Renewable Energy 85 (2016) 181–194

Contents lists available at ScienceDirect

Renewable Energy

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

Improved particle swarm optimization for photovoltaic system connected to the grid with low voltage ride through capability

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ARTICLE INFO

Article history:
Received 1 March 2015
Received in revised form
7 June 2015
Accepted 13 June 2015
Available online xxx

Keywords:
Particle swarm optimization
Maximum power point tracking
PV system
High frequency isolated converter
Low voltage ride through
Grid

ABSTRACT

Grid connected photovoltaic (PV) system encounters different types of abnormalities during grid faults; the grid side inverter is subjected to three serious problems which are excessive DC link voltage, high AC currents and loss of grid-voltage synchronization. This high DC link voltage may damage the inverter. Also, the voltage sags will force the PV system to be disconnected from the grid according to grid code. This paper presents a novel control strategy of the two-stage three-phase PV system to improve the Low-Voltage Ride-Through (**LVRT**) capability according to the grid connection requirement. The non-linear control technique using Improved Particle Swarm Optimization (**IPSO**) of a PV system connected to the grid through an isolated high frequency DC–DC full bridge converter and a three-phase three level neutral point clamped DC-AC converter (**3LNPC^2**) with output power control under severe faults of grid voltage. The paper, also discusses the transient behavior and the performance limit for LVRT by using a DC-Chopper circuit. The model has been implemented in MATLAB/SIMULINK. The proposed control succeeded to track MPP, achieved LVRT requirements and improving the quality of DC link voltage. The paper shows superiority of IPSO than Incremental Conductance (IC) method during MPPT mode of PV system.

1. Introduction

PV power generation systems connected to the grid, have been spread in many countries because of its potential long-term benefits. To optimize the utilization of large arrays of PV modules, maximum power point tracker (MPPT) is normally employed in conjunction with the power converter (DC–DC converter and/or inverter). Due to the varying environmental condition, as temperature and solar insolation, the P–V characteristic curve exhibits a maximum power point (MPP) that varies nonlinearly with these conditions, thus posing a challenge for the tracking algorithm.

To date, various MPP tracking methods have been proposed [1–2]. Most commonly used techniques of MPPT are Perturb and Observation (P&O), Incremental Conductance, Hill-climbing method; Constant Voltage and Current, Parasitic Capacitance along with some DSP based methods. Each of the above techniques is accompanied with problems.

Also, the modified algorithms based on the earlier mentioned ones were able to improve some of the drawbacks, but not the efficiency such as the modified P&O technique that improved the convergence problem at the rapidly changing weather but couldn't increase the efficiency. Similarly, Artificial intelligence algorithms are used to improve MPPT and it began to increase the efficiency of the solar panels while presenting other trade-offs and disadvantages [3]. Many researchers used PSO techniques for MPPT of standalone or grid connected photovoltaic arrays [4–8].

High penetration level of PV systems may also introduce negative impacts on the grid; power quality issues, frequency stability, voltage stability, the efficiency and the emerging reliability. Thus, many grid codes have been released to regulate PV system integration with the distribution grid. The regulation should contain requirements concerning the active and reactive power control and the behavior of the generation unit during grid disturbances.

Low voltage ride through capabilities is now being a general requirement of PV systems connected to the Grid in many countries and many researchers are working on different types of PV systems. Single phase PV system with different transformer less inverters are discussed in Refs. [9], single phase two stage PV system in Refs. [10],

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http://dx.doi.org/10.1016/j.renene.2015.06.029

[11]. Single phase single stage PV system in Ref. [12]. Single stage three phase PV system is introduced in Ref. [13].

This paper presents an improved particle swarm optimization for MPPT depends on modulation index swarm, in other hand, all researchers used PSO technique in generating duty cycle for the DC–DC converters. Two diode model PV array with real characteristics connected to the grid through an isolated high frequency DC–DC full bridge converter and a three-phase **3LNPC**^{2} with output power control. Also; the paper presents a two stage three phase PV system which is more complex in control and analysis than others but provides more accurate results. In addition, an IPSO for MMPT, HF transformer and LVRT capabilities through control of excessive DC link voltage and high AC currents are used when the grid presents a voltage sag fault. The control strategies were developed to support PV system ride through during the grid faults.

This paper is organized as follows: Section 2 discusses the modeling of the PV array based on two diode model and the required power electronics for interfacing to the grid. This would be the basis for the simulation work that ensues. Section 3 describes the overview of the PSO and how it is applied to track the MPP. In addition, the modified PSO algorithm used to improve the tracking performance is also outlined in this section. Section 4 describes the overview of the overall simulation for the proposed system under different scenarios such as (i) normal operation condition (MPP mode), (ii) grid fault condition (grid-fault mode) and (iii) fault with LVRT capability using DC chopper and anti-wind up technique (LVRT mode). Finally, the conclusion is made in the last section.

