A new control scheme of back-to-back converter for wind energy technology

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3 authors:

Mahran Quraan
Birzeit University

Qassam A. Farhat
Birzeit University

Mohamad Bornat
Birzeit University

A New Control Scheme of Back-to-Back Converter for Wind Energy Technology

M. Quraan
Dept. of Electrical and Computer Engineering
Birzeit University
Ramallah, Palestine
mquraan@birzeit.edu

Q. Farhat
Dept. of Electrical and Computer Engineering
Birzeit University
Ramallah, Palestine
q.1995barg@gmail.com

M. Bornat
Dept. of Electrical and Computer Engineering
Birzeit University
Ramallah, Palestine
mohbornat@gmail.com

***Abstract*—This paper proposes a new control scheme for a permanent magnet synchronous generator (PMSG) based wind energy conversion system (WECS). In this scheme, the generator and grid currents are controlled using a hysteresis current controller (HCC). The control system of the back-to-back converter based on the HCC is described. Modeling and simulation of the system are developed using Matlab/Simulink to validate the performance of the proposed current controllers.**

Keywords—WECS; PMSG; HCC; back-to-back converter

I. Introduction

With expanding industry and world population explosion, energy demands increase dramatically with negative trends and rapid depletion of traditional energy resources. The increase in greenhouse gases, acid rains, and degradation of public health are attributed to pollution results from huge amounts of fossil fuels being burned everyday all over the world. Solution to this problem can be achieved by harnessing the renewable energy resources such as wind energy by providing highly efficient power converters responsible for energy conversion with minimized costs and easy -to- implement control methods [1-2].

The wind energy conversion system (WECS) has three major elements, the wind turbine, the electrical generator, and the power electronic converter [3]. The most commonly used electrical generators are either the Doubly-Fed Induction Generator (DFIG) or PMSG. In [4-6], the direct driven PMSG is proven to be a good choice for WECS and it is the most employed machine type in literature with a 42% of all other types uses, as it offers many advantages such as the absence of gearbox and field excitation which increases the system efficiency and reduces maintenance as well as having a wide range of speed control. The PMSG is connected to the grid via a back-to-back converter which consists of two PWM voltage source converters, a machine side converter and a grid side converter allowing a bidirectional power flow [7]. In literature, such converter is controlled usually using the traditional decoupled *dq*-control method to independently control the active and reactive powers delivered to the grid [6], [8-12]. This control approach has become very common in the control of such type of converters due to its good performance under different operating conditions. In [8] the authors presented a vector control algorithm for the GSC with a Phase Locked Loop (PLL) for phase compensation between grid and GSC and space vector modulation technique was utilized to generate the gate signals for the back-to-back converters. A Vector–Oriented Control (VOC) strategy was discussed in [13] to control a 3-level Neutral Point Clamped (NPC) GSC and MSC. Furthermore, the authors in [9] and [14] used the symmetrical optimum method to tune the proportional–integral (PI) controllers which were used for their simple implementation and common use in industry. According to authors, this method was utilized since it maximizes the gain margin of the control system and has good rejection for disturbances compared to other methods. However, PI controllers cannot control non linear systems or systems operating with varying parameters. Grid parameters are subject to change; especially under fault condition which severely affects the performance of control system. The change of grid impedance changes the gain and phase margins of the controller. Therefore, the PI controller should be designed considering a function of variable gains [15-17]. On the other hand, the hysteresis current controller gives fast response and good accuracy. It can be easily implemented and operates well without the need of knowing load parameters [18-21].

Other than the mentioned converter topology, there are other topologies discussed in literature such as using controlled and uncontrolled rectifiers at generator side [22-23]. Three controlled rectifiers were employed to connect three PMSGs based wind farm with the DC-bus and then the reactive and active powers were controlled independently using vector control to drive a PWM multi-cellular inverter [22].

This paper presents a back-to-back current controlled converter for PMSG based WECS, the generator side and grid sides' converters are both controlled using hysteresis current controllers (HCC) to interface the PMSG and the grid. Other than the introduction, this paper includes two more sections, in section II the control algorithms of MSC and GSC are developed, the simulation results are presented in section III, and final conclusions are drawn in section IV.

II. Control System

Figure 1 shows the block diagram of WECS. The AC power is delivered to the grid by the PMSG through a power conversion system. The converter consists of two inverters connected in a back-to-back configuration, called machine side converter (MSC) and grid side converter (GSC) [8].

