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Predictive direct power control for photovoltaic grid connected system: An approach based on multilevel converters

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ABSTRACT

The paper presents an improved predictive power control for a photovoltaic conversion chain connected to a grid based on finite states space model of the converter. The proposed control algorithm selects the switching state of the inverter that minimizes the error between active and reactive power predictions to their computed values for all different voltage vectors. The optimal voltage vector that minimizes a cost function is then applied to the output of the power converter. Once the proposed predictive strategy is validated, a multilevel converter is then used to improve and highlight the obtained results. The proposed predictive control strategy uses only one sample time prediction and it is very intuitive since it is very simple and provides best performances compared to other modulation techniques.

1. Introduction

Photovoltaic (PV) energy offers an environmentally friends source of electricity and considered as the most promising source of energy which the fuel is sunshine, renewable, without pollution, abundant and broadly available. The PV energy applications can be divided into two categories, namely: (1) stand alone systems (water pumping, domestic and street lighting, electric vehicles, military and space applications) requiring storage batteries suitable for low power systems. (2) Grid connected systems (hybrid systems, power plants) which does not requiring storage batteries and used for medium and high power applications [1-9].

Grid connected PV system consists of a series/parallel connection array of PV panels connected to a power conditioning system stage which is responsible for the proper transfer of the energy produced by PV array to the grid generally via a DC/DC converter that used as a MPPT controller and an inverter that converts the DC voltage to a single or three-phase AC voltage and at last a AC filter that absorbs voltage/current harmonics due to switching functions [10-14].

Due to nonlinear *I–V* characteristics of photovoltaic cells, a maximum power point tracking algorithm MPPT is adopted to extract maximum output power to the environmental changes such as solar insulation, temperature and load variations. Among the two last decades, several algorithms have been developed and addressed in many literatures in order to achieve maximum power point tracker, these techniques vary between them in many aspects, including simplicity, convergence speed, hardware implementation, sensors required, cost, range of effectiveness and need for parameterization. The most classical methods commonly used are Perturb and Observe (P&O), Incremental Conductance (IncCond), Hill Climbing (HC) and Open/Short circuit methods [2–4]. Note that the MPPT methods based artificial intelligence (MPPT based fuzzy logic and neural network), robust MPPT using sliding mode controller are not cited here.

Model Predictive Control (MPC) is a very powerful control strategy that uses the model of the system to precalculate the behavior of the system for a predefined horizon in the future. A cost function evaluates the precalculated results and determines the optimal future control actions. Generalized Predictive Control (GPC) is the most popular method of MPC family methods since it can be applied to a great variety of systems where dead times can be easily compensated, the concept is very intuitive and easy to understand, the multivariable case can be easily considered, easy inclusion of non-linearities in the model. The main disadvantages of the GPC control is the large amount of calculations, compared to classic controllers and the direct influence of the model on the quality of the resulting controller.

Recently, Finite States Model Predictive Control (FS-MPC) appears as an attractive alternative and offers a completely different and powerful approach to control power converters due to its fast dynamic response, no need for linear controllers, no need for modulator (PWM or SVM), completely different approach compared to PWM, extremely simple, very good performance and can be implemented with standard commercial microprocessors. The method is based on the fact that a finite number of possible switching states can be generated by power converter (7 states for a two levels three-phase inverter, 27 states for a three levels, 64 states for a four

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levels,...) and that the model of the system can be used to predict the behaviour of the variables for each switching state. For the selection of the appropriate switching state to be applied to the system a quality function must be defined. The cost function is then evaluated for the predicted values on each sampling interval and the optimal switching state that minimizes the quality function is selected to apply during the next sampling interval [15–18].

The paper presents a simple method to control a photovoltaic conversion chain connected to a three phase AC grid. The method uses at first a predictive control associated with a two-level three phase voltage source inverter to validate the control strategy, then a three-level inverter is used to improve and highlight the results. The paper is organized as follows. Section 2 is dedicated to the modelling framework of the considered PV array. Section 3 presents the modified Incremental Conductance MPPT algorithm. Section 4 models a two level voltage source inverter before its inclusion in the predictive power control well explained in Section 5, while the results are presented and commented in Section 6 followed by the predictive power control associated to a three-level converter in Section 7 and finally a conclusion is given in the last Section 8.

2. PV modeling

The mathematical model of a solar cell composed of a light generated current source, diode, series and parallel resistance is given for the output current, photocurrent and PV saturation current by [9]:

$$I_{PV} = I_{ph} - I_d\left[\exp\left(\frac{q}{K_b TA} V_{PV}\right) - 1\right] \tag{1}$$

$$I_{ph} = S(I_{scr} + k_i(T - T_r)) \tag{2}$$

$$I_d = I_{rr}\left(\frac{T}{T_r}\right)^3 \exp\left(\frac{qE_g}{kQA}\left[\frac{1}{T_r} - \frac{1}{T}\right]\right) \tag{3}$$

where I_{PV}, V_{PV} is the output current and voltage (A, V), T is cell temperature (K), S is solar irradiance (W/m^2), I_{ph} is light generated current, I_d is PV saturation current, I_{rr} is saturation current at T_r, I_{scr} short circuit current at reference condition, T_r is reference temperature, q is charge of an electron, k_b is the Boltzmann's constant.

