A Benefit Evaluation Model for Peak-Clipping Benefits of Distributed Photovoltaic Grids Taking into Account Uncertain Low-Voltage Distribution

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Abstract. Due to the high energy consumption in the traditional AC-DC hybrid microgrid, the benefit evaluation may be difficult. In this paper, an AC-DC low-voltage hybrid distribution network suitable for distributed photovoltaic power generation access is proposed. DC power directly supplies DC household appliances, and AC power grid directly supplies AC appliances. In this way, the loss of electric energy in the process of energy conversion can be reduced, and good economy can be achieved. The 24-pulse thyristor bidirectional converter is used in the connection between AC and DC power grids, which can reduce the loss and prevent the failure of benefit evaluation. The photovoltaic low-voltage distribution tracking adopts conductance increment method, and the converter control adopts constant voltage control to maintain the bus voltage stability. The simulation results prove the feasibility of the scheme.

Keywords: Photovoltaic Power Grid, Low Voltage Distribution, Perturbation Observation Method, Pulse Converter

1. Introduction

Under the dual pressure of global energy demand and environmental protection, distributed photovoltaic power generation has been paid more and more attention. It is an important direction for the future development of power grid to support the reasonable access of a large number of distributed photovoltaic power sources. Therefore, this paper introduces an AC-DC hybrid low-voltage distribution system suitable for distributed photovoltaic power generation access: the direct current from the photovoltaic power supply directly to the DC load, and the alternating current from the grid directly to the AC load. The bidirectional DC-AC converter used in the traditional AC-DC hybrid microgrid uses fully controlled IG-BT devices. Compared with the semi-controlled thyristor, IGBT devices have high loss, low voltage withstand value and the possibility of failure in benefit evaluation. Therefore, the converter used in this paper is a 24-pulse thyristor converter.

2. Characteristics of AC/DC hybrid low voltage distribution network
The structure of the AC-DC hybrid low-voltage distribution system suitable for distributed photovoltaic power generation has several characteristics: (1) reduce power loss; Photovoltaic power generation system is adopted DC output power, for ordinary users, made by photovoltaic (pv) power to the electrical appliances using general should pass the DC - AC - DC energy conversion process, the process will be a power loss, and many existing household appliances use DC power driver, if universal DC electrical appliances in the house, will save DC - AC - DC power conversion process, according to the analysis, save the process of reducing energy consumption can reach 10% ~ 20%. (2) It has good economy; Can dispense with the DC electrical equipment to convert AC to DC power supply device, reduce the manufacturing cost of equipment. (3) The bidirectional converter (DC-AC) used in this paper adopts 24 pulse thyristor converter; The use of this converter has two main advantages: 1 can reduce the loss, the loss of ordinary thyristor is much smaller than IGBT loss; 2 can avoid using IGBT benefit evaluation of failure and pose a threat to line maintenance staff's safety, even benefit assessment methods are varied, now no one way can absolutely reliable, if ac power grid, and benefit evaluation of failure, pv electricity continue to feedback to the ac power grid, is bound to pose a threat to the safety of the maintenance staff, and use 24 pulse wave thyristor inverter can avoid this situation. As shown in Figure 1.

**Figure 1.** Characteristics of low voltage distribution network

3. Photovoltaic grid model and low-voltage distribution tracking

The photovoltaic effect of photovoltaic (pv) grid is the use of semiconductor material will absorb light energy into electrical energy by the device, its output characteristic by the external factors such as temperature, radiation intensity, load, the influence of the ambient temperature changes mainly affect the output of the photovoltaic (pv) grid voltage, the output of the photovoltaic (pv) grid current is mainly affected by light radiation intensity change.

At present, there are many kinds of MPPT algorithms at home and abroad, and they have their own advantages and disadvantages. Among them, the perturbation observation method (P&O) and the incremental conductance method (INC) are widely used because of their mature development, simple control and high precision. In this paper, incremental conductance method is used to track low voltage distribution.

