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Low voltage ride-through capability control for single-stage inverter-based grid-connected photovoltaic power plant

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ABSTRACT

The low voltage ride-through (LVRT) capability is one of the challenges faced by the integration of large-scale photovoltaic (PV) power stations into electrical grid which has not been fully investigated. Therefore, this paper presents a comprehensive control strategy of single-stage PV power plant to enhance the LVRT capability based on the Malaysian standards and modern grid codes connection requirements. The proposed control overcomes the problems of dc-link over-voltage and ac over-current that may cause disconnection or damage to the inverter. For this purpose, dc-chopper brake controller and current limiter are used to absorb the excessive dc-voltage and limits excessive ac current, respectively. This control strategy can also ensure the reactive power support through the injection of reactive current according to the standard requirements as soon as the voltage sag is detected. Furthermore, to keep the power balance between both sides of the inverter, PV array can generate possible amount of active power according to the rating of grid inverter and voltage sag depth by the operating in different modes. The results illustrate that the proposed control strategy is effective, not only to improve the capability of ride-through fault safely and keep the inverter connected, but also to provide grid support through active and reactive power control at different type of faults.

1. Introduction

Over the recent years, photovoltaic system has become one of the most promising renewable energy in the world and is expected develop rapidly in the future. With high level of photovoltaic power plants (PVPPs) penetration in the electric power grids, disconnections of these plants during faults are no longer possible as it may cause problems concerning stability, reliability, and operation of the power system (Hasanien, 2016). Due to that, many countries have established new grid codes (GCs) requirements for grid-connected PV system that should be met. These requirements impose that the PVPPs should avoid a high loss of power and stay connected to the grid in case of voltage sag, which is usually caused by grid faults. This ability is known as low voltage ride-through (LVRT) capability CEI - Comitato Elettrotecnico Italiano, 2014; Kobayashi, 2012; García-Sánchez et al., 2012; Troester, 2009; E.ON Netz GmbH; Al-Shetwi et al., 2015. Recent studies have compared LVRT requirements for grid-connected PV power plants (GCPPPs) in different GCs were done in Al-Shetwi et al. (2015), Cabrera-Tobar et al. (2016). Many countries have proposed and implemented grid code connection requirements for LVRT, such as German, Spain, Japan (Kobayashi, 2012; Al-Shetwi et al., 2015; Cabrera-Tobar et al., 2016; Obi and Bass, 2016; Neumann and Erlich, 2012). In Malaysia, the LVRT requirements for large-scale GCPPPs have been recently imposed by Malaysian GC as shown in Fig. 1 (Commission Malaysia (ECM), 2017). These requirements stipulate that when voltage sag happens, the PVPP should stay connected to the grid in case it operates in the connection area above the blue curve in order to avoid power loss and grid frequency decreasing. The PVPP must not be disconnected from the grid for 150 ms when the line voltage (V) drops to 0% of the nominal voltage (V_n). Additionally, the voltage should recover 90% from its pre-fault value within 1.5 s from the occurrence of voltage sag. Besides keeping the inverter connected, the PV power stations are required to support grid voltage recovery through the injection of reactive power according to the standard requirements (Al-Shetwi et al., 2015; Commission Malaysia (ECM), 2017; Ding et al., 2016; Shah et al., 2015). Based on these requirements, the amount of injected reactive power is represented according to the ratio of injected reactive current and rated current (Neumann and Erlich, 2012; Ding et al., 2016).

During grid faults, there-are-two-major-issues-that-should be

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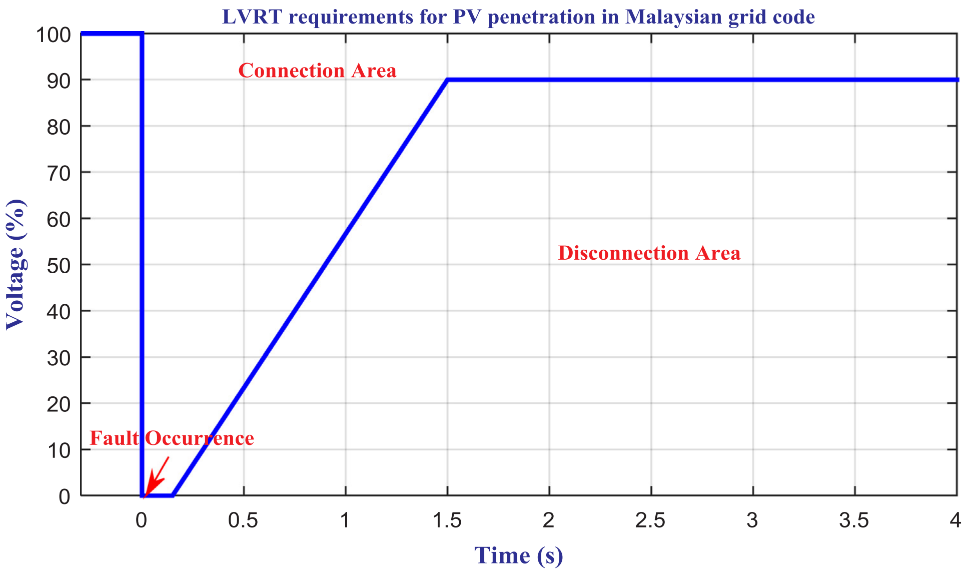