The PV panel considered here is a typical MSX60-60W PV module. Figures from Figs. 1–4 illustrate a 3D plot of the *I–V* and *P–V* characteristics for different insulation and temperature levels. On these curves, one can see that the characteristics are nonlinear and are crucially influenced by solar radiations and temperature variations.

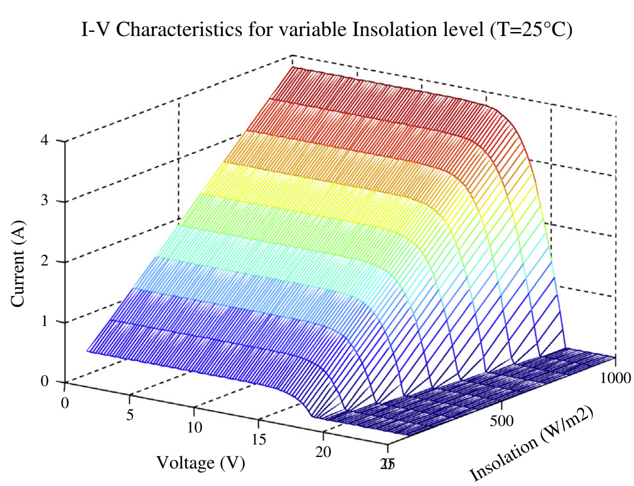

Fig. 1. 3D plot of *I–V* characteristics for different irradiance levels.

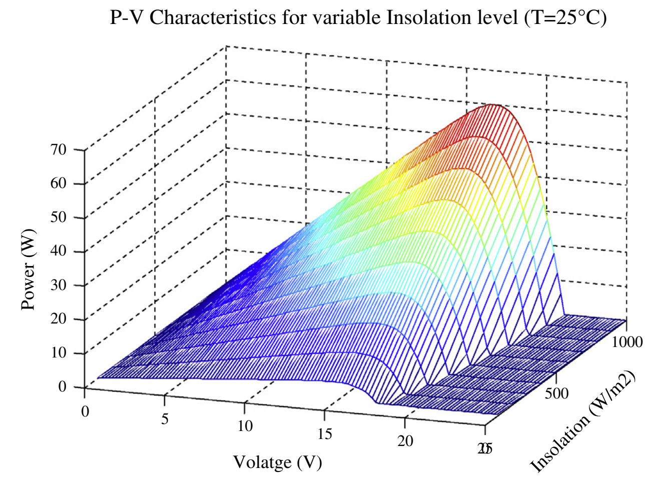

Fig. 2. 3D plot of *P–V* characteristics for different irradiance levels.

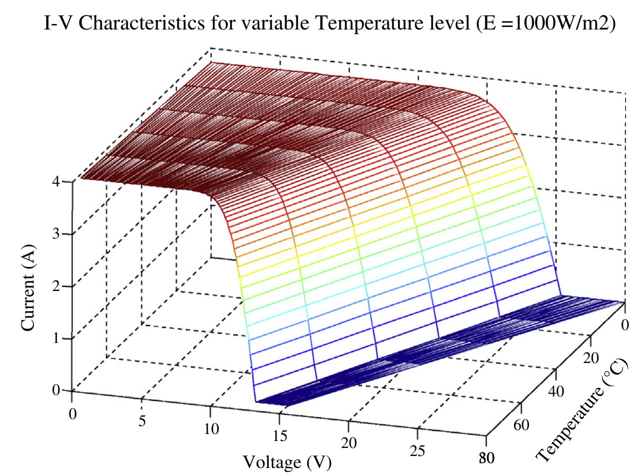

Fig. 3. 3D plot of *I–V* characteristics with temperature effect.

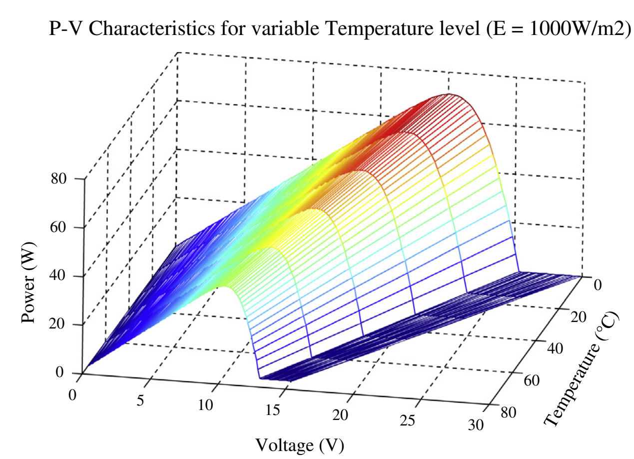

Fig. 4. 3D plot of *P–V* characteristics with temperature effect.

3. MPPT algorithm

Consider a photovoltaic grid conversion chain composed of a PV array, a two-level three phase voltage source inverter VSI, a R-L filter and a three phase symmetric electric grid as illustrated by Fig. 5.