Low-Voltage Ride-Through Technology in Photovoltaic Power Generation

Ke Xu *

School of Electrical Engineering and Automation, Fuzhou University, Fuzhou, 350116, China

* Corresponding Author Email: 1912100131@mail.sit.edu.cn

Abstract. As global photovoltaic (PV) integration surges, the ramifications of PV systems on the power grid have become increasingly pronounced. When faced with grid disturbances or faults, the abrupt disconnection of PV systems can critically imperil grid stability. In light of this, the low-voltage ride-through (LVRT) technology, pivotal for resilient grid fault recovery, stands out as an essential topic in PV power generation's advancement. This paper initiates a deep dive into the contemporary prerequisites for PV LVRT capabilities and delineates pathways for their effective realization. It then meticulously unpacks the evolution and multifaceted methods associated with the twin primary LVRT strategies: the assimilation of auxiliary apparatuses and the nuanced control of inverters. A critical analysis is presented in the succeeding sections, contrasting these cardinal strategies' relative merits and demerits and their diverse implementation modalities. The paper culminates with insightful recommendations, positioning itself as an invaluable scaffold for subsequent scholarly explorations in PV LVRT paradigms.

Keywords: Photovoltaic, power generation, low-voltage ride-through technology, inverter control.

1. Introduction

Energy is an important material basis for social development. Humans have long relied on fossil energy sources such as coal, oil, natural gas, etc. Fossil energy-dominated energy structure, many regions have been facing the crisis of insufficient fossil fuel reserves. The burning of fossil energy causes the greenhouse effect, acid rain and other environmental problems, affecting the sustainable development of the human economy and society [1]. Therefore, to solve the problems of energy shortage and ecological environment deterioration, it is necessary to strengthen the development and utilization of clean and renewable energy sources such as solar and wind energy.

The abnormal operation state of the power grid will have a certain impact and influence on the photovoltaic system, and the large-capacity grid-connected photovoltaic power generation system will bring a great impact to the power grid once it is running off-grid, affecting the quality of power, and in serious cases, leading to the collapse of the power grid and affecting the stability of the whole power system [2]. To ensure that the occurrence of voltage dips in photovoltaic power generation can still be maintained grid-connected, domestic and foreign grid-connected standards require large and medium-sized photovoltaic power plants to have a certain low-voltage ride-through (LVRT) capability. Many research results have been achieved in studying photovoltaic (PV) LVRT strategies. In this study, the main technical achievements in various aspects of PV LVRT strategy are sorted out and summarized, and the problems that still need to be solved in the future are presented.

2. Research the Status of LVRT Technology

2.1. LVRT Technology Requirements

In the latest grid-connected standard issued by China in 2012, large-capacity photovoltaic power stations must have low-voltage or fault ride-through functions. This function enables the PV grid-connected inverter to maintain off-grid operation in the event of a grid fault while injecting a certain amount of reactive power into the grid within a specified period, supporting the grid voltage and reducing the grid recovery time. Fig. 1 shows the LVRT curve of a PV grid-connected power generation system.

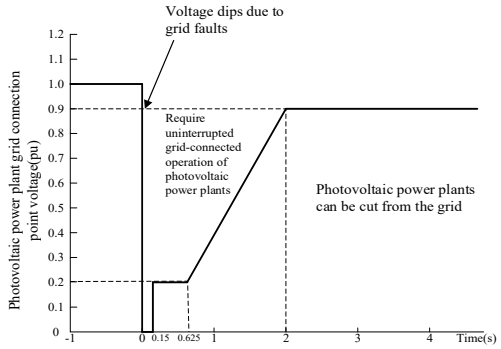


Fig. 1 PV LVRT requirements (Photo/Picture credit: Original)

When the fault causes the voltage to fall to 0 pu, the system can continue not to go off-grid for 0.15 s, and when the voltage rises to 0.2 pu, the grid-connected inverter has to run continuously for 0.475 s. Between 0.625 s and 2 s, the PV power generation system needs to be excised if the voltage falls below the curve requirement. If above the curve, the voltage drop amplitude needs to be restored to 0.9 pu after a voltage drop of 2 s. In Spain and other European countries, the continuous operation conditions of PV grid-connected power generation systems are between 0.88 pu and 1.1 pu, while in our country, the minimum operation condition is 0.9 pu [3].

2.2. PV LVRT Realization Way

At present, there are two main ways to realize LVRT: i) by adding auxiliary equipment and ii) through the photovoltaic inverter control strategy to achieve. Their characteristics and realization methods are different. The following two types of methods are analyzed.

