the selection of the input signal is limited by the channel of information acquisition, and the additional damping control cannot suppress the oscillation under all working conditions and can only provide negative damping for the oscillation of a specific frequency. The key problem is to select the compensation signal and compensation coefficient to improve the stability of the system by feedforward compensation or additional filters [57–59]. The branch compensation includes damping compensation [57], decoupling compensation [58], and energy compensation [59]; damping compensation can improve the damping level of the resonance point, decoupling compensation can achieve oscillation suppression by constructing a reverse compensation branch of oscillation, and energy compensation can improve the kinetic energy and potential energy in the energy flow path to realize the active damping of wide-band oscillation. Control branch compensation is usually used for improvement in small systems, and the performance of this suppression strategy is poor when considering large systems or interconnected wide-area systems. Both additional damping control and control branch compensation essentially improve the damping of the system through phase compensation. In terms of application scenarios, additional damping control can be used for equipment or power grids, while control branch compensation is usually used inside components [57]. From the perspective of design, the key to additional damping control is to select the feedback signal and design the transfer function [56], while the key to branch compensation is to select the compensation signal and compensation coefficient [58]. Both methods can modify the resonant frequency and damping characteristics of the controller connected to the grid and effectively improve the stability of the system.

4.2. Grid-Side Oscillation Suppression

The suppression strategy of wide-band oscillation on the grid side is mainly achieved by two means, FACTS and the additional control of DC transmission. Grid-side suppression is mainly used for lines that are prone to resonance and transmission lines that can cause SSCI. By eliminating resonance conditions or increasing damping, the line and equipment in the near zone that are prone to oscillation are protected. The FACTS device can quickly adjust the power flow of the system at the power frequency and inject a reverse oscillation current into the system to improve the transmission capacity and stability of the system [60,61]. Existing studies utilize a variety of FACTS devices or synergies between FACTS and additional damping control to accommodate the oscillation of the system under different operating conditions. Due to their variety, flexible control, and obvious suppression effects, FACTS devices have been used to varying degrees in actual power grids. Static var compensator (SVC) and thyristor-controlled series compensation (TCSC) are both series devices, which are mostly used to suppress the resonance generated by the series compensation line. A static synchronous compensator (STATCOM) and a static synchronous series compensator (SSSC) are parallel devices; the former is connected in parallel to the parallel point to support the bus voltage through reactive power adjustment, and the latter achieves the oscillation suppression function by adjusting the bus voltage. The unified power flow controller (UPFC) is part of a new generation of FACTS devices with better characteristics and has a good application prospect [61]. The use of FACTS devices for damping control requires additional control devices, which are expensive. In a grid where a high proportion of power electronics are connected, FACTS may also interact with other devices to create new stability problems, so it is only suitable for oscillation suppression in specific scenarios.

The study of additional damping control for DC transmission is in its preliminary stage, and oscillation suppression can be achieved by adding a sub-synchronous damping controller or in conjunction with other devices [62,63]. Additional sub-synchronous damping control was proposed in ref. [62] to provide damping electromagnetic torque, but this control strategy does not consider the interaction between multiple devices. Ref. [63] proposes a coordinated control strategy between DC additive damping and a generator, which can improve the stability and robustness of the system. Some scholars can improve the dynamic performance and suppression effect of the system through adaptive algorithms and neural networks.

According to the analysis of the suppression methods on the grid side and the source side, the source-side suppression can be actively suppressed from the source of oscillation, the electrical quantity related to the oscillation can be directly extracted, and the generation mechanism can be dampened nearby to achieve a stronger damping effect, but it is mainly designed around a certain oscillation frequency band. The network-side control relies on the built-up control equipment, and oscillation suppression cannot be achieved from the source. The research on adaptive oscillation strategies for wide-band oscillation is still in its infancy.

5. Conclusions and Prospects

In the new power system, there is a high proportion of power electronic devices between power electronic equipment and the power grid, there are complex electromechanical and electromagnetic coupling effects, and the multi-form wide-band oscillation problem covering low frequency, sub/hypersynchronous, medium, and high frequency has brought new challenges to the safe and stable operation of the power system.

This paper briefly introduces and classifies typical wide-band oscillation cases in the world in recent years, revealing the extensiveness and severity of wide-band oscillation problems. The relevant research methods are summarized, and it can be seen that the modal analysis method and the impedance analysis method are the analysis methods that have certain practicability, but in general, there is no oscillation mechanism analysis method with both universality and practicality. Finally, some measures of wide-band oscillation suppression are summarized, and the suppression strategies of the source side and the network side have not yet formed a linkage; for future research, an adaptive suppression method that uniformly mobilizes the power electronic equipment on the source side and the grid side will be the focus. The full range of aspects involved in the field of wide-band oscillation research, such as the monitoring, processing, and identification of oscillating signals, has not been fully developed in this paper. The absence of this section does not affect the overall framework of this review because it mainly involves disciplines such as signal analysis and algorithms, but it is still worth studying. The goals of this paper are to analyze the occurrence mechanism of wide-band oscillation events from the perspective of a power grid structure, classify the characteristics, and study the suppression methods with the hope of helping researchers in the field of stability in new power grids.

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