According to the PV power voltage (P-U) curve, in the low-voltage distribution point, the reciprocal of power to voltage is zero, and in the case of constant illumination intensity, temperature and other conditions affecting the output characteristics of the photovoltaic network, each low-voltage distribution corresponds to a voltage. Since the output voltage of the Boost circuit changes very little, changing the
duty cycle D of the switch tube can find the voltage of the PV grid at the low-voltage distribution point, so that the photovoltaic power generation can output low-voltage distribution.

4. Design of pulse converter and its control system

In AC-DC hybrid distribution network, bidirectional AC/DC converter controls the power flow between DC bus and AC bus, and plays an important role in voltage stability and power quality improvement of the system. Bidirectional AC/DC converters can work in both rectifying and inverting modes according to actual needs, and play an important role in supporting and coordinating power flow in AC-DC hybrid distribution network. The bidirectional converter used in this paper is a 24 - pulse thyristor converter.

4.1. Principle of pulse converter

24 pulse wave of four groups usually has four groups of rectifier bridge and way, four groups of concatenated way and two groups of string and ways, but they are all through the transformer rectifier ac voltage phase 15° staggered, so that the output rectifier voltage pulsation 24 times in each ac power cycle, and phase shift and primary windings connection type mainly has twists and turns, hexagon and denotation triangle, etc. In this paper, the epitaxial triangle connection method is adopted. First, the voltage of the main winding side is phase-shifted by +7.5° and -7.5° respectively, and then the two phase-shifted windings are connected to the three-winding transformer respectively. The three-winding transformer adopts Y-Y-D connection mode, so that the voltage and phase of the AC side of the four groups of rectifier bridge are staggered by 15°. The relation between the AC side voltage phase and the main winding side voltage phase of each rectifier bridge is +7.5°, -22.5°, -7.5° and -37.5° respectively.

In the schematic diagram of the main circuit of the pulse converter, the primary side of the phase-shifting transformer is connected into a triangle, and the secondary side has a two-phase winding. Take the first group of windings as an example: if one part (K2) of each phase winding is connected into a triangle, and the other part (K1) is the extension of the triangle, the output voltage UA1, UB1 and UC1 are the sum of the voltage of the triangle winding and the voltage of the triangle extension winding respectively, and the phase of the leading input voltage UA, UB and UC is 7.5°. The second group of secondary side winding is also composed of triangle winding and its extension, but its connection method is slightly different. The phase of the output voltage UA2, UB2 and UC2 lags the phase of the input voltage UA, UB and UC by 7.5° respectively. Therefore, the difference between UA1, UB1 and UC1 and UA2, UB2 and UC2 is 15° respectively. As shown in Figure 2.

Figure 2. UB1 and UC1 and UA2, UB2 and UC2 is 15° respectively

4.2. Control system design of 24 pulse converter
In network mode, the converter is responsible for maintaining the constant voltage of the DC bus. When the converter is disconnected during operation, the system will not feed electric energy to the power grid, which can prevent the failure of benefit evaluation and improve the safety of line maintenance. The bidirectional converter with constant voltage control makes the DC bus voltage constant and improves the stability of the system. The output voltage of 24 pulse rectifier (UD) is different from the given voltage reference signal (UD^*) through the filtering link, and its deviation (UE) is output through the PI regulator and the Angle adjustment link to output the trigger Angle reference signal (α), and together with the 6 line voltage synchronous reference signal, 24 pulse signals are output through two 12-pulse trigger circuits. So as to control the stability of DC bus voltage.

