Sustainable Energy, Grids and Networks 5 (2016) 50–57

Contents lists available at ScienceDirect

Sustainable Energy, Grids and Networks

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

Analysis of sensorless MPPT method for hybrid PV–Wind system using DFIG Wind Turbines

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ARTICLE INFO

Article history:
Received 27 March 2015
Received in revised form
5 August 2015
Accepted 3 November 2015
Available online 12 November 2015

Keywords:
Doubly-Fed Induction Generator
Photovoltaic
Sensorless MPPT
PV–Wind system

ABSTRACT

In this paper, a sensorless Maximum Power Point Tracking (MPPT) method for a hybrid Photovoltaic–Wind system, which consists of Photovoltaic (PV) system and Doubly-Fed Induction Generator (DFIG) Wind Turbine (WT), is proposed. In the hybrid system, the DC/DC converter output of the PV system is directly connected to the DC-link of DFIG's back-to-back converter. Therefore, the PV inverter and its associated circuit can be removed in this structure. Typically, the PV power is monitored by using PV current sensor and PV voltage sensor for MPPT. In this research, the powers of converters on grid side and rotor side of DFIG are used to estimate the PV power without the PV current sensor. In the other words, the available sensors of DFIG are applied to track the maximum power of the PV system without the measured value of the PV power. That can efficiently reduce the cost of system compared to two separate systems with traditional MPPT method. Simulation studies are conducted to investigate the performance of the proposed method. The sensorless MPPT hybrid system can work very well under changes of operational conditions, such as irradiation and input power. As illustrated in the simulation results, the proposed system can handle powers in various direction harmoniously. The DC-link is also maintained stable during these variations. Overall, the proposed method can be utilized to harness the maximum power of PV system without the PV power information.

1. Introduction

With rising concerns about shortage of conventional energy sources such as oil, coal or natural gas, renewable energy sources become more attractive and sustainable alternative for future. Wind and photovoltaic (PV) powers have recently been two most promising sources. During the past several decades, the world has witnessed the novel developments of power electronics and semi-conductor technology. Those play an important role to reduce the cost of PV and make the energy conversion of PV more efficient than ever before. The improvements of power electronics also boost the wind industry to become more practical. In addition, nowadays Doubly-Fed Induction Generator (DFIG) wind turbines (WTs) are most popularly used in variable-speed wind power system due to advantages of variable speed operation and bidirectional power control [1–4].

A traditional structure of DFIG WTs is shown in Fig. 1. A back-to-back converter including a Rotor Side Converter (RSC) and a Grid Side Converter (GSC) is employed in this structure. Fig. 2 illustrates a typical grid-tied configuration of PV system. In this configuration, a DC/DC converter is used maximum power point tracking (MPPT) method of PV system. Moreover, an inverter is employed to convert the DC power into the AC power. To combine these configurations, the inverter of PV system is eliminated and the DC/DC converter output is directly connected to the DC-link of back-to-back converter in the hybrid system, as demonstrated in Fig. 3.

The combination of DFIG and PV systems is introduced and analyzed in the literature [5–10]. In [5], energy management method of PV–DFIG system is presented. This system also includes the battery storage for energy back-up. Efficient control methods are proposed for this hybrid system as well. For example, Khemiri et al. introduce the backstepping control strategy for DFIG in the hybrid system [6]. In [7], Zarei et al. present the predictive DPC method for DFIG and an analytical method for MPPT of PV. Using the GSC of the hybrid system as an active power filter for harmonic compensation is reported in [8]. A multilevel neutral point clamped inverter is proposed for this hybrid system [9]. Moreover, the integration of hydropower plant into the hybrid PV–DFIG system is presented in [10].

The basic advantage of the hybrid PV–DFIG system is to reduce the cost of the traditional systems. A low-cost system is very

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http://dx.doi.org/10.1016/j.segan.2015.11.001
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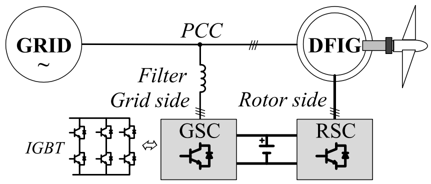

Fig. 1. Typical structure of DFIG WTs.

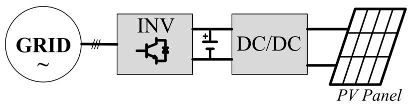

Fig. 2. Typical structure of grid-tied PV system.

competitive in the market of renewable energy, especially in rural area. Therefore, to go further for cost decrease, a sensorless maximum power point tracking (MPPT) method is proposed for the PV source of the hybrid system. The main idea of this approach is using output powers to estimate the input power. In operation, the powers from GSC and RSC can be applied to estimate the PV power due to balance of DC-link in the hybrid system. A detailed estimation algorithm is presented in next sections. In our previous research [11], this sensorless MPPT approach is introduced and successfully applied for a stand-alone PV system. Employing this approach for the combined system can decrease the cost compared to the hybrid system with a traditional MPPT method. Using a less number of required power converters and a less number of required sensors makes the cost of the hybrid system much cheaper.

