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Strategy to enhance the low-voltage ride-through in photovoltaic system during multi-mode transition

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ABSTRACT

With the increasing capacity of distributed generation (DG) connected to the power grid, the future generation of photovoltaic (PV) systems are expected to provide a full range of voltage regulation during grid faults in order to enhance the low-voltage ride-through (LVRT) capability of a PV system. In such a condition, the DG should remain connected to the grid for reactive power support, thereby improving voltage profile. This paper aims to propose a control strategy of active and reactive power for a single-stage three-phase grid-connected PV system to enhance the LVRT. The dynamic behaviours of the system were investigated by considering various scenarios such as varying irradiance, local load disconnection, and short circuits, at different locations during the multi-DG operation. Results confirm that the grid-connected PV system is able to remain connected to the power grid during steady-state and transient-state conditions without violating the grid code requirements. The established dynamic behaviour analysis model of the proposed control for grid-connected PV systems can be used in planning an operational strategy for a practical system.

1. Introduction

With the upsurge in awareness about the necessity to reduce the world's dependence on fossil fuels, DG systems based on renewable energy sources (RES) such as wind, solar and hydro have gained popularity. However, the total electricity generation based on these RES is not reliable as reverse power flow may occur and it may possibly contribute to grid failure which can affect the operation and control of the power system (Babacan et al., 2017; Bevrani et al., 2010). The literature review shows that more than 80% of the cause of poor power quality in developed countries is due to voltage disturbances such as voltage sags and short interruptions (Honrubia-Escribano et al., 2014; Moreno-Munoz et al., 2010; Perpinan et al., 2013). A short-term voltage sag may occur as a result of lightning strikes, short circuits or even when large loads are connected (Dirksen, 2013; Montero-Hernandez and Enjeti, 2002). When such faults happened in the past, the IEEE-1547 allowed wind turbines (WT) to disconnect from the grid and reconnect it after a certain period of time. However, this standard (1547) was designed many years ago where the capacity of DG based on RES installation was small (Schauder, 2012; Balathandayuthapani et al., 2012). Nowadays, this practice is no longer efficient as it can contribute to voltage flickers or system instability and could lead to power outages if too many generating plants are being disconnected at the same time (Dirksen, 2013; Yang et al., 2015). This situation will affect a large number of customers. Though voltage sag generated from RES cannot be eliminated due to its stochastic nature, it can be mitigated (Ipinnimo et al., 2013). As a result, the recent grid codes require keeping the WT connected to the power grid for a pre-specified voltage sag value and duration during a fault condition.

Considering the voltage sag problems associated with RES, a so-called grid code known as LVRT has been established. The main objective of LVRT is to maintain the grid voltage stability and to avoid gigantic loss of power during the faults (Carrasco et al., 2013; Kirtley et al., 2013). Consequently, the generation based on RES should stay connected to the grid during such faults and at the same time provides grid support by injecting a reactive power in order to avoid grid collapse (Schwartfeger and Santos-Martin, 2014; Sousa et al., 2015). Fig. 1 shows the LVRT limiting curves defined by Italy, Germany, Japan, China, Spain, USA, and Denmark. Generally, if the voltage drop value is above the curve for a given specific time, the generating plant should remain connected to

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Nomenclature

Acronyms

AC	alternative current
BIPV	building integrated PV
CIGRE	International Council for Large Electric Systems
DC	direct current
DG	distributed generation
LVRT	low-voltage ride-through
MPPT	maximum power point tracking
PCC	point of common coupling
PI	proportional integral
PR	proportional resonant
PV	photovoltaic
RES	renewable energy sources
WT	wind-turbine

Symbol description

abc	natural reference frame
$\alpha\beta$	stationary reference frame
dq	synchronous rotating frame
i_d	active current
i_d^*	active current reference
$i_{d,\max}$	maximum allowed of active current
i_{dnew}^*	active current during LVRT
i_q	reactive current
i_q^*	reactive current reference
i_{qnew}^*	reactive current during LVRT
I_{rated}	rated value of the grid inverter current
P	active power
P_{inv}	inverter's active power
P_{load}	load's active power
P_{PCC}	PCC's active power
Q	reactive power
Q_{inv}	inverter's reactive power
Q_{load}	load's reactive power
Q_{PCC}	PCC's reactive power
S	apparent power
V_{DC}	DC link voltage
V_g	grid voltage
V_{gn}	normal grid voltage
V_{inv}	inverter's voltage
V_L	load's voltage
V_L^*	load's voltage reference
V_{load}	load's voltage
σ	irradiance

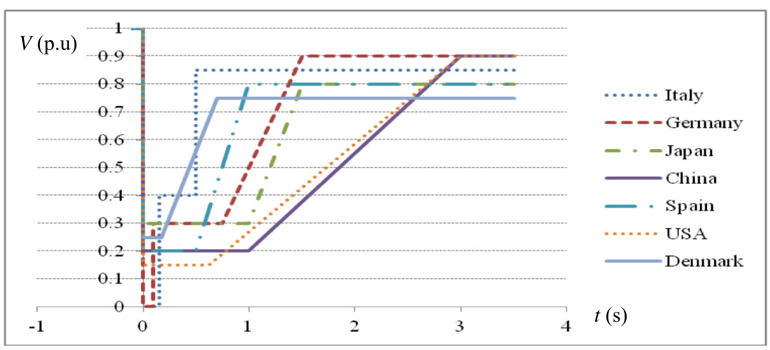

Fig. 1. LVRT requirements defined by different countries (Yang et al., 2014; Ma et al., 2012; Perpinias et al., 2015; Tang et al., 2015).

the grid and an injection of reactive current is needed to support the grid voltage. Due to the maturity of wind power technology and high penetration of wind power generation, the grid codes for WT already existed in many countries (Marinopoulos et al., 2011). However, implementation of grid codes for PV system is still in its early stage and specific standards vary from one country to another (Carrasco et al., 2013).

Yang et al. (2014a) proposed a new control strategy for a 500 kW two-stage three-phase grid-connected PV system. This system operated without maximum power point tracking (MPPT) mode when a fault occurred. In this case, the active power was generated based on the voltage sag magnitude while the inverter injected the appropriate reactive current for the voltage recovery. A feed forward compensation term was also proposed to smooth the DC-link voltage. Nanou and Papathanassiou (2014) used two-stage power processing for a 100 kW PV system. In this controlling method, a proportional-resonant (PR) compensator was employed to produce inverter output current while the proportional-integral (PI) controller was used to regulate the DC link voltage (V_{DC}). In Yang et al. (2014b), a 1 kW two-stage single-phase grid-connected system was developed to test four reactive power injection strategies – constant average active power control, constant active current control, constant peak current control, and thermally optimized control strategy. A 500 kW PV inverter test bench was built in by Carrasco et al. (2013) with two back-to-back inverters. A full-load test was conducted in the study with different types of voltage sag to test the LVRT capability.

Additionally, Miret et al. (2013) and Sosa et al. (2016) injected reactive current for both positive and negative sequences to realize the voltage support control. While both systems were tested for different types of voltage sags, Sosa et al. (2016) also looked into the low and high power generation scenarios. A flexible active power control which is based on a fast current controller and a reconfigurable current selector was proposed in by Rodriguez et al. (2007). Wu et al. (2014) examined the system for an unbalanced grid fault (single-phase to ground) at a distance of 7.7 km from the point of common coupling (PCC). Meanwhile, the RES has been integrated to the low voltage smart micro-grid with energy storage coupling in compliance to the Italian Standards (Falvo et al., 2015; Graditi et al., 2015). Though the effectiveness of the above-mentioned system was confirmed for restoring the voltage drops, the dynamic performance in variable conditions including varying irradiance, fault distance and in cascaded DG outage is still inadequate.

This paper proposes an approach to control the active and reactive powers when disturbances occur. In this study, dynamic