A. MSC Control System

The MSC control system is based on HCC. The MSC controls the amount of the active power generated by the PMSG. The reference active power, P^*, is obtained from the pitch angel controller to apply the principle of tracking the maximum power. The inputs of the MSC control system are: P^* and Q^*, The reference value of Q^* is assumed to be zero in the paper to obtain a unity power factor operation and achieve maximum power delivery to grid as a desired operating condition. The stator reference currents, $i_{abc,m}{}^*$, are given by:

$$i_{abc,m}{}^* = \begin{bmatrix} i_a{}^* \\ i_b{}^* \\ i_c{}^* \end{bmatrix} = I_{p,m}{}^* \begin{bmatrix} \cos(\theta_m - \varphi_m{}^*) \\ \cos(\theta_m - \varphi_m{}^* - 2\pi/3) \\ \cos(\theta_m - \varphi_m{}^* + 2\pi/3) \end{bmatrix}, \quad (1)$$

where $I_{p,m}{}^*$ is the reference peak value of the machine current, $V_{p,m}$ is the peak value of the line-to-neutral machine voltage, $\varphi_m{}^*$ is the reference power factor angle, and θ_m is the angle of the generator voltage which is estimated using a phase locked loop (PLL).

The reference peak current is calculated as:

$$I_{p,m}{}^* = \frac{2}{3} \frac{P^*}{V_{p,m} \cos(\varphi_m{}^*)}, \quad (2)$$

and the reference power angle is given by:

$$\varphi_m{}^* = \tan^{-1}\left(\frac{Q^*}{P^*}\right) \quad (3)$$

The measured stator phase currents of the PMSG, $i_{abc,m}$, are compared with the derived reference stator currents, $i_{abc,m}{}^*$. The error signals are then sent to HCC to generate the gate signals for the MSC. The generator currents are controlled within a hysteresis band around the reference generator currents. The hysteresis band determines deviation in the actual current. The reference and actual currents of phase k where $k = \{a, b, c\}$ are shown in Fig. 2 with the hysteresis band of H. The inverter output voltage of phase k is determined by the following logic:

$$\begin{aligned} i_k \le i_k{}^* - H &\Rightarrow \text{set } v_k = V_{DC}/2 \\ i_k \ge i_k{}^* + H &\Rightarrow \text{set } v_k = -V_{DC}/2 \end{aligned} \quad (4)$$

The implementation of this logic is shown in Fig. 2. The band H is externally set as a function of modulation index, M, by proper programming to make the converter switching frequency, f_{sw}, constant. The switching frequency is given by [9]:

$$f_{sw} = \frac{V_{DC}}{4L_s}\left(\frac{1 - M^2}{H}\right), \quad (5)$$

where L_s is the machine stator inductance. Since V_{DC} is kept constant by the control system of GSC, the switching frequency can be kept constant by varying H linearly with the term, $1–M^2$, according to equation (5).

The modulation index M is defined as [9]:

