A Brief Review of Smart Control of Renewable Energy Power Generation

Yu Xiao, Chunni Xia, Qinqin Cai and Yongqiang Zhu

School of Electrical and Electronic Engineering, North China Electric Power University, Beijing 102206, China
zyq@ncepu.edu.cn

Abstract. The smart control strategy in the operation of renewable energy station is of great significance to alleviating the shortage of fossil energy, improving the efficiency of renewable energy utilization and the safe operation of power system. Firstly, this paper took the renewable energy stations represented by wind and solar energy as the research object, summarized the smart control strategy of single unit power generation, and elaborate introduced the mechanical structure control, maximum power point tracking control and virtual synchronous machine control in electrical converter level. Secondly, the self-protection control of renewable energy power generation station in the case of power system faults were analysed. The key issues involved in the low voltage ride-through, high voltage ride-through, protection circuit of rotor side, stator side and converters were summarized. Thus, a brief overview of smart control of renewable energy station operation is presented in this paper, hoping to provide technical guide for prosperous development of renewable energy in the future.

1. Introduction
In the future, Electric power system will be characterized by renewable and clean energy sources. For sure, the development of global renewable energy has developed rapidly over the past decade. Statistics indicate that the total global installed capacity of renewable energy reached 2536.85 GW in 2019, which accounted for 23% of the total energy installed capacity. Especially, solar and wind energy accounts for 85% among all renewable energy. By the end of 2019, the installed capacity of renewable energy generation accounts for about 39.5% of the total installed capacity of electricity. [1] The installed capacity of grid-connected wind turbine reached 210 GW, and photovoltaic power generation reached 204.7 GW in China. “Prospect of Renewable Energy in China” predicted that 70% of electricity supply will come from renewable sources by 2050. Undeniably, high proportion of renewable energy generation can alleviate the contradiction between the shortage of fossil energy and the increment of energy demand, which may promote the friendly development of ecological environment ultimately.

Different from the problems of environmental pollution and excessive carbon emission caused by traditional energy generation, renewable energy power generation has the advantages of green and renewable. However, the randomness, uncertainty and uncontrollable performance of its output power, which is determined by natural resource factors, has a negative effect on the operation of power system. As a result, it may cause the problems such as off-grid accidents, stability, not accurate scheduling, low efficiency, wind curtailment and so on. In the face of the problems of renewable energy stations centralized connect to the power system, it is necessary to sum up the smart operation
control methods of renewable energy stations, aimed to improve energy utilization efficiency and achieve clean energy utilization.

On the basis of reading a large number of literatures, this paper summarized the smart control of a single unit and power connected grid, aims at the unit pitch control, maximum power point tracking control, virtual synchronous machine control, low voltage ride-through, high voltage ride-through, the unit protection circuit, in order to provide a reference for other renewable energy generation operation and grid-connected control with fluctuating characteristics.

2. Smart control of single unit power generation
The operational goal of renewable energy generate units is how to improve the output power of the generation, which is consistent with the objective of operation control of traditional energy unit. Power generation from renewable energy sources is mainly determined by natural resource conditions. However, the efficiency of energy utilization is not only closely related to the regulation of mechanical components of power generation devices, but also related to its operation and control mode. Therefore, intelligent control of single unit power generation includes mechanical variable pitch control and electrical control of converter, in order to improve the efficiency of renewable energy conversion and achieve maximum power tracking.

2.1. Mechanical variable pitch control
Renewable energy units can complete the secondary conversion of "renewable energy (wind energy, solar energy, ocean energy, etc.) - mechanical energy - electrical energy" generally, the former is realized by the prime mover, and the generator converts mechanical energy into electric energy, as shown in figure 1. Renewable energy generation cannot be separated from the hardware design of power generation device.

Figure 1. Conversion of energy and power connect to grid.

Whether solar thermal power generation directly or photovoltaic power generation, the maximum efficiency capture of primary energy can be achieved by adjusting the mechanical structure of the renewable energy unit automatically. The physical and mechanical devices receiving solar energy should track changes of the incident angle of the sun, and keep the solar heat heliostat or photovoltaic panel is perpendicular to the direction of light, so as to ensure the maximum utilization efficiency of solar energy. Literature [2] designed a single-axis tracking system to maximize energy collection, validated that single-axis tracking structure is superior to the existing ones at almost all latitudes.

For wind power generation, when the wind direction changes, the ability to absorb wind energy will be affected obviously if the wind turbine does not adjust the direction. The yaw technology of wind turbine is used to make the wind turbine rotating surface always in the upwind state, and the wind turbine absorbs the wind energy best.