2. PV system connected to the grid

Fig. 1 shows the blocks that constitute the system under study in this paper. The PV array based on two diode model feeds the DC–DC full bridge converter, which in turns feeds the three phase DC/AC inverter that connected to the Grid.

2.1. Two diode PV module characteristics

Among various modeling methods of the PV module, there is the two-diode model as shown in Fig. 2. It is known to be more accurate one; where the recombination loss in the depletion layer is considered and leads to a more precise model [14–15].

The output current of the cell is given by

$$I = I_{PV} - I_{D1} - I_{D2} - \left(\frac{V + IR_S}{R_p}\right) \tag{1}$$

I_{PV} is the current generated by the incident light, I_{D1} is the Shockley diode equation due to diffusion, I_{D2} is the Shockley diode equation due to charge recombination mechanisms.

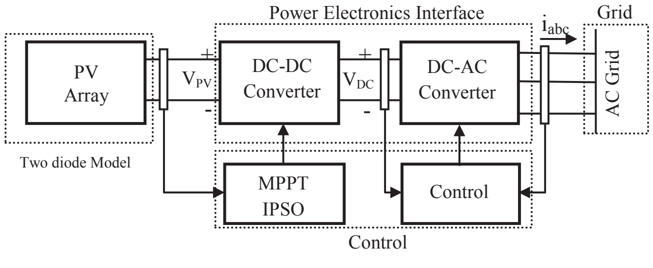

Fig. 1. Block diagram of the PV system connected to the grid.

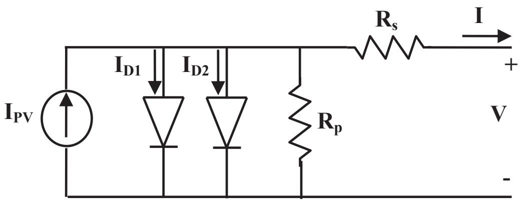

Fig. 2. Two diode model of PV module.

$$I_{D1} = I_{o1}\left[\exp\left(\frac{V + IR_S}{a_1 V_{T1}}\right) - 1\right] \tag{2}$$

$$I_{D2} = I_{o2}\left[\exp\left(\frac{V + IR_S}{a_2 V_{T2}}\right) - 1\right] \tag{3}$$

where I_{o1} and I_{o2} are the reverse saturation currents of diode 1 and diode 2, $V_{T1}=a_1 \times \mathrm{NskT}/q$ and $V_{T2}=a_1 \times \mathrm{NskT}/q$ are the thermal voltages having Ns cells connected in series, a_1 and a_2 represent the diode ideality constants, q is the electron charge (1.60217646×10^{-19} C), k is the Boltzmann constant (1.3806503×10^{-23} J/K), and T is the temperature of the p-n junction in °K.

An improved equation to describe the saturation current which considers the temperature variation is given by:

$$I_o = \frac{I_{SC\_STC} + K_i \Delta T}{\left[exp\left(\frac{V_{OC_{STC}} + K_V \Delta T}{aV_T}\right) - 1\right]} \tag{4}$$

The constant K_V is the open circuit voltage coefficient. Where I_{SC_STC} (in Ampere) is the short circuit current at Standard Test Conditions (STC), $\Delta T = T - T_{STC}$ (in Kelvin, $T_{STC}=25°C$), V_{OCSTC} (in volt) is the open circuit voltage at STC. The constant K_i is the short-circuit current coefficient, normally provided by the manufacturer. This value is available from the datasheet. To further simplify the model, in this work, both of the reverse saturation currents, I_{o1} and I_{o2} are set to be equal in magnitude as follows:

$$I_{o1} = I_{o2} = \frac{I_{SC\_STC} + K_i \Delta T}{\left[exp\left(\frac{V_{OC_{STC}} + K_V \Delta T}{\{(a_1 + a_2)/p\} V_T}\right) - 1\right]} \tag{5}$$

Since $(a_1+a_2)/p = 1$ and $a_1 = 1$, it follows that variable p can be chosen to be ≥ 2.2, [15]. The following expression for I_{o1}, I_{o2} results:

$$I_{o1} = I_{o2} = \frac{I_{SC\_STC} + K_i \Delta T}{\left[exp\left(\frac{V_{OC_{STC}} + K_V \Delta T}{V_T}\right) - 1\right]} \tag{6}$$

Fig. 3 depicts the different characteristics of PV module at different insolation levels(0.2 kw/m^2–1 kw/m^2) and constant temperature. The PV module maximum power reaches 305.2 W at voltage 54.7 V during insolation 1 kw/m^2.

2.1.1. Modeling of the PV array

In a typical installation of a PV power generation system, the modules are configured in a series–parallel combination as shown in Fig. 4.

The output current of the array will be modified to

$$I = N_{pp}\{I_{PV} - I_o(I_p - 2)\} - \left(\frac{V + IR_S n}{R_p n}\right) \tag{7}$$