The entire system is implemented and analyzed by using Matlab/Simulink. As shown in simulation results, the sensorless MPPT hybrid system can perform very well under changes of environmental conditions and control scenarios. Three converters can operate seamlessly and cooperatively when the operation mode of DFIG varies both in a subsynchronous mode and a supersynchronous mode. Furthermore, the back-to-back converter can handle the DC-power from the PV system and keep the DC-link stable without the inverter. Hence, the PV system can robustly generate the maximum power without the information of the PV power regardless of irradiation variations. Finally, it is concluded that the sensorless combined system can be an efficient and stable alternative for separate configurations of PV and DFIG.

2. Studied model

The proposed system studied in this research is illustrated in Fig. 3. In this structure, the DC output of DC/DC converter is directly connected to the DC-link of the back-to-back converter. Therefore, the inverter of PV system is eliminated. That can reduce the cost of the entire system. In this research, the DC/DC converter is Buck–Boost (BB) converter, which has very stable operation and fast-response. The BB converter can maintain the maximum power generation from PV system. This maximum power is supplied to the DC-link voltage. Then the RSC and GSC can convert that DC power into AC power which is fed to the rotor or the grid. The coordination of these converters to handle the power flow is investigated and explained in details in simulation study.

As mentioned above, the combined system can work without the inverter of PV system. Hence it is cost-effective compared to two separate configurations, as shown in Figs. 1 and 2. Also, all associated circuits of the inverter, such as heat-sink and protection circuits, are removed. That can decrease the cost of maintenance services. Moreover, a sensorless control method is proposed for the hybrid system. This method can reduce the numbers of sensors of PV system, so the cost of the hybrid system can be decreased more. The sensorless method is presented in next sections in detail. Parameters of the proposed system are shown in Tables 1 and 2.

Table 1
DFIG system parameters.

Rated power	15 kW
Rated stator voltage	460 V
Pair of poles	1
Inductance of filter	1 mH
Rotor speed ω_m	365 rad/s
Stator, rotor resistance (R_s, R_r)	0.02 pu
Stator, rotor leakage inductance (L_{ls}, L_{lr})	0.06 pu
Magnetizing inductance L_m	1.5 pu
Inertia	0.04 kqm^2
Rated DC-link voltage	200 V
DC-link capacitor	500 µF
Rated wind speed	9.11 m/s

Table 2
PV system parameters.

Open voltage	100 V
Short-circuit current	25 A
Maximum power	1.8 kW
Number of parallel modules	5
Number of series modules	5

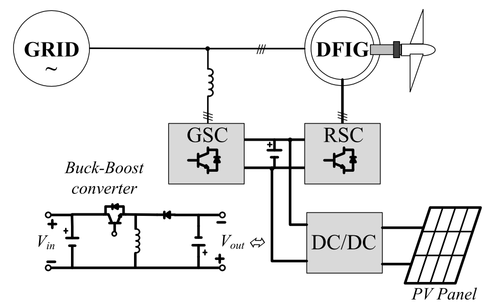

Fig. 3. Studied system.

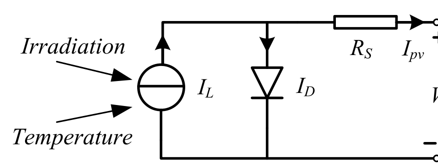

Fig. 4. Equivalent circuit of PV.

3. Modeling of PV and DFIG

Mathematical models of PV and DFIG are presented in this section. These models are very necessary to figure out operations and control methods of PV and DFIG.

3.1. Modeling of PV

An equivalent circuit of a PV module is shown in Fig. 4. This circuit consists of a current source in parallel with a diode. The diode and the output resistor mainly determine the characteristics of the PV module. The mathematical relationship between PV current and voltage can be written as [12]:

$$I_{pv} = I_L - I_D\left[\exp\left(\frac{qV_{pv} + qIR_S}{AKT}\right) - 1\right] \quad (1)$$

where I_{pv} and V_{pv} are PV current and voltage respectively, I_D is the diode saturation current, q is the electron charge, A is the material factor of diode, K is the Boltzmann constant, R_S is the series resistor, and T is the absolute temperature.

Environmental conditions, such as temperature and irradiation, strongly affect the characteristic of the PV module. Therefore, a maximum power point tracking method is required to remain the