5. System Simulation

This article USES the photovoltaic electric screen each of 100 w, the parameters of each electric screen for: Isc = 6.46 A short circuit current, open circuit voltage Uoc = 21.5 V, current 5.71 A low-voltage distribution point, low-voltage distribution point Um = 17.5 V voltage, photovoltaic panels use every five pieces of board series as A group, two groups of parallel connection mode, the total power of 1 kw, rated phase voltage RMS ac grid setting of 220 V, dc bus A given value is 88 V. During simulation, the abscess of all simulation waveforms is time, and the unit is seconds (s). When light intensity when setting 1 s take 500 w/m2 to 1000 w/m2, 1.5 s 50 Ω input resistance, inductance is 0.1 H sense of resistance load, busbar voltage setting of 88 v. Power curve respectively with low-voltage distribution track when the power curve and without low-voltage distribution power curve when tracking, when the light intensity increases, pv electricity screen output power will increase, before 1 s, that is to say, light intensity of 500 w/m2, clear and low-voltage distribution basic can achieve maximum power tracking control, ignoring low-voltage distribution tracking can't achieve low-voltage distribution; When the illumination intensity is 1000W/m2, the set bus voltage is 88V, which is close to the voltage when the photovoltaic grid panel reaches the low-voltage distribution. Therefore, when the illumination intensity is 1000W/m2, the power can reach the low-voltage distribution.

As the power increases, the output voltage of the photovoltaic grid will also increase accordingly, which will cause voltage fluctuation of the DC bus, because the converter adopts constant voltage closed-loop control. When the load is put in at 1.5s, it also causes the fluctuation of the trigger Angle and bus voltage, but it becomes stable quickly. It can be seen that the trigger Angle and DC bus voltage fluctuate, but it becomes stable quickly.

6. Conclusion

It is an important direction for future power grid development to support reasonable access of a large number of distributed photovoltaic power sources. In this paper, the AC-DC hybrid distribution network proposed in this paper, the photovoltaic produces direct current to supply the DC load, and the AC grid supplies the AC load, which not only saves energy but also has good economy. The low-voltage distribution tracking adopted in this paper can make photovoltaic reach low-voltage distribution; As an important part of AC/DC hybrid distribution network, the 24 pulse converter has lower total harmonic distortion (THD) than the thyristor converter using 6 pulse and 12 pulse, and the total harmonic distortion (THD) of the 24 pulse converter is 0.1% in the simulation time 2s. Can meet the requirements of the power grid. The output DC voltage is more stable, and compared with other PWM fully controlled rectifier devices, it has the advantages of small switching loss and large capacity. Finally, the simulation results show that the voltage control strategy adopted in this paper can maintain the voltage stability of DC bus.

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References

[1] Alessandro C, Boicea V A, Gianfranco C, et al. Voltage Control in Low-Voltage Grids Using Distributed Photovoltaic Converters and Centralized Devices[J]. IEEE Transactions on Industry Applications, 2018, PP:1-1.

[2] Perpinias, Ioannis, I. Optimum design of low-voltage distributed photovoltaic systems oriented to enhanced fault ride through capability.[J]. Iet Generation, 2015.

[3] Perpinias I /, Papanikolaou N P, Tatakis E C. Optimum design of low-voltage distributed photovoltaic systems oriented to enhanced fault ride through capability[J]. IET Generation Transmission & Distribution, 2015, 9(10):903-910.

[4] Tatakis, Emmanuel, C, et al. Optimum design of low-voltage distributed photovoltaic systems oriented to enhanced fault ride through capability[J]. IET generation, transmission & distribution, 2015, 9(10):903-910.

[5] Liu N, Wang H M, Song T, et al. Study on Access System of Low Voltage Distributed Photovoltaic Power Station[J]. Applied Mechanics & Materials, 2014, 624:397-400.

[6] Shertukde H M. Distributed Photovoltaic Grid Transformers[J]. Crc Press, 2014.

[7] Chen S F, Lin F T, Zhao S, et al. Analysis of the Impact Caused by Residential Users Distributed Photovoltaic Grid-Connected on Distribution Network[J]. Advanced Materials Research, 2013, 834-836:1110-1113.

[8] A E H , A M O , B P C, et al. Estimating national and local low-voltage grid capacity for residential solar photovoltaic in Sweden, UK and Germany[J]. Renewable Energy, 2021.

[9] Lisi G, DJabbari A, Zhang J . System and method for over-Voltage protection of a photovoltaic string with distributed maximum power point tracking[J]. US.

[10] Zheng L, Liu Z, Shen J, et al. Very short-term maximum Lyapunov exponent forecasting tool for distributed photovoltaic output[J]. Applied Energy, 2018, 229:1128-1139.