2.2.1 Through the addition of auxiliary equipment

DC side added through two-stage grid-connected PV. In the LVRT, people can add loading and unloading equipment on the DC side of the inverter [4]. Its realization is shown in Fig. 2. When the grid voltage drops, the system, through the unloading control, achieves DC voltage stabilization and then realizes the LVRT of PV. When PV undergoes LVRT, due to the voltage drop on the AC side, if the active power input to the inverter is not changed, it will lead to a rapid increase in the active current, which in turn leads to the inverter protection action and exit from grid operation. To maintain its grid-connected operation, the input active power size is dynamically adjusted on the DC side by unloading control to realize the active balance of the PV, thus realizing the LVRT of the PV.

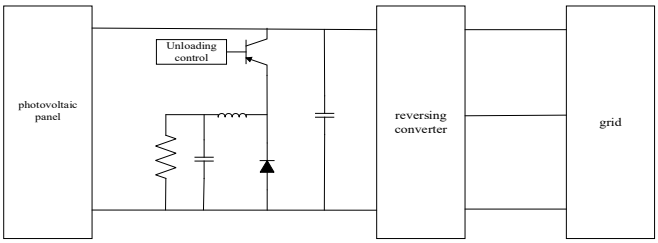


Fig. 2 DC-side auxiliary equipment LVRT strategy (Photo/Picture credit: Original)

In addition to adding auxiliary equipment on the AC side, auxiliary equipment can be added on the AC side to realize PV LVRT. Its realization is shown in Fig. 3. A dynamic resistor is connected in series between the PV and the grid, and the LVRT of the PV is realized by controlling the dynamic braking resistor. When a voltage dip on the grid side is detected, this study controls the bypass switch's opening and closing according to the dip's degree. During the LVRT, the active power output of the PV remains unchanged, and a portion of the active power can be consumed in the bypass resistor through the closure of the bypass switch, thus realizing the LVRT of the PV. Both of the above auxiliary devices reduce the active output of PV to the grid by consuming the excess active power generated by the PV panels during LVRT, thus realizing off-grid operation.

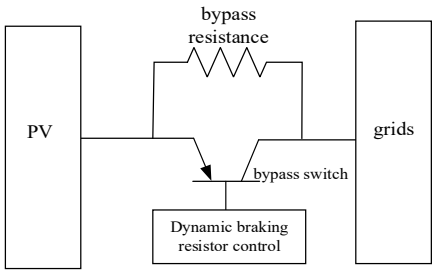


Fig. 3 LVRT strategy for AC-side auxiliary equipment (Photo/Picture credit: Original)

Adding energy storage When the grid voltage dips or recovers, the power can be absorbed or released by controlling the energy storage system, realizing bidirectional transmission of power and improving the LVRT capability of the PV system. When the grid voltage drops, the active power is absorbed by controlling the supercapacitor to balance the DC bus voltage and reduce the power injected into the inverter by the PV array. A supercapacitor energy storage system topology is given. Energy storage systems can enhance the LVRT capability of PV systems and reduce problems such as wasted power compared to protection circuits, but the disadvantage is that the high price of energy storage systems restricts their large-scale utilization. Two energy storage devices are often used: supercapacitors and storage batteries. Supercapacitor devices are usually connected in parallel to the DC side of the inverter. During a voltage dip, the supercapacitor can maintain the voltage balance on the DC side by absorbing the excess energy generated on the DC side, thus realizing LVRT.

The storage battery unit is usually connected in parallel on the AC side of the inverter. During voltage dips due to faults, the storage battery absorbs the remaining active power of the PV system, and in addition, the storage battery can also inject reactive power into the grid to support voltage recovery. This method still uses maximum power tracking in the front stage of the PV grid-connected system during LVRT to store the excess active power, which reduces energy loss and is more energy efficient and environmentally friendly. A supercapacitor energy storage system topology is shown in Fig. 4.

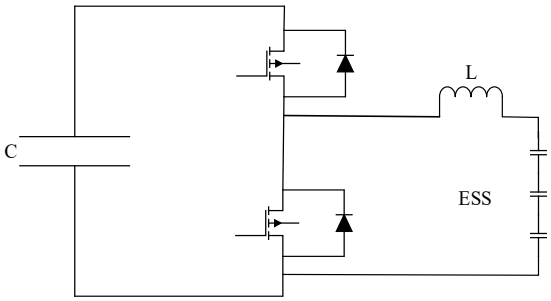


Fig. 4 A supercapacitor energy storage system topology (Photo/Picture credit: Original)

Adding reactive power compensator power system transient faults occur. Its own cannot provide instantaneous voltage support, so a reactive power compensation device should be installed. A reactive power compensation device can provide instantaneous bus voltage support for the PV system, significantly enhancing the low voltage crossing ability of the PV power station. At present, a dynamic reactive power compensation device can be used as a static variable compensator (SVC). Although it can meet the operational requirements, the dynamic performance is poor, and the impact voltage is larger during the fault.