$$M = \frac{2V_{p,m}}{V_{DC}} \quad (6)$$

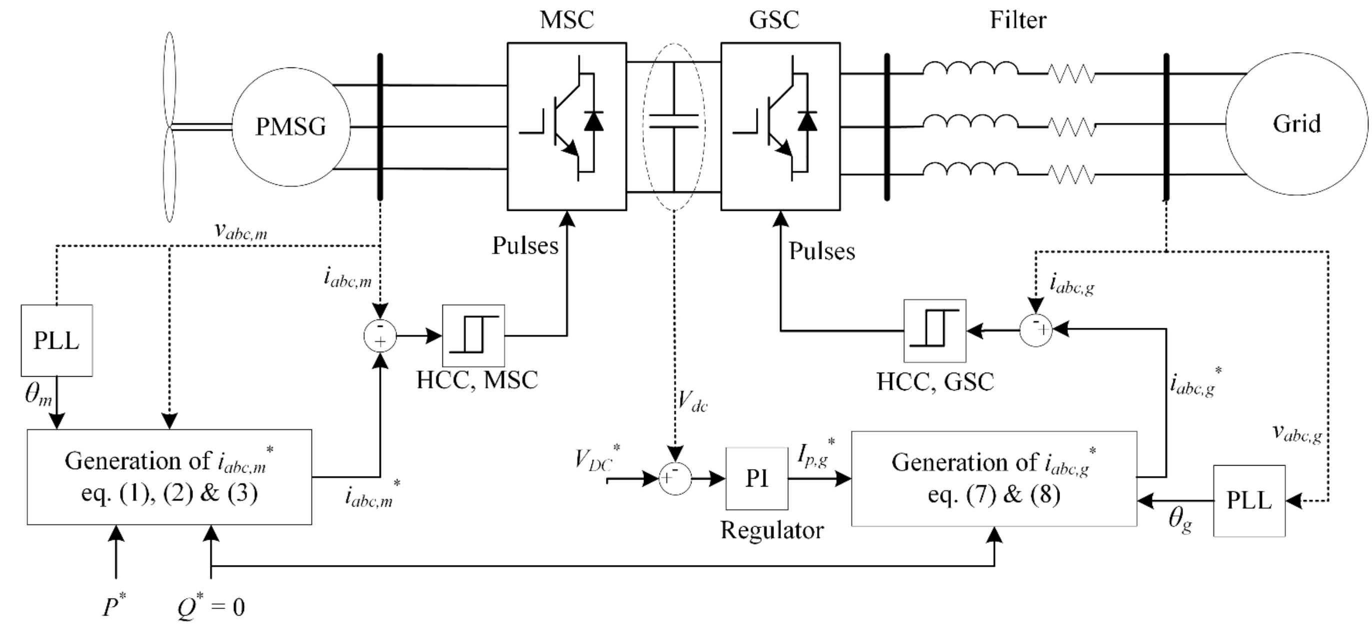

Fig. 1. Configuration of WECS with PMSG and back-to-back converter used in WECS.

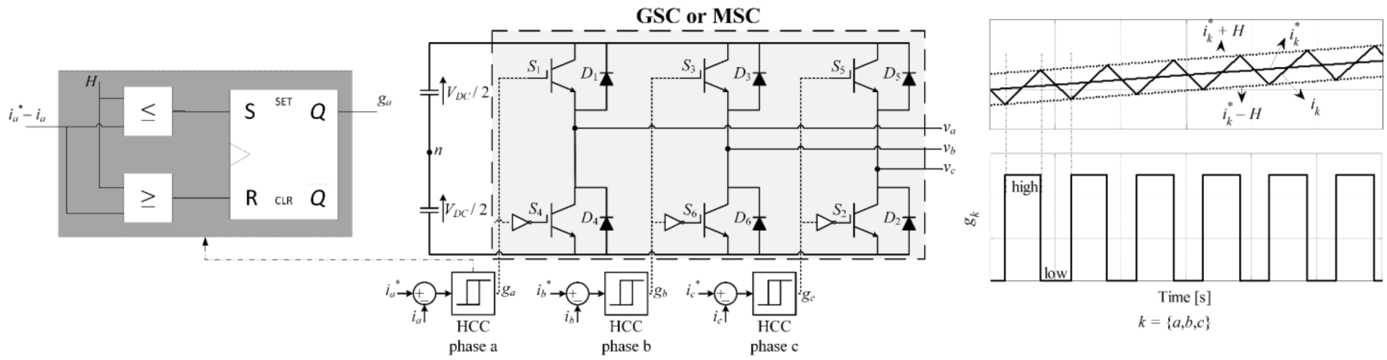

Fig. 2. Operating principle and implementation of HCC scheme

B. GSC Control System

The function of the GSC is to transfer the power into the AC grid and regulates the DC voltage across the DC link of the back-to-back converter under wind speed variations. The GSC control system adjusts the grid active and reactive powers based on HCC. The grid reference currents, $i_{abc,g}^*$, are given as follows:

$$i_{abc,g}^* = \begin{bmatrix} i_{a,g}^* \\ i_{b,g}^* \\ i_{c,g}^* \end{bmatrix} = I_{p,g}^* \begin{bmatrix} \cos(\theta_g - \varphi_g^*) \\ \cos(\theta_g - \varphi_g^* - 2\pi/3) \\ \cos(\theta_g - \varphi_g^* + 2\pi/3) \end{bmatrix}, \qquad (7)$$

where $I_{p,g}^*$ is the reference peak value of the grid current, $V_{p,g}$ is the peak value of the line-to-neutral grid voltage, φ_g^* is the power factor angle. The angle of the grid voltage, θ_g, is obtained from a phase locked loop (PLL).

