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High quality model predictive control for single phase grid-connected photovoltaic inverters

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ABSTRACT

Single phase grid-connected inverters with LCL filter are widely used to connect the photovoltaic systems to the utility grid. Among the presented control schemes, predictive control methods are faster and more accurate but are more complex to implement. Recently, the model-predictive control algorithm for single-phase inverter has been presented, where the algorithm implementation is straightforward. In the proposed approach, all switching states are tested in each switching period to achieve the control objectives. However, since the number of the switching states in single-phase inverter is low, the inverter output current has a high total harmonic distortions. In order to reduce the total harmonic distortions of the injected current, this paper presents a high-quality model-predictive control for one of the newest structure of the grid connected photovoltaic inverter, i.e., HERIC inverter with LCL filter. In the proposed approach, the switching algorithm is changed and the number of the switching states is increased by some virtual vectors. Simulation results show that the proposed approach lead to a lower total harmonic distortions in the injected current along with a fast dynamic response. The proposed predictive control has been simulated and implemented in a 1 kW single-phase HERIC inverter with LCL filter at the output.

1. Introduction

Single-phase grid-connected inverters are the most important part of a small-scaled renewable energy resources. In recent years the installation of the single phase photovoltaic systems in networks has remarkably grown [1,2]. One of the main challenges in these systems is the efficiency. To achieve high efficiency in the PV systems, single-phase transformerless grid-connected inverters are widely used. Different topologies for single-phase transformerless PV inverter have been presented [3,4]. Among them, the Highly Efficient and Reliable Inverter Concept (HERIC) has the highest efficiency [5,6]. Also, LCL filters are more attractive to use at the output of transformerless inverters. In contrast to L filters, LCL filters have higher harmonic attenuation and help the inverter to work in both standalone and grid-connected operation [7,8]. On the other hand, different linear and non-linear controllers have been proposed for such systems including, hysteretic controllers, proportional controller (PR), voltage oriented controller (VOC), sliding mode controller, artificial intelligence controllers. Among these control methods, hysteretic control is simple and robust but it has a current ripple because of its variable switching frequency [9,10]. PI controllers are the most common controllers for the power converters but they have a steady state error and need to accurate gain tuning as well [11,12]. In order to implement the PI controllers in the stationary reference frame, PR controller has been proposed. PR controllers are widely used to control the single phase inverters but they also need to tune the control gains for any purpose [13,14]. Nearest Level Control (NLC) are widely used for high power and high level inverter applications [15]. Other controllers, such as neural networks, sliding mode and fuzzy control methods have been used for single phase grid connected inverter but they have a high computational burden [16–19].

Predictive controllers are fast, robust, and easy for digital implementation. These controllers determine the best amount of inverter voltages to force the output currents to track the reference current [20,21].

Different robust methods of the predictive control based on the deadbeat control have been presented such as robust predictive current control (RPCC) [22], adaptive robust predictive current

