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Performance Improvement Of A Grid Connected Wind Energy Conversion System Fed By A Matrix Converter

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ABSTRACT

This paper describes the control of a grid-connected wind energy conversion system based on an induction machine fed by a matrix converter. The matrix converter is controlled using a space vector modulation algorithm with zero displacement factor at the input. A model reference adaptive system observer, for sensorless control of the proposed wind energy conversion system is implemented and the output performance of a proposed system is discussed. The model reference adaptive system observer is implemented using the output voltage demand instead of measuring the machine voltage by voltage transducers .The complete control system has been developed and validated by simulation.

INTRODUCTION

A matrix converters provides direct ac-ac conversion and is consider an emerging alternative to the conventional two-stage ac-dc-ac converter topology. Matrix converters provide bidirectional power flow, sinusoidal input/output currents and controllable input power factor (Wheeler, P.W., *et al*., 2002; Casadei, D., *et al*., 2002). Due to the absence of components with significant, wear out characteristics such as electrolytic capacitors the matrix converters can potentially be very robust and reliable. The amount of space saved by a matrix converter, when compared to a conventional back-to-back converter, has been estimated as a factor of three (Podlesak, T.F., *et al*., 2005). Therefore, due to its small size in some applications, the matrix converter can be embedded in the machine itself. The matrix converter draws sinusoidal input current and depending on the modulation technique, it can be provide zero displacement factor. The advantages of cage induction machines for wind energy applications are documented in (Lopes, L.A. and R.G. Almeida, 2006; Wheeler, P.W., *et al*., 2005). When induction machines are operated using vector control techniques, fast dynamic response, and accurate torque control is obtained. The advantages of cage induction machines for wind energy applications are documented in (Lopes, L.A. and R.G. Almeida, 2006; Wheeler, P.W., *et al*., 2005). A variable speed wind energy conversion system (WECS) based on a grid-connected induction generator fed by a matrix converter is proposed which is shown in Figure 1.A rotor flux oriented sensorless vector control scheme is used for induction generator(IG). A space vector modulation (SVM) algorithm (Casadei, D., *et al*., 2002) is used to control the matrix converter by regulating the torque and the magnetizing current in the generator. For output voltage and input current control of matrix converter the SVM technique can be used. Out of 27 switching states, it is divided into three groups. First group consist of 6 space vectors, second group consist of 18 space vectors and third group consist of 3 space vectors which is also known as zero vectors. SVM technique generates the three phase sinusoidal output voltage by proper selection of switching states of a matrix converter

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and to calculate the corresponding ON time duration. In the matrix converter, a second-order input filter is required in order to reduce the input voltage distortion and to improve the input current waveform. MRAS observer is used in the proposed WECS. The methodology necessary to implement this observer is using the commanded voltages instead of measured values (Cardenas, R., *et al*., 2005; Comanescu, M. and L. Xu, 2006; Schauder, C., 1992; Cárdenas, R., *et al*., 2009; Saranya, U. and S. Allirani, 2015). The modeling of MRAS observer is explained in (Jeong, I.W., *et al*., 2004). The performance of a grid connected wind energy conversion system with MRAS observer and without MRAS observer is analyzed and the improvement of a wind energy conversion system with MRAS observer is presented.

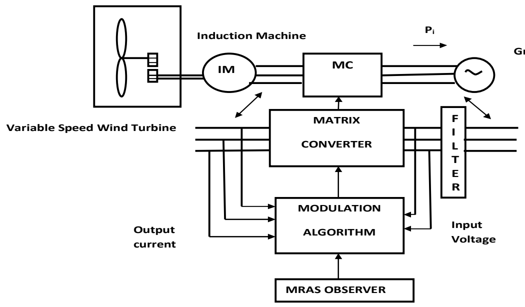

Fig. 1: Block diagram for WECS

II. Control of grid connected WECS using MRAS observer:

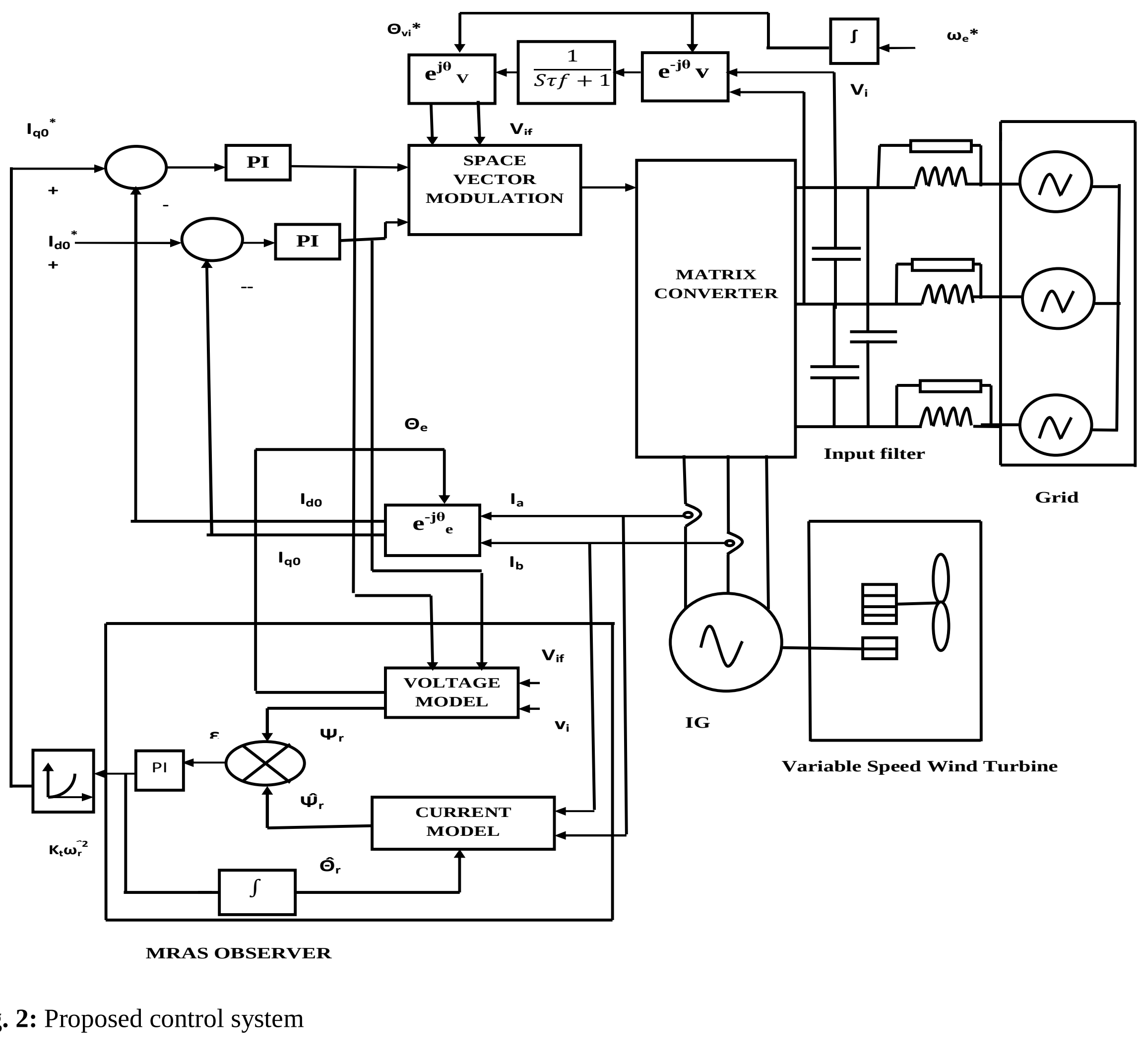

Fig. 2: Proposed control system

Figure 2 shows the proposed control system. A variable speed wind turbine drives the IG. The MC is controlled using the space vector modulation algorithm. In figure 2 MRAS Observer is used to estimate the rotational speed ω_r and the rotor position θ_r. The electrical angle θ_e is obtained from the α–β components of the rotor flux ψ_r. The angle θ_{iv} is used to obtain the d–q components of the input voltage vector in a synchronous rotating frame. Two rotating axes are required for the analysis. On the input side, a synchronous frame rotating at grid electrical frequency ω_e is used. This frame is orientated along the input voltage vector. A conventional vector control system, for cage machine is required for the output side (Cárdenas, R. and R. Pena, 2004). In this case, the induction machine is controlled using a direct vector control system oriented along ψ_r (Cárdenas, R. and R. Pena, 2004; Cardenas, R., *et al*., 2005). The demand i_{do}^* is constant for the whole operating range because the wind energy conversion system is not required to operate at nominal flux.

It can be demonstrated that in steady state, when the wind turbine is operating at the maximum aerodynamic efficiency, the captured power P_m, and the induction machine rotational speed are related by

$$P_m = K_{opt}\omega_r^3 \tag{1}$$

Where, K_{opt} depends on the blade aerodynamics, gear box ratio, and wind turbine parameters (Cárdenas, R. and R. Pena, 2004). From the above equation (1) and neglecting the losses, the WECS operates at the optimal aerodynamic efficiency point when T_e is controlled to

$$T_e = K_{opt}\omega_r^2 \tag{2}$$

Using the state equations of a cage induction machine orientated along the rotor flux (Cárdenas, R. and R. Pena, 2004), it can be shown that for optimal power capture, the torque current demand i_{q0}^* is obtained from (2) as follows

$$i_{qo}^* = \frac{3K_{opt}L_r}{2PL_0^2 i_{do}^*} \tag{3}$$

Where, P is the pole number, L_r rotor inductance. Considering that sensorless operation is used in the proposed WECS shown in Figure 2, the rotational speed estimated by the MRAS observer is used to regulate i_{q0}^* which is analogous to torque T_e

III. Modeling of MRAS Observer:

In this paper, an MRAS observer is used to estimate the rotational speed of the induction machine. The speed ω_r is estimated by the MRAS observer which consists of two models, namely reference model and adaptive model where the output of the reference model compared with the output of the adjustable model until the errors between the two models vanish to zero. Voltage model is known as a reference model. Current model is known as an adaptive model. Voltage model use the stator voltage equation to calculate rotor flux linkage. Current model calculates the flux linkage from the input stator current and speed signal ω_r.For low speed operation current model is useful but for high speed operation voltage model is preferred. The combination of voltage model and current model provide good performance for wide speed range.

3.1. Voltage model equations:

$$\Psi_{ds}^s = \int (V_{ds}^s - R_s I_{ds})dt \tag{4}$$

$$\Psi_{qs}^s = \int \left(V_{qs}^s - R_s I_{qs}\right)dt \tag{5}$$

$$\Psi_{dr}^s = \frac{L_r}{L_m}(\Psi_{ds}^s - \sigma L_{ls} I_{ds}^s) \tag{6}$$

$$\Psi_{qr}^s = \frac{L_r}{L_m}(\Psi_{qs}^s - \sigma L_{ls} I_{qs}^s) \tag{7}$$

$$\Psi_s = \sqrt{(\Psi_{dr}^{s2} + \Psi_{qr}^{s2})} \tag{8}$$

Where,

d^s-q^s Stationary reference frame direct and quadrature axis
, V_{qs}^s d-axis and q-axis stator voltages
I_{ds}^s , I_{qs}^s d-axis and q-axis stator current
Ψ_{ds}^s , Ψ_{qs}^s d-axis and q-axis stator flux linkage
Ψ_{dr}^s , Ψ_{qr}^s d-axis and q-axis rotor flux linkage

3.1.1. Simulink model for voltage model

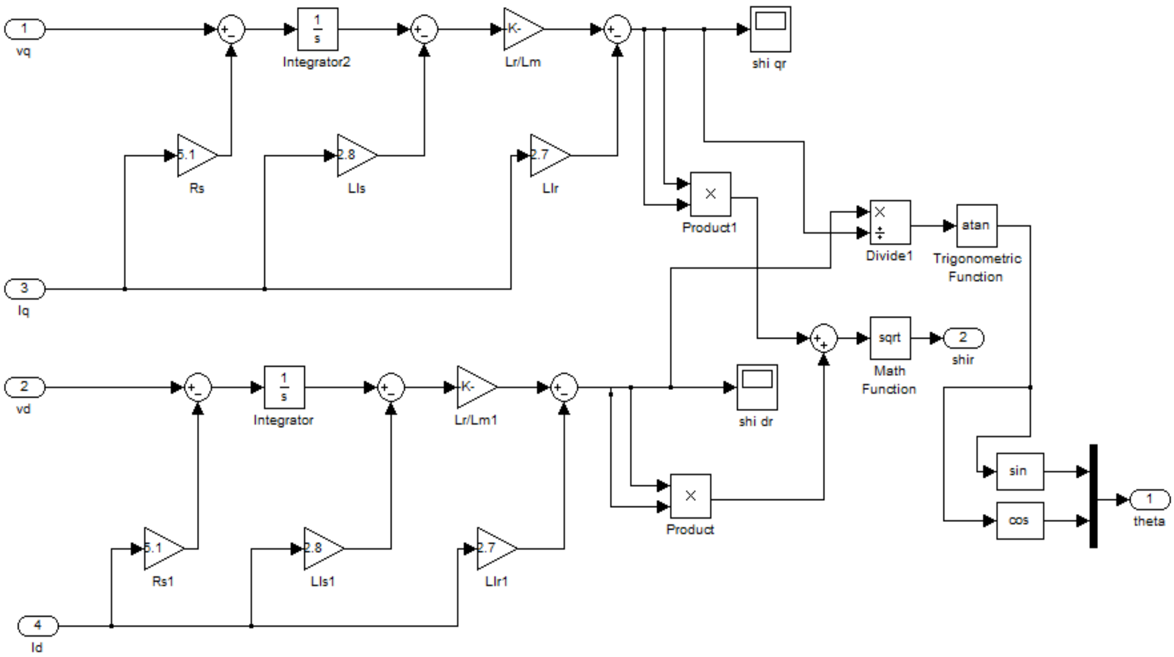

Fig. 3: voltage model

3.2. Current model equations:

$$\frac{d}{dt}\Psi_{dr}^{s} = \frac{L_m}{\tau_r} i_{ds}^{s} - \frac{1}{\tau_r}\Psi_{dr}^{s} - \omega_r \Psi_{qr}^{s} \tag{9}$$

$$\frac{d}{dt}\Psi_{qr}^{s} = \frac{L_m}{\tau_r} i_{qs}^{s} - \frac{1}{\tau_r}\Psi_{qr}^{s} - \omega_r \Psi_{dr}^{s} \tag{10}$$

$$\Psi_s = \sqrt{(\Psi_{dr}^{s2} + \Psi_{qr}^{s2})} \tag{11}$$

3.2.1. Simulink model for current model:

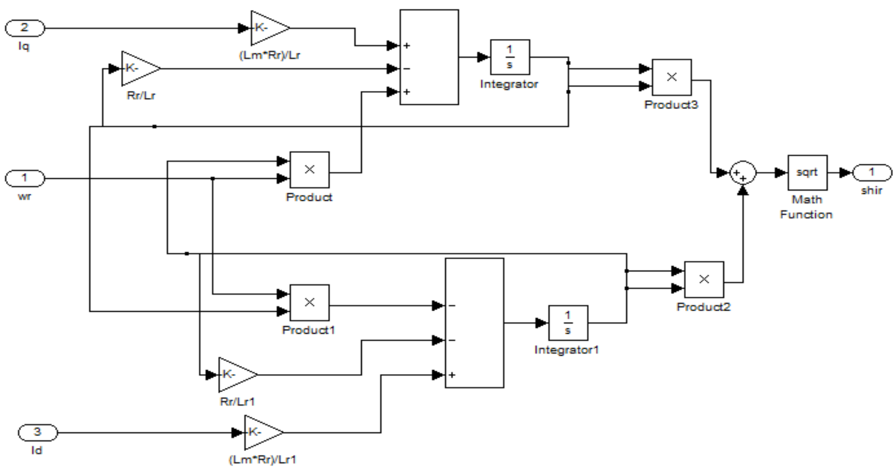

Fig. 4: Current model

IV. Simulation Diagram and Results:

The simulation diagram of grid connected WECS through matrix converter shown in figure 5. Here wind turbine is modeled to provide 100 volts and grid is modeled to 230 volts.MC is connected between wind turbine and grid.MC is controlled by SVM technique. SVM technique has two input modulating signals, one of the

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input modulating signal is from the grid reference voltage and the other input modulating signal is from the torque components i_{d0}^{*} which is controlled by MRAS Observer. Three phase to two phase transformation is done at the output current of the induction generator which is given as a feedback for PI controller.