The power factor angle can be calculated as:

$$\varphi_g^* = \sin^{-1}\left(\frac{2Q^*}{3V_{p,g} I_{p,g}^*}\right), \qquad (8)$$

III. Simulation Results

In order to to validate the operation of the proposed control system of the back-to-back converters by means of numerical simulations obtained from Matlab/ Simulink. The simulation has been carried out based on the data and parameters summarized in Table 1.

TABLE I. SYSTEM PARAMETERS USED FOR SIMULATION

Parameter	Symbol	Value
Active power	P	200 kW
Stator winding resistance	R_s	1 mΩ
Stator winding inductance	L_s	1 mH
DC-link capacitance	C_f	4.7 mF
Grid filter inductance	L_f	1 mH
Proportional gain of PI	K_p	0.5 A/V
Integral gain of PI	K_i	20 A/(V.s)

The PMSG wind turbine system was modeled using a variable frequency and variable voltage three phase source whose frequency range is 5 Hz-45 Hz. The value of P^* is commanded in steps of about 70 kW to reach a maximum value of 200 kW while Q^* is kept at zero. Figure 3 presents the response of the stator and grid currents. The time values of the stator currents are shown to fluctuate according to the wind speed changes assuming that the generator frequency changes from 5 Hz to 45 Hz. The grid frequency is assumed fixed at 50 Hz. The amplitude of machine side currents is decreasing as the frequency of the fluctuating source is increasing in order to maintain a constant active power supplied by PMSG. The simulation results show the good performance and quick response of proposed control system.

In order to verify the response of both controllers, different step changes of the reference active power have been applied, as shown in Fig. 4, while the reference reactive power has been set to zero in order to obtain a (nearly) unity power factor operation. The control system shows a good capability of tracking the reference active power. Figure 4 presents the voltage V_{DC} measured across the DC link of the back-to-back converter system. The voltage is stable at all step changes of active power, which shows a good operation of the proposed control system.

IV. Conclusion

This paper has presented a new control strategy of back-to-back converters used in WECS. The proposed control scheme has accomplished the task of transferring electric power from the generator-side to the grid via a very simple mathematical approach which confirms instantaneous current operation. Results obtained have validated the operation of both controllers and confirmed the stabile operation under changes in active power demands. The presented controller has eliminated the complexity involved in other control schemes and it can be built practically with great reduction in cost and processing amount. This work presents several opportunities for further research and study; the grid-side converter will be replaced by a modular multilevel inverter topology which is expected to add great improvements on power quality, filter size, and power transfer efficiency between the two sides with simple control approach.