Given that the static var generator (SVG) cost is getting lower and lower, people can also consider using a static synchronous compensator (STATCOM) and so on. At present, there has been introduced into dynamic voltage resisters (DVR) in the wind power system; the photovoltaic system can also refer to this practice [5]. The topology of the DVR circuit is shown in Fig. 5.

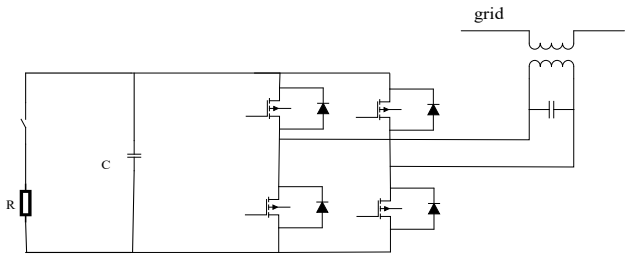


Fig. 5 Topology of the DVR circuit (Photo/Picture credit: Original)

2.2.2 Control Strategies through PV Inverters

Predictive Current Control Predictive current control forces the inverter output current to follow a pre-given current reference value during a switching cycle, which has been widely used in inverter control in recent years because of its good dynamic and static characteristics [6]. The commonly used predictive current control includes deadbeat predictive current control and model predictive current control [7]. The deadbeat predictive current control is to project the switching time of the inverter in the next control cycle according to the state equation of the photovoltaic system and the feedback current signal of the output when the switching frequency is high so that the error between the given current signal and the actual current signal in the next switching cycle is zero (Fig. 6).

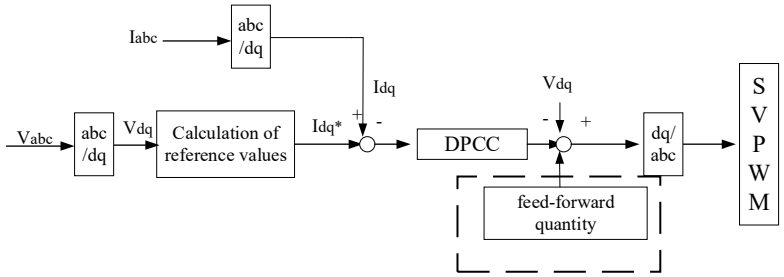


Fig. 6 Typical deadbeat predictive current control block diagram (Photo/Picture credit: Original)

Harmonics in the grid can be suppressed or eliminated by adding a grid voltage feed-forward link, as shown in the dashed box in Fig. 6. However, the above control method is mainly for the occurrence of three-phase symmetrical voltage dips on the PV grid side. For asymmetrical grid voltage dips, accurate control of positive-sequence negative-sequence currents can be realized based on voltage space vector modulation (SVM) [8]. Its control block diagram is shown in Fig. 7.

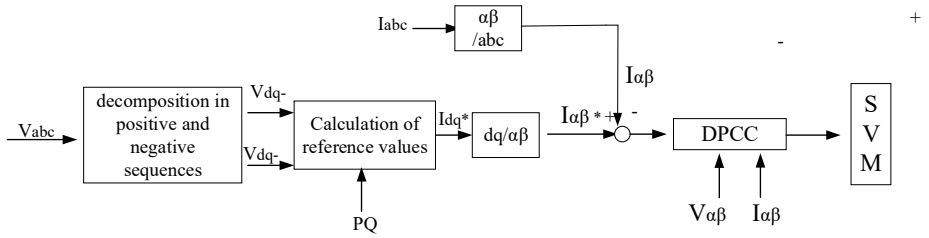


Fig. 7 SVM-based deadbeat predictive current control (Photo/Picture credit: Original)

Model predictive control starts with a system model that predicts future behavior. Usually, a value function is constructed to predict future behavior, and the best variable of the next sampling period is selected as the control variable to minimize the value function [9]. This control method has the advantages of good real-time performance and high accuracy, and its control block diagram is shown in Fig. 8.

