Electric Power Systems Research 154 (2018) 287–298

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Control of PV grid connected systems using MPC technique and different inverter configuration models

Badis Lekouaghet[a,*], Abdelkrim Boukabou[a], Nabil Lourci[b], Kamel Bedrine[b]

[a] Department of Electronics, University of MSB Jijel, BP 98 Ouled Aissa, Jijel 18000, Algeria
[b] Department of Electrotechnics, University of MSB Jijel, BP 98 Ouled Aissa, Jijel 18000, Algeria

ARTICLE INFO

Article history:
Received 11 April 2017
Received in revised form 19 July 2017
Accepted 21 August 2017

Keywords:
PV generator
Grid connected system
Power inverter model
MPC
Total harmonic distortion

ABSTRACT

This paper addresses the control problem of a PV power generating chain such that the maximum power is provided to the grid connected system without the need of any additional module stages. For this purpose, the proposed control system is directly applied to the power inverter using power-MOS switches, for which, a prediction-based model selects the switch state while minimizing the error between actual and predicted power outputs. Obtained predictions are evaluated using a cost function. Attention is paid in this paper to the validation of the proposed control method using one and two steps future predictions. Finally, simulation results are provided to demonstrate the effectiveness of the proposed control methodology.

1. Introduction

Recently, photovoltaic (PV) technology has become one of the most promising alternative solution to produce electrical energy due to the broad viability of solar irradiances. In fact, PV technology offers many advantages: clean, renewable, ease of implementation and subject to weak external noise since there are no moving parts. However, this technology is characterized by low electrical energy generation, limiting its application to low power systems such as LED lighting, watches, calculators, and some standalone electrical systems. For its application at medium and high power levels, PV energy source must be connected to the grid system, generally using industrial electronic inverters. As a consequence, the resulting hybrid PV grid connected system can be applied to a wide range of electrical systems. In this context, PV systems are requested to deliver a maximum energy to be fully operational. Therefore, a control block must be introduced to guarantee that the maximum power is produced at the output of the PV energy source. A controller which satisfies this PV operational mode is known as maximum power point tracking (MPPT) controller.

In the last two decades, extensive research studies have been devoted to the development of MPPT controllers. In particular, MPPT in PV grid connected systems has been established using different kinds of controllers, such as adaptive control [1,2], robust control [3], model predictive control (MPC) [4,5], state feedback control [6], input–output feedback linearization [7], particle swarm optimization algorithm [8,9], and intelligent controllers [10–13]. Among the aforementioned methods and techniques, MPC has demonstrated its good performance in tracking the maximum power point since it offers a perfect control and monitoring of the system. However, in a real-time implementation, the time needed to calculate the control signal could take a significant portion of the sample period, leading to one sampling time-delay between the input and its actuation. An easy resolution to compensate this delay is to take into consideration the calculation time and apply the chosen switching state after the following sampling instant [14]. This problem is not associated with the control law used for the reason that each predictive controller implemented on a real-time platform needs such a time-delay compensation or the respect of this delay in the model [15]. Therefore, the MPC technique can be implemented in specialized microprocessor platform such as DSP or FPGA without requiring any addition blocks. Basically, MPC utilizes the system model to predict its corresponding behavior for a predefined horizon in the future using a cost function. This latter represents the most important part when designing an MPC since it allows selection of the control objectives, thus obtaining better performances for the PV grid connected system in terms of operating efficiency, improved power quality, remote operations control and environmental efficiency. In particular, +++Kakosimos and Kladas [4] developed an MPC technique which provides the capacity of predicting system behavior by considering a two-step future prediction in order to avoid undesirable oscillations around

* Corresponding author.
E-mail address: badis.lekouaghet@univ-jijel.dz (B. Lekouaghet).

http://dx.doi.org/10.1016/j.epsr.2017.08.027
0378-7796/

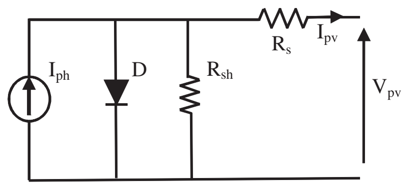

Fig. 1. Structure of an individual PV cell.

MPP and provide more robustness to the system behavior. Advantages of this MPC technique have been proven using real solar irradiance data into the simulation model. However, it is well-known in industry that conventional voltage source inverters (VSI) have limitations in the sense that, for some applications like PV grid connected systems where the input voltage fluctuates over a wide range of voltage boost operation, it may be difficult to stabilize the output voltage at a desired value. On the other hand, multi-level inverters have gained much attention in industry for several attractive features, such as near-sinusoidal staircase output voltage waveforms, reduced dv/dt stress, operating with a lower switching frequency stress, etc. [16–18]. In particular, the two-level voltage source inverter (2L-VSI) is considered as one of the most effective inverter topology found in industry since it features a generic structure and operating principle that can be easily extended to other inverter topologies [14]. In this context, Barra and Rahem [5] developed an MPC technique for a PV grid connected system on the basis of finite states space model of the converter. The proposed strategy has been applied to 2L-VSI and 3L-VSI topologies using one-step future prediction. Obtained results demonstrated the effectiveness of the proposed strategy, however, simulations show relatively persistent oscillations around stabilized reached maximum power points.