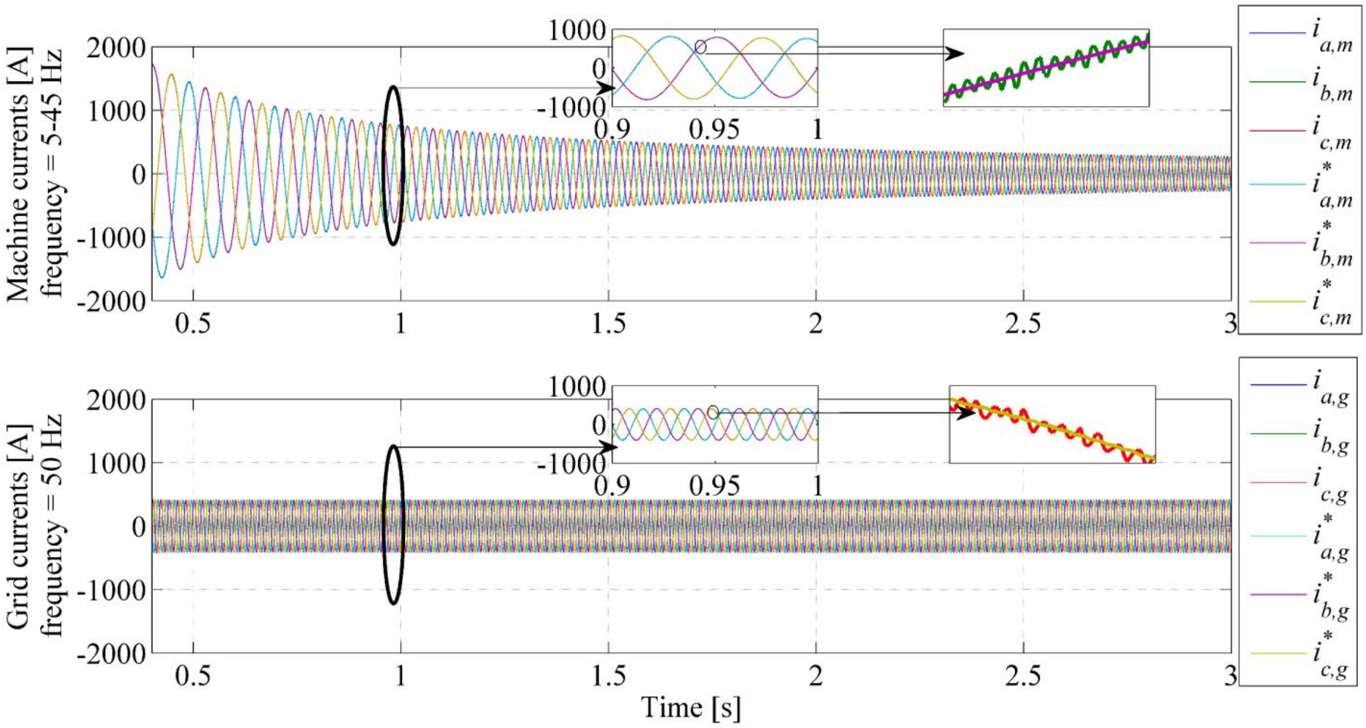

Fig. 3. Waveforms of machine and grid currents.

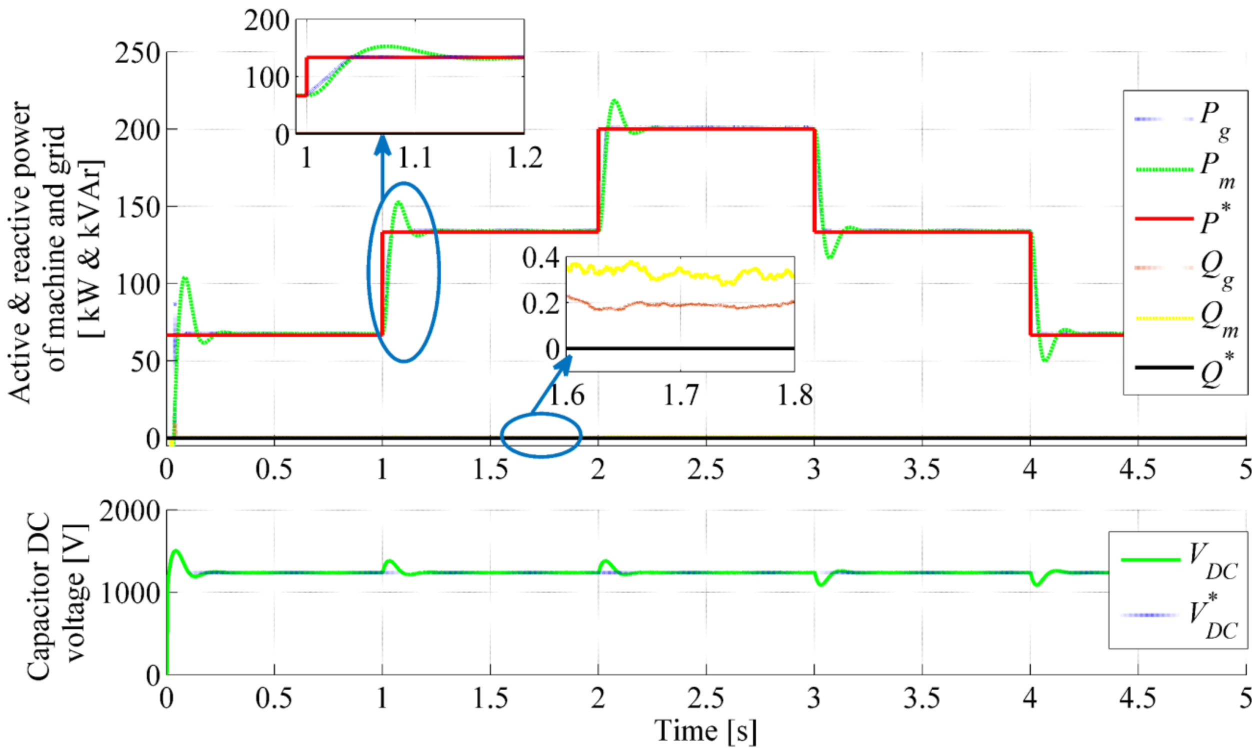

Fig. 4. Machine and grid active and reactive power step responses and the DC-link voltage response waveform.

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