2.2. Maximum power point tracking
The output power of renewable energy generation is affected by many factors. For example, the output power of photovoltaic panels is affected by the combination of solar irradiance and temperature. Under different irradiance and temperature, photovoltaic output power has a different and unique maximum power point, as shown in figure 2. The method of Maximum Power Point Tracking (MPPT) determines the maximum value of the power curve by controlling the output voltage or current, thereby the system can output the maximum power at each moment.
In photovoltaic power generation systems, the common methods to achieve MPPT are: perturb-observe method, conductance increment method. Among them, the perturb-observe method is to find the power extremum by changing the variable step size constantly and judging the correctness of the tracking direction. However, the incremental conductance method is used to determine the operation area of photovoltaic cells by calculating the value of output conductance. Due to the influence of shadow, there exists multiple peaks in the output power curve of photovoltaic array. In view of the situation, the above two methods have limitations, and the suitable solutions include the method of extreme search, bionic intelligent algorithm and so on.

The output power of wind turbine is determined by many factors, including blade radius, wind speed, air density, pitch angle, tip speed ratio and so on. Under the same wind speed, the output power of generator will change with the variation of wind turbine speed. Therefore, the core of MPPT real-time control of wind turbine is that, under different wind speeds, the wind turbine can always run at the optimal speed by adjusting the speed of wind turbine, so as to capture wind energy to the maximum extent.

According to the analysis of the photovoltaic system and wind turbine, the following three aspects are needed to realize the maximum power point tracking control of renewable energy units: analyzing the factors affecting the maximum output power; determining the optimization algorithm to solve the control parameters; realizing real-time control.

2.3. Virtual synchronous machine control
In order to maximize the utilization of renewable energy, the new energy unit cannot provide active power backup under the maximum power output control mode, so it does not possess the frequency adjustment capability that similar to the traditional synchronous machine when the power system frequency changes. In addition, the grid-connected inverters are also the static components that without moment of inertia, and obviously it cannot respond to the frequency changes spontaneously. With the continuous increasing proportion of renewable energy power generation and the number of power electronic converters continuously, the problems of inertia and damping in the power system become serious. [3] To solve this problem, the theory of virtual synchronous generator (VSG) is proposed. The essence is to simulate the output characteristics of synchronous generator, and the core realization method lies in the control strategy of converter. And the purpose is to provide inertia and damping characteristics that similar to traditional generate units, and auxiliary functions such as frequency adjustment to power system, which connected with high proportion of renewable energy sources. The specific functions are as follows:

(1) Autonomous frequency adjustment control. When the system frequency fluctuation exceeds the adjustment dead zone range (50 ± 0.03Hz), and the active power output of VSG is greater than 20% P_N, then VSG should participate in the frequency adjustment of the power grid independently.
(2) Autonomous voltage adjustment control. The VSG should have the ability to respond to reactive power control commands within 10s, and the adjustable reactive power shall not be less than 30% $P_N$.

(3) Virtual inertia control and damping control. When the power system is disturbed, the input power and output power of VSG are unbalanced. The VSG employ energy storage unit to realize the electromechanical swing process of the traditional synchronous generator, aiming to slow down the changing speed of frequency.

For a single wind turbine, in the realization of virtual inertia support, there are mainly supplementary reserve capacity control of variable pitch, the control of rotor kinetic energy, and coordinated control using energy storage system and fan rotor kinetic energy.

1) The reserve capacity control mainly refers to that the main control system can pitch in advance to reduce the wind energy capture efficiency and make the wind turbine run under the original power characteristic curve. In this way, a fixed range of spare capacity is reserved for frequency adjustment in real time.

2) The kinetic energy that absorbed or released by generator rotor and released by fan impeller can be used to achieve inertial response, which can be used as frequency modulation backup of virtual synchronous machine.

3) Using energy storage system and the kinetic energy of wind turbine rotor can compensate grid inertia synergistically, which can damp the change of grid frequency better. So as to provide power support for power grid for a long time and improve the transient stability of the power grid. [4]

![Figure 3](image)

**Figure 3.** The application of VSG in photovoltaic power generation system.

The application of VSG in the field of photovoltaic power generation refers to the configuration of DC-DC converters and energy storage units on DC bus side, as shown in figure 3. They are two control modes of the DC-DC converter, namely, simulated rotor motion equation and changing the values of reference power. Taking a demonstrative engineering of ‘Integrated wind energy power generation, photovoltaic power generation, and storage in Zhangbei, China’ as an example, the configuration plan of energy storage capacity is a combination of 50 kW / 30 min lithium iron phosphate batteries and 50 kW / 15s super capacitors, aiming to achieve different extents of frequency adjustment. [5]