On the basis of the cited above works, we address in this paper the MPPT in a PV grid connected system using MPC with different prediction steps, by considering both 2L-VSI and 3L-VSI topologies. Since such study requires a complete modeling of the PV grid connected system in an electromagnetic transient software environment, Matlab/Simulink 8.1 was chosen using a 3.3 GHz intel Core i3 computer with 4 GB of RAM memory. The proposed controller is developed using the MPC technique combined with the modified incremental conductance (Inc Cond) algorithm [6] such that, a predictive model selects the switches states in order to minimize errors of active and reactive power predictions. Then, obtained predictions are evaluated according to predefined cost functions according to the type of horizon prediction. In this way, the proposed controller is used to extract the optimal PV power, a current and a dc link voltage regulator are used to transfer the PV power and to synchronize the output inverter with the grid. The main contribution of this paper is to apply the MPC principle in order to eliminate the current sensor required for some well-known techniques such as the perturb and observe (P&O) technique. Moreover, the proposed control method leads to a faster response and lower power ripple in steady state regim under rapidly changing atmospheric conditions for both one and two-step ahead prediction cases. The performance of the proposed method is evaluated on the basis of data provided from a real PV module for varying atmospheric conditions, that assesses the efficiency of this method under dynamic environmental conditions. Note that the problem of time consumption is not related to the applied model predictive control law used because every predictive controller implemented on a real-time platform requires time-delay compensation or the consideration of this delay in the model. Thus, the PI controller is added to compensate this delay, taking into consideration the calculation time and applying the chosen switching state after the following sampling instant. In this context, the paper investigates first the different structures of the PV gird connected system, i.e., the 2L-VSI and 3L-VSI. It also investigates the effect of solar irradiance and PV cell's temperature on the performance of the different components in the system using both inverter models. MPC technique is developed on the basis of finite states space model of the inverter models. Finally, total harmonic distortion (THD) analysis on the inverter output current at MPP will be applied and the obtained THD values are provided to demonstrate that high energy efficiencies can be achieved using both inverters topologies even for low-power sources. A comparison between the proposed method and some other existing techniques is also provided to demonstrate the superiority of the proposed controller to avoid undesirable oscillations around MPP and provide more robustness to the system behavior.

The rest of this paper is organized as follows: Section 2 describes the simulated PV array model. Section 3 presents the MPPT algorithm using the modified incremental conductance method. Section 4 presents the proposed MPC method when applied to the PV grid connected system characterized by a 2L-VSI and simulation results are given herein. Section 5 presents the proposed control method using a 3L-VSI, and obtained results are also given in this section. Performance analysis of the proposed control method in terms of the THD is addressed in Section 6. Finally, Section 7 gives some concluding remakes.

2. PV array model

A PV array is characterized by a set of PV cells connected in a series/parallel combination to produce a desired output power. Basically, a PV cell, as shown in Fig. 1, transforms the solar irradiance into electrical energy.

According to Fig. 1, each individual PV cell is composed of a light generated current source I_{ph}, a parallel ideal diode fully defined by the reverse saturation current I_s, a series resistant R_s, and a shunt resistance R_{sh}. The I–V characteristic is determined from Kirchoff's law as follows

$$i = I_{ph} - I_s \left[\exp\left(\frac{v + iR_s}{AV_t} \right) - 1 \right] - \frac{v + iR_s}{R_{sh}}, \tag{1}$$

where i and v are the output current and voltage, respectively, A is the diode quality factor, $V_t = KT/q$ is the thermal voltage in which T is the cell temperature, K is the Boltzman's constant, and q is the electron charge. The currents I_{ph} and I_s are given by [19]:

$$I_{ph} = S \left[I_{sc} + K_i \left(T - T_{ref} \right) \right], \tag{2}$$

$$I_s = I_{rs} \left(\frac{T}{T_{ref}} \right)^3 \exp\left[\frac{qE_g}{KA} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \right], \tag{3}$$

where I_{sc} and I_{rs} represent the short circuit current at standard test conditions (STC) and the reverse saturation current at reference temperature T_{ref}, respectively. The symbols S, K_i and E_g are the solar irradiance (W/m^2), coefficient of the short circuit current temperature, and the band-gap of the cells p–n junction, respectively. In this paper, we have considered the PV array using 30 modules MSX60-60W for which, the model input parameters listed in Table 1 are estimated from data used in Lalili et al. [6] in STC (1 kW/m^2 and 25 °C). Note that, by using the default values given in Table 1 the final output of the single module is 60 W and 1.8 kW for the total of 30 modules in series such that each modules includes 36 PV cells in series. Note also that increasing the input solar irradiance value would increase the short circuit current of the PV while increasing the input PV cell's temperature value would decrease the open circuit voltage of the PV.

Fig. 2 shows the I–V and the P–V curves of the considered PV array at different irradiance and temperature levels. Obviously, both solar irradiance and temperature have crucial influence on