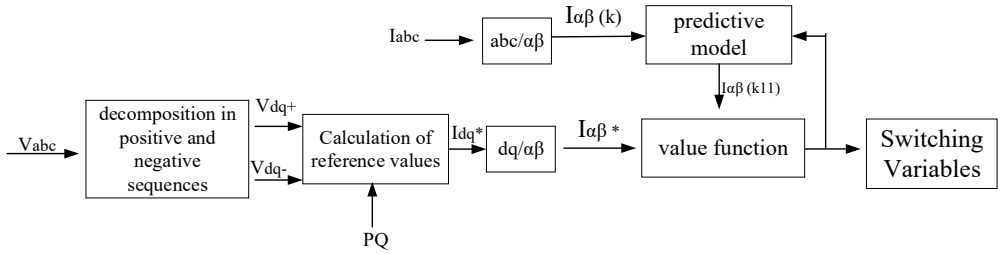


Fig. 8 Model prediction current control block diagram (Photo/Picture credit: Original)

Direct power control (DPC) addresses the need for active and reactive power control for LVRT during voltage dips, i.e., increasing reactive power and reducing active power input, comparing the instantaneous power parameters of the system with the commanded power parameters in real time, and then performing a table lookup to derive the value of the voltage vector that should be output, to minimize the value of the system's instantaneous power tracks the commanded power parameters, thus accomplishing the process of LVRT. In the literature, a complex switching table DPC is adopted to suppress the harmonics due to cycle errors during the switching table checking, which improves the LVRT capability. The LVRT method based on direct power control has the advantages of simple structure and good dynamics [10].

3. Conclusion

In this paper, based on the analysis and summarization of current research results at home and abroad, PV LVRT technology can be divided into two programs based on PV system control strategy and increased auxiliary power equipment devices. It compares and summarizes the advantages and disadvantages of different LVRT schemes and puts forward the problems that still need to be solved. With the development of the power grid, the PV LVRT strategy generally prioritizes the inverter control strategy, which provides a reference for the research and application of LVRT technology for PV power generation systems. When the grid voltage drop is mild, the LVRT capability of the PV system can be effectively improved by the improvement of the system control strategy. When the voltage drop is large, the PV system may be unable to withstand the instantaneous voltage and current shocks.

Considering the inverter capacity limitation, the PV provides limited reactive power compensation capability when the active power output is unchanged, and the reactive power output can be improved if the active power output is reduced during the LVRT. If the active power output is reduced during LVRT, the reactive power output can be increased, but it is necessary to increase the corresponding control strategy or add the corresponding external equipment. Although the cost is large, increasing auxiliary power equipment programs can improve the system's stability. It can be seen that the two types of LVRT strategies can be used individually or in conjunction with each other according to the actual situation. Due to time constraints and the limitations of personal knowledge reserved in the research process, the principles and specific applications of the two main paths of photovoltaic LVRT, as well as the research on the more novel LVRT principles and the corresponding topologies, are not in-depth enough and remain to be studied and researched at a later stage.

References

[1] Wang Xiaona. Research on low voltage ride-through technology of photovoltaic grid-connected converter. Yanshan University, 2015.

[2] Tian Hao. Research on low voltage ride-through technology of photovoltaic grid-connected inverter. Shandong University, 2014.

[3] Yang Zhenxing. Research on low-voltage ride-through technology of three-phase photovoltaic grid-connected inverter. Yanshan University, 2016.

[4] Zhang Mingguang, Chen Xiaojing. Low-voltage ride-through control strategy for photovoltaic grid-connected power generation system. Power System Protection and Control, 2014, 42(11): 28-33.

[5] Jiang Tingting. A review of low voltage ride-through technology for photovoltaic power generation system. New Industrialization, 2015, 5(08): 57-62.

[6] Li Jianlin, Xu Honghua. Low-voltage operation technology of wind power generation system. Beijing: Machinery Industry Press, 2008.

[7] Liang Haifeng, Feng Yanchuang, Liu Zixing, et al. Research on low voltage ride-through technology of photovoltaic power plant based on differential-free beat control. Power System Protection and Control, 2013, 41(21): 110-115.

[8] Nian Heng, Yu Nisa, Zeng Rong. Predictive current control technique for grid-connected inverters under unbalanced voltage. Grid Technology, 2013, 37(5): 1223-1229.

[9] Correa Pablo, Rodriguez Jose, Rivera Marco, et al. Predictive control of an indirect matrix converter. IEEE Transactions on Industrial Electronics, 2009, 56(6): 1847-1853.

[10] Pang Yuan. Research on low voltage ride-through method for grid-connected photovoltaic. Liaoning University of Technology, 2021.