3. Smart control of renewable energy generation power

3.1. Low voltage ride-through

The voltage of the public grid point of the renewable energy power station will drop instantly when power grid fault occurs. Under the time conditions specified in figure 4, the process of low voltage ride-through (LVRT) can be described as that the renewable energy station keeps grid-connected operation continuously and the unit can resume normal operation automatically after the failure is eliminated.
In case of mild voltage drop, the renewable energy station can operate without disconnection through effective control of two converters. However, in case of deep voltage drop, on the one hand, it can suppress the damage of transient surge current to converters and bus capacitors by adding additional hardware (such as Crowbar device in parallel at rotor side, parallel Chopper circuit in DC link, etc.). On the other hand, the control strategy of generator unit is improved to provide reactive current or power support for faulty power grid immediately when conditions permit, and enhance the fault recovery capability of new energy generator set. [6]

To achieve low voltage ride-through, the following three problems need to be solved.

1) The acquisition of asymmetric information rapidly and accurately in three phases: using the software PLL to obtain the voltage information of the power network requires certain steady-state accuracy and dynamic rapidity, so that the control system can take effective measures in time.

2) Energy management during voltage drop: during the voltage drop, due to the power imbalance between the two ends of the machine side and the grid side converter, the DC voltage rises. Therefore, it is necessary to store or consume excess energy to solve the problem of energy mismatch, which is generally realized by adding hardware circuit and improving control strategy. The concrete measures can be divided into the following four kinds.

1) Adjusting mechanical components to reduce the conversion of renewable energy to mechanical energy. For example, adjust pitch angle of wind turbine to reduce absorption of wind energy. The response time and speed of the regulating measures are slow, generally in seconds. Therefore, it is suitable for the case of long-time shallow grid voltage drop.

2) Adding energy storage equipment, using DC bus capacitance to store energy that cannot be transported to the grid. Limited by capacitance capacity, the increase of DC voltage is small. And the measure is only suitable for shallow drop of power grid voltage. In addition, other energy storage methods such as energy storage batteries can also be considered. [7]

3) Adding a crowbar protection circuit on DC side to consume excess energy. Usually the brake resistance and chopper are connected on the DC bus to consume the excess energy on the brake resistance, which control method is simple and low cost. The disadvantage of DC resistance circuit is that it can only restrain the over-voltage of DC bus, but cannot do anything for voltage drop on DC bus,

4) Transmitting reactive power compensation with converter to restore grid voltage. Due to the limitations of its own capacity and the depth of grid voltage sag, especially when the voltage drop is deep, the ability of converter to compensate the grid reactive power is particularly limited. As shown in table 1, it is the comparison of typical control strategies in regard to low voltage ride-through.

**Table 1.** Comparison of typical LVRT control strategies.
Control Strategy | Effect | Main Disadvantage
--- | --- | ---
Generator power control | Reduce generator output power | Limited speed range
Pitch control | Reduce wind energy capture | Slow response
DC side resistance circuit | Release excess energy on the DC side | Cooling costs of resistor are higher
DC side ES circuit | Store excess energy on the DC side | Complex control and high cost

(3) Control of converter under unsymmetrical power grid. Due to the negative sequence component of grid voltage when three-phase asymmetry occurs, the output active power will produce abnormal fluctuation, so as to stabilize the active power output of the converter and suppress the DC capacitor voltage fluctuation.

3.2. High voltage ride-through
Corresponding to voltage sags, the voltage swells of power system are actually common failure, which often occurs when there is excess reactive power in the power grid. The typical process of large-scale wind power fall away the power system can be depicted as that wind turbines disconnect with system due to low-voltage fault firstly, resulting in the voltage increment of wind farm on-site, and then wind turbines come off as a result of high-voltage. Therefore, it is necessary to implement high voltage ride-through (HVRT) control in renewable energy stations. Literature [8] listed the national standard of grid codes in regard to high voltage ride-through, as shown in table 2.

| Country | Maximum voltage | Duration/s |
|---------|-----------------|------------|
| Australia | 1.3 | 0.06 |
| Spain | 1.3 | 0.25 |
| Denmark | 1.2 | 0.10 |
| Germany | 1.2 | 0.10 |

The existing technical means to realize the HVRT of the renewable energy generation system can be divided into two categories: adding additional auxiliary devices and improving system control strategies. Obviously, the solution of adding auxiliary devices will increase the total cost of the station, and the problem of coordinated control between the devices and the power generation system is also more complicated.

Methods to achieve high voltage ride-through by improving the system control strategies include: control strategies based on wind turbine converters or grid-connected converters (voltage source converters), which are generally improved on the basis of traditional PI to achieve dynamic reactive power support and other targets. In addition, the sudden rise of grid voltage will reduce the control margin of the grid-connected inverter (GCI). During the period of grid voltage swell, the control margin of GCI can be increased by increasing the inductive reactive current output or increasing the DC bus voltage reference value.