Fig. 1. Malaysian-low voltage-ride-through-requirements (Commission Malaysia (ECM), 2017).

addressed by the PVPPs to achieve the LVRT requirements mentioned above. The first one is the dc-link over-voltage in the dc-side of the PV inverter as well as the over-current that may occur in the ac side. The second one is the injection of reactive current, which is considered as an effective solution for voltage recovery and to support the grid in order to overcome the voltage dip problems (Obi and Bass, 2016; Perpinias et al., 2015). Most publications in the past focused only on ride-through of the fault for either single or two stages grid-connected PV power plants. However, always not sufficiently deal with the reactive current injection during voltage dip under all types of the grid faults along with the fault-ride-through capability and inverter protection.

Till date, some of the existing fault ride-through control studies focus on reducing the amplitude of PV inverter output current and dc-link over-voltage as well as protecting the inverter during voltage dip. For instance, a method was proposed in Ding et al. (2016) applied adaptive dc-link voltage control for PV inverter to enhance the output waveform quality. The proposed control overcome the excessive dc-link voltage during voltage dip by setting a variable dc-link voltage. Zeng et al., proposed a new control strategy to avoid over-current and over-voltage until the fault is ride-through safely (Zeng et al., 2015). In this study, the simulation results show the effectiveness of this control of improving the point of common coupling (PCC) voltage support and helping to ensure the safety of semiconductor devices. Another study (Miret et al., 2012) introduced a proportional-resonant (PR) current controller for the current limiter to suppress the over-current as well as guarantee a sinusoidal output current waveform. In the event of low voltage duration, some existing solutions are proposed by Reisi et al. (2013), Tian et al. (2012), Yajing et al. (2011), Islam et al. (2011) which just pay attention for enhancing the output waveform of the PV system in addition to keep the inverter stay connected during grid faults. However, the reactive power support had not been considered in all references mentioned above.

Among the existing LVRT control strategies with dynamic voltage support (injection of reactive power) for grid connected voltage source inverter (VSI), some recent studies had been done on wind turbine applications and are compared in Howlader and Senjyu (2016). In the application of PVPPs connected grid, some researches were done with the configuration of two-stage inverter-based GCPPP. A method was proposed by Worku and Abido (2015), this method applied the reactive power injection for GCPPP based-on-German GC using-supercapacitor-energy-storage-system (SCESS). The SCESS is connected-to-the-system via bi-directional buck-boost converter and then to dc-link in which it provides the grid with-both-active and-reactive-power using specific control in order to support utility-grid-during-the fault. But, this control not only increases the-cost-but-also-effects the reliability of the system. Another study used the takagi-sugeno-kang probabilistic fuzzy neural network intelligent control to regulate and control the reactive power value under grid faults (Lin et al., 2015). Although both methods can provide reactive current, the methods have drawbacks of additional components which incur additional cost, and also do not address the power balance and inverter protection problems during voltage dip processes. However, in the application of single-stage inverter-based GCPPP, no paper so far has sufficiently covered a comprehensive strategy to protect the inverter during voltage dips occurrences whilst providing reactive power support to the grid.

In view of the above discussion, this paper presents an overall new control strategy for single-stage-three-phase-PVPP connected Malaysian grid in the faulty mode operation to ride-through the fault and support the grid based on Malaysian LVRT requirements and GCs (Commission Malaysia (ECM), 2017; Azit et al., 2012). The main objective of this study is to propose a comprehensive control strategy that enables the PVPP to withstand grid faults, to allow the inverter remains connected, to continuously produce electricity, and to absorb excessive energy whilst injecting the required reactive power under various types of fault to meet the standard requirements. As compared to other methods, this method not only effectively suppresses the ac over-current as well as the dc-link over-voltage and protect the inverter during voltage dip, but also support the grid via injection of reactive power. Furthermore, once the fault is cleared, all values will recover to pre-fault values directly. Some selected simulation results are presented to validate the performance of the proposed control strategy.

The paper is organized as follows: background review provided in the introduction followed by modeling steps of the PV power plant and its control including PV panel modeling, PV array sizing-with-MPPT algorithm, and the inverter control strategy at normal operations, in the second section. Methodology of the proposed LVRT control strategy during fault conditions to avoid excessive ac-current, protect the inverter from excessive dc over-voltage, fault detection method, and injection of reactive power control are presented in the third section. The fourth section presents the results of the proposed LVRT control with reactive power injection according to the modern GCs' standard requirements. The conclusion and summary in addition to remarks are provided in fifth section.

2. Modeling of single-stage PV power station

The schematic diagram of Fig. 2 shows the power stage of the grid-connected single-stage PV system modeled in this study. It includes the