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A grid-tied PV-fuel cell multilevel inverter under PQ open-loop control scheme

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Power generating entities' connection to utility grids requires power converters to achieve high efficiency and low injected current harmonic distortion. The control of the power converter plays a crucial role in the grid-tied power converter's performance. Various control techniques for grid-tied inverters ranging from classical to intelligent are introduced in several exist. Evaluating the current state and trend in grid-tied power inverters and related control methods, research shows that most works in this area focus on grid integration using the close-loop and other advanced control approaches. This is because these control methods are preferred since they provide adequate performance in case of uncertainties in the system. This investigation can aprove that PQ open-loop control technique can operate sufficiently and cost-effectively in grid-tied renewable and alternative power systems under normal operating conditions. Hence, this paper aims to assess the performance of a centralized single-stage grid-tied three-level diode clamped inverter connected to a PV-Fuel cell unit. An active and reactive power open-loop control scheme is employed to operate the inverter and achieves a current harmonic distortion below 5%. The system comprises a 150 kW/700 V PV, a 150 kW/1400 V fuel cell, a 265 kW multilevel inverter operating at a rated voltage of 415 V, and an LCL filter. Two operating scenarios are adopted to investigate the system's responses further. In the first scenario, a local load of 509.2 kW is supplied from the PV-fuel cell inverter. The load also receives the grid's power to meet the demand as the PV-fuel cell inverter provides only 265 kW. Whereas in the other scenario, the PV-fuel cell unit provides power to supply a local load while transporting the surplus to the grid. The results reveal the developed model's good performance with a current harmonic distortion of 0.33%.

KEYWORDS

fuel cell, microgrid, photovoltaic system, PQ open-control, harmonic

1 Introduction

Restructuring the electricity system from vertically into a horizontally integrated system opens the door for many innovative system design and operation ideas. The technological advancement of distributed generation technologies and the significant concerns over fossil fuel consumption's negative environmental impact shifted the traditional way of designing and operating electric power systems. Distributed energy resources are now integral parts of modern power systems. They consist of power generating units such as the fuel cell (FC) system, solar PV, solar thermal, wind energy conversion system, wave energy harvester, biogas, diesel generators, energy storage systems, and different technologies controllable electric loads. Such power generating entities' connection to utility grids requires power converters to condition the power generated and guarantee power quality when operating tied to the grid (Yu et al., 2007; Gao et al., 2009). The grid-tied power converter must achieve high efficiency and low injected current harmonic distortion while regulating the power exported to the grid. The inverter control scheme plays a crucial role in the grid-tied power converter's performance; it manages the dc-link voltage and adjusts the power injected into the grid. Two power converter topologies are predominant for grid-tied distributed power systems, namely a one-stage power converter (1-SPC) consisting only of a grid-connected inverter *via* a power transformer and a two-stage power converter (2-SPC) that consists of DC/AC and DC/DC converters (Gao et al., 2009). Nonetheless, the two-stage power converter is more favored due to its advantages, such as operating under a broad voltage range. This guarantees a decent energy conversion.

Furthermore, the topology decouples the distributed generation unit from the inverter terminals to prevent the induction of double-line-frequency ripple by the ripple of the AC power. The 1-SPC is once again the most cost-efficient configuration as it requires no DC/DC converter (Xiao et al., 2016). This configuration is not popular because of the need for the minimum dc-link voltage is supposed to be greater than the peak grid voltage required to prevent over-modulation system operation. Although both 1-SPC and 2-SPC can be designed in centralized, multi-string, and string structures, the implementation of different types of 1-SPC, ranging from low to high levels, is a function of the power specification (Islam and Mekhilef, 2014). For instance, the 2-SPC arrangement is the most utilized inverters for low power and low voltage usages.

Similarly, for applications with high-power requirements, the multilevel inverter is more appropriate (Çelik et al., 2018). Multilevel inverters (MLIs) may also be utilized in medium to high voltage applications, such as power distribution, motor drives, etc. (Mancilla-David et al., 2012). However, several design trade-offs govern the decision on the type of MLI structure and the suitable control scheme to be used (Marx et al., 2014). Nevertheless, the most developed multilevel inverter arrangements comprise the Diode Clamped, the Flying Capacitor inverter, and the Cascade Full Bridge (Lai and Ellis, 2017). Amongst them, the three-level diode-clamped inverter is one of the most commercially used topologies.

Additionally, inverters' most well-known control scheme is the closed-loop control scheme consisting of the DC voltage and inner current controls. Four closed-loop control strategies are generally employed for regulating current injected into the grid, namely the direct control with current feedback on either the grid side or inverter-side inductor, the cascade control with either the capacitor current feedback or the inverter-side inductor current that serves as the inner loop (Mahlooji et al., 2018). In the direct control technique, the grid injected and the reference currents are compared, and the resulting error serves as the input to a PI controller; this aids steady-state error elimination. In this configuration, the output of the PI controller serves as the inverter voltage reference. Both the grid and inverter voltages determine the current fed to the grid.

Regarding the cascade control current feedback on the inverter side, the current feedback on the grid side inductor acts as the external loop, while the current feedback on the inverter-side inductor is the internal loop. Similarly, the active and reactive power (PQ) open-loop control scheme is also suitable for the control of inverters. The control is designed either in a stationary or in a synchronous frame (Teodorescu et al., 2011). The control carried out in a synchronous frame regulated the active and reactive power by using a current regulator implemented in the dq0 frame and feed-forward. The regulation of the DC voltage provides the active power reference. Whereas in the stationary frame, the control is achieved in the αβ0 frame, prompting an indirect voltage-oriented control scheme. The approach requires the feed-forward regulation of the active and reactive power, with the control of the DC voltage following up the power reference (Teodorescu et al., 2011). As mentioned above, the power system is undergoing a major shift from centralized power generation to distributed power generation. More and more distributed generators (DGs) are connected to the grid through power inverters. To cut down the impact of many inverters tied to the grid, the inverters' control scheme must be carefully designed. In the same vein, the inverter is the critical interface for DGs in smart grids. Hence, it is important to determine the appropriate control strategy to ensure a smart and friendly connection of the DG to the grid for smart grid management (Hornik and Zhong, 2012). Various control techniques for grid-tied inverters ranging from classical to intelligent are introduced in several studies (Hornik and Zhong, 2012; Zeb et al., 2018). The PQ open-loop control technique refers to a classical inverter control method. Evaluating the current state and trend in grid-tied power inverters and their existing control methods showed that most works in this area have focused on grid integration using the close-loop control approach. This is because the control method