There are two ways to add additional auxiliary devices to achieve high voltage ride-through. 1) By adding reactive power compensation devices (STACOM, SVG, SVC) or dynamic voltage restorers or superconducting magnetic energy storage to stabilize the grid voltage at the grid connection point, so as to realize the safe operation of the renewable energy generation system without going off the grid. 2) Adding additional power consumption circuits, such as Crowbar, series dynamic resistance, etc., to suppress fault current and improve the HVRT capability of the turbine. [9] Above two methods are
often generally triggered after the power generation system is affected by a grid fault and arouses its own electromagnetic transient.

3.3. Smart control of protection circuits

In order to maintain the safe and stable operation of renewable energy power generation system, intelligent protection circuits are needed. According to the protection position, it can be divided into rotor side protection, stator side protection and converter protection circuits.

![Protection circuits of DFIG wind turbine.](image)

Figure 5. Protection circuits of DFIG wind turbine.

(1) Rotor side protection circuit adopts a controllable rectifier bridge, as shown in figure 5, the energy that cannot be delivered into grid will be consumed on resistances, while the rotor and rotor-side converter remain connected during the periods of fault. When the fault is eliminated, the wind power system will recover normal operation quickly only making the protection circuit out of service, which enable the system more flexible.

(2) Stator side protection circuit adopts anti-parallel double thyristors of each phase between the stator side and the grid as electronic switches, so that the stator can be quickly separated when the grid fails.

(3) The protection of converter is divided into overcurrent protection and overvoltage protection. In the event of asymmetrical drop of grid side voltage, protecting against current surge impact at the moment of voltage drop and current limiting protection during the fall are required. There are four types of overvoltage protection circuits on DC bus side, namely, adding a chopper circuit on the DC side; adding an additional energy discharge circuit on the DC bus; design energy storage units on DC bus to absorb excess energy and maintain voltage stability; adding additional auxiliary converters on the grid side. Among them, putting into load and consuming excess energy on the DC side is an easiest method to restrain rotor side overcurrent.

4. Conclusion

This paper summarized the smart control methods of wind and photovoltaic power generation from the perspective of units and station. After sorting out the control methods of single unit power generation, in order to achieve the maximum renewable energy collection and maximum power conversion, it is recommended to consider the combination of the mechanical control of unit’s components and the MPPT control. In addition, virtual synchronous control is an important way to support the synchronization characteristics such as inertia and damping of the system, which theoretical core is to utilize the controllable characteristic of grid-connected converter to realize auxiliary functions, such as frequency adjustment, voltage regulation, virtual inertia control and damping control. Furthermore, improve the control strategy of converter or add auxiliary devices in renewable energy station can realize fault ride-through when the voltage of power grid rises or drops abnormally, so as to enhance the intelligent control ability of power grid-connected in new energy stations. As the proportion of renewable energy installed capacity continues to increase, the realization of intelligent control of renewable energy generating units is of great significance for improving the safe and stable operation of the power system.
References

[1] Miller L and Carriveau R 2019 *Sustain. Energy. Techn.* 35(Oct.):172-179
[2] Zhu Y Q, Liu J H and Yang X H 2020 Appl. Energy 264
[3] Kavya Santhoshi B, Mohana Sundaram K, Sanjeevikumar P, Holm-Nielsen J B and Prabhakaran K 2019 KbEnergies
[4] Zhong Q C 2016 IEEE Power Electron. Mag 3(4):18-27
[5] Ge J, Song P, Liu H M, Liu H, Li Z, Wang X S and Zhu S 2018 JGEI 1(01):39-47
[6] Yang D, Cheng H Z, Ma Z F, Fang S D, Xu G D, Guan S C and Sun Q C 2015 EPAE 35(12):1-10+20
[7] Huang X B, Lin D, Wang H F and Wu T 2016 J. Mech. Electr. Eng 33(05):589-594+601
[8] Xu H L, Zhang W, He Y K and Chen J S 2013 AEPS 37(20):8-15
[9] Yu H, Xiao P Y, Lin Y, Gong X F, Gong D Q, Qin Y, Zhang Z J and Luo S C 2020 SP 48(03):30-38

AUTHORS’ BACKGROUND

| Your Name       | Title*          | Research Field                                                                 |
|-----------------|-----------------|-------------------------------------------------------------------------------|
| Yu Xiao         | master student  | Renewable Energy Power Generation                                             |
| Chunni Xia      | master student  | Solar Energy Power Generation                                                 |
| Qin Qin Cai     | master student  | Wind Energy power generation                                                  |
| Yongqiang Zhu   | associate professor | Renewable energy power generation, Integrated Energy System, Micro-grid Control |