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Improving performance of LVRT capability in single-phase grid-tied PV inverters by a model-predictive controller

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ABSTRACT

New interconnection standards for Photovoltaic systems are going to be mandatory in some countries. Such that the next generation of PV should support a full range of operation mode like in a power plant and also support Low-Voltage Ride-Through (LVRT) capability during voltage sag fault. Since the voltage sag period is short, a fast dynamic performance along with a soft behavior of the controller is the most important issue in the LVRT duration. Recently, some methods like Proportional Resonant (PR) controllers, have been presented to control the single phase PV systems in LVRT mode. However, these methods have had uncertainties in respect their contribution in LVRT mode. In PR controllers, a fast dynamic response can be obtained by tuning the gains of PR controllers for a high bandwidth, but typically the phase margin is decreased. Therefore, the design of PR controllers needs a tradeoff between dynamic response and stability. To fill in this gap, this paper presents a fast and robust current controller based on a Model-Predictive Control (MPC) for single-phase PV inverters in other to deal with the LVRT operation. In order to confirm the effectiveness of the proposed controller, results of the proposed controller are compared with the classical PR controller. They are also implemented in a 1 kW single-phase transformerless HERIC (Highly Efficient and Reliable Inverter Concept) inverter.

1. Introduction

In last decades, the capacity of PV systems in the utility grid is dramatically increasing [1–3]. According to European Photovoltaic Industry Assertion (EPIA), the installation of PV systems is estimated to be around 345 GW in the world until 2020 [4]. Along with the increasing capacity, some concerns exist about their effects on the power quality and reliability of the grid. Hence, different studies have been carried out in other to evaluate such challenges [5–11]. For example, a sudden drop in the grid voltage may activate the islanding mode protection of PV systems and can lead to the interruption of the injected power to the network [12,13]. Because of such problems, some countries like Germany, Italy and Japan have updated their grid codes to connected distribution systems to have Low-Voltage Ride-Through (LVRT). This means the PV system should support a full range of power even under fault conditions [14–19].

The control scheme of PV systems is one of the most important parts, where an adaptive and suitable control scheme not only can reduce power quality problems but can also guarantee a reliable operation of connection to the grid. In recent years, a limited number of papers have discussed the PV control systems with LVRT capability e.g. [20–22,17,19]. In [19] a benchmark of grid fault modes has been studied for future single-phase PV systems. In [20], for the three-phase PV systems, a control method based on neural network and fuzzy controller has been presented. In [21], a synchronization method for single-phase grid-connected photovoltaic systems under grid faults is also introduced. In [22], the authors worked on modelling and control of three phase PV systems with respect to the German grid code by a positive sequence current control in order to operate during LVRT.

Some interesting work has been done in [17], where a transformerless single-phase grid connected inverter with LVRT capability has been handled and controlled by using a classical PR controller. The results of the paper have shown that the PV system can have a positive participation in the LVRT, but the control system did not have a fast dynamic response during the LVRT. Since the period of the voltage sag is usually short, a faster control system can lead to a more effective contribution in the LVRT mode.

In order to fill in this gap, this paper presents a fast current

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controller for a PV system based on a Model-Predictive Controller (MPC). The proposed approach has a fast dynamic response in LVRT duration comparing with the existing methods.

The paper is organized as follows: first a summary of selected transformerless inverter is explained. Then paper focus on the demands for PV inverters in the LVRT mode. A classical PR controller is discussed in section III. In section IV, the proposed method based on MPC for single-phase PV system is presented. LVRT challenges and the proposed switching plan has been discussed in section VI. Finally before the conclusions, simulation and experimental results of the proposed controller are compared with the classical PR controller.

2. Transformerless PV-inverters

In [23], various single phase inverter topologies are presented and compared from the view point of power quality and reliability. In addition to the power quality and reliability, efficiency is also an important factor. In order to achieve a high efficiency, transformerless inverters are widely used to connect the PV systems to the utility grid. Different structures for single-phase transformerless PV inverters have been presented [24–26]. Among them, the HERIC inverter has the highest efficiency [27,28]. Therefore, it is selected in this paper to connect the PV inverter to the utility grid.

Recently, the LCL filters are widely used at the output of these inverters. The LCL filter attenuates high-frequency harmonics more than the L filter and can also be used in both standalone systems and grid-connected systems [29,30].

Therefore, in this paper, one of the newest structures of the single-phase grid-connected PV inverters, which has a low leakage current and high efficiency, has been used, which is the HERIC inverter with an LCL filter. As the proposed PV structure has two stages, a DC/DC converter has been considered before the inverter as shown in Fig. 1.

3. Demands for PV inverters in LVRT

According to the report of ABB, reactive power injection can help to the voltage recovery process in distribution grids [31,32]. As mentioned before, recently some countries have updated their grid codes, where they force that the inverters should be stay connected when sudden voltage drop occurs for a determined short time as shown in Fig. 2. Fig. 3 shows the relationship between reactive power and voltage in LVRT duration in German grid code.

According to the Q-V profile in Fig. 3, depending on the grid voltage, reactive power reference (Q^*) is calculated and should be injected into the grid. Some control strategies are proposed in [16] among them, two important strategies are selected as it will be explained in the following.

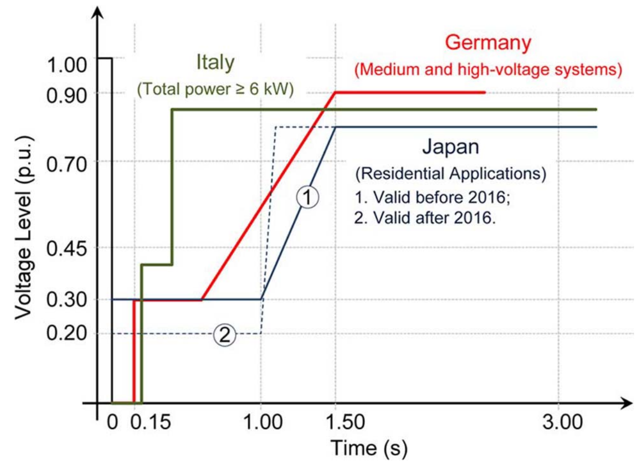

Fig. 2. LVRT requirements forced in some countries [13,33–35,17].

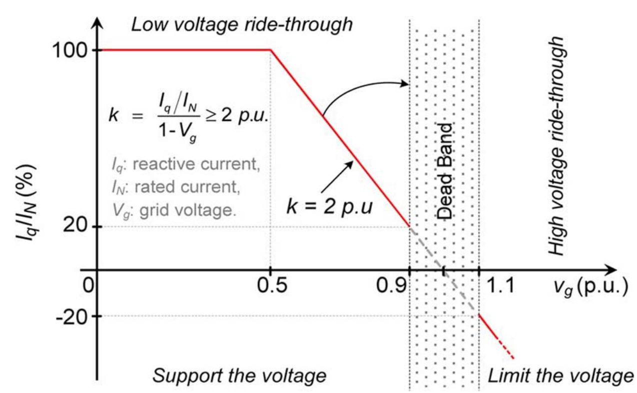

Fig. 3. Reactive current injection requirements in E.ON grid code [12,22].

3.1. Constant peak current

This strategy protects the inverter system against overcurrent and guarantees there is no danger for shutting down the inverter by the protection system. In this case, I_d is the component of the active power coming from the Maximum Power Point Tracker (MPPT) and I_q is the component of the reactive power determined from a sag detector and the LVRT controller. In this strategy, I_d and I_q are calculated by

$$\begin{cases} I_q = k(1-v_{gm})I_N \\ I_d = \sqrt{I_{gmax}^2 - I_q^2} \end{cases} \quad I_{\text{gmax}} = I_N = \sqrt{I_d^2 + I_q^2} \tag{1}$$

where v_{gm} is the per unit of the grid voltage amplitude and I_N is the nominal current of the inverter and $k \geqslant 2$. It can be seen from Fig. 3 that the PV inverter should only inject reactive power ($I_q = I_{gmax}, I_d = 0$)

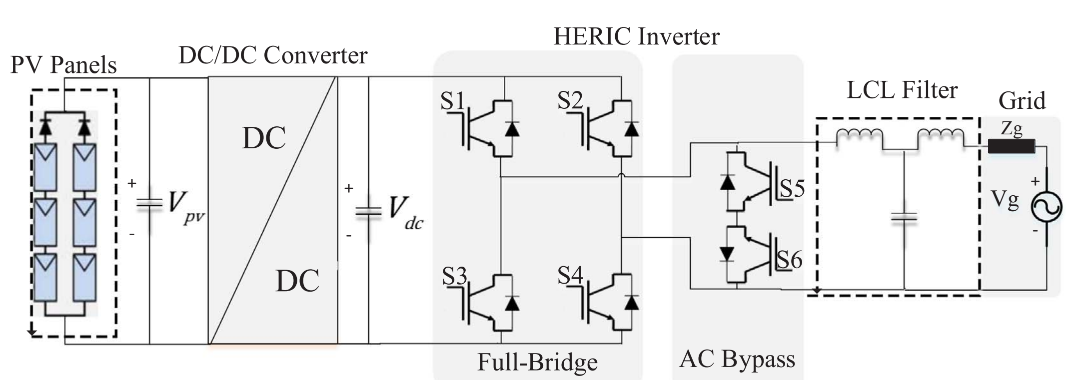

Fig. 1. The system hardware: DC/DC converter and HERIC inverter with LCL filter at the output.

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