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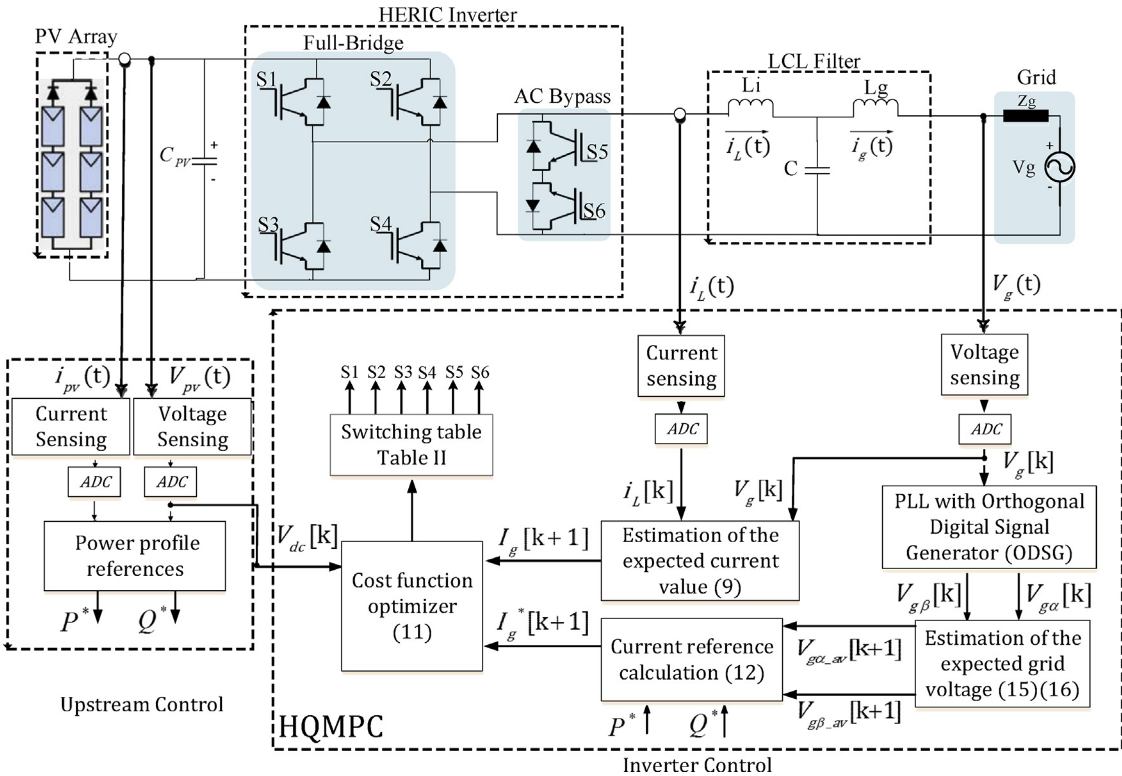

Fig. 1. Single phase grid-connected photovoltaic inverter with LCL filter and HQMPC.

control (ARPCC) [23], synchronous reference frame robust predictive current control (SRF-RPCC) [24], generalized robust predictive current control (GRPCC) [25], and full state observer predictive current control (FSOPCC) [26]. The mentioned methods have shown acceptable results but they have a high complexity to implement. In addition, due to the advent of powerful processors, MPC is recently used in the power converters, which are simple to implement for different control objectives. In the MPC approach, the system equations, including inverter, filter and grid are determined and the next sample of the current is calculated. Then it is compared with the current reference and the best switching state is determined by a cost function [27–29].

In Refs. [30,31], the algorithms based on MPC with different control objectives have been presented. However, since the number of switching modes is very low, the accuracy of the method is reduced and leads to a high THD in the inverter output current.

In order to reduce this, this paper presents a high quality-model-predictive control for the newest version of grid connected photovoltaic inverters, HERIC inverter, with LCL filter, where the THD of the injected current is improved. In the proposed control, the number of switching states has been optimized and increased. After determining the best switching mode by a cost function, switching will be done by a switching table. Simulation results show that the proposed controller present a lower THD at the injected current than the traditional MPC, and at the same time is very fast, robust, and accurate too.

2. System Description

Fig. 1 shows the block diagram of the proposed scheme including a DC link supplied by the PV panels and a HERIC inverter connected to the grid through an LCL filter. And also, an upstream control block that determines the power references to be injected to the grid. Finally, this power references are controlled and injected to the grid by the proposed HQMPC blocks.

3. Proposed HQMPC

3.1. Principle of MPC

Model-predictive control design and implement consist of the following three steps:

- Using a model to predict the behavior of control variables for the next time step.
- Determining a cost function including the control objectives and expected behavior of the system.
- Extract the appropriate command to minimize the cost function value.

The discrete model to predict the next step can be shown in the following equations [28].

$$\begin{aligned} x(k+1) &= Ax(k) + Bu(k) \\ y(k) &= Cx(k) + Du(k) \end{aligned} \tag{1}$$

The vector of $x[k]$ is the current values of state space variables, $x[k+1]$ is the next values of state space variables, $u[k]$ is the current values of the input variables, and $y[k]$ is the current values of the output variables. In the next step, the cost function can been written as

$$J = f(x(k), u(k), \ldots, u(k+N)) \tag{2}$$

3.2. Control objectives definition

In the proposed approach, the controller is a current controller based on a cost function as

$$g = |i_g{}^* - i_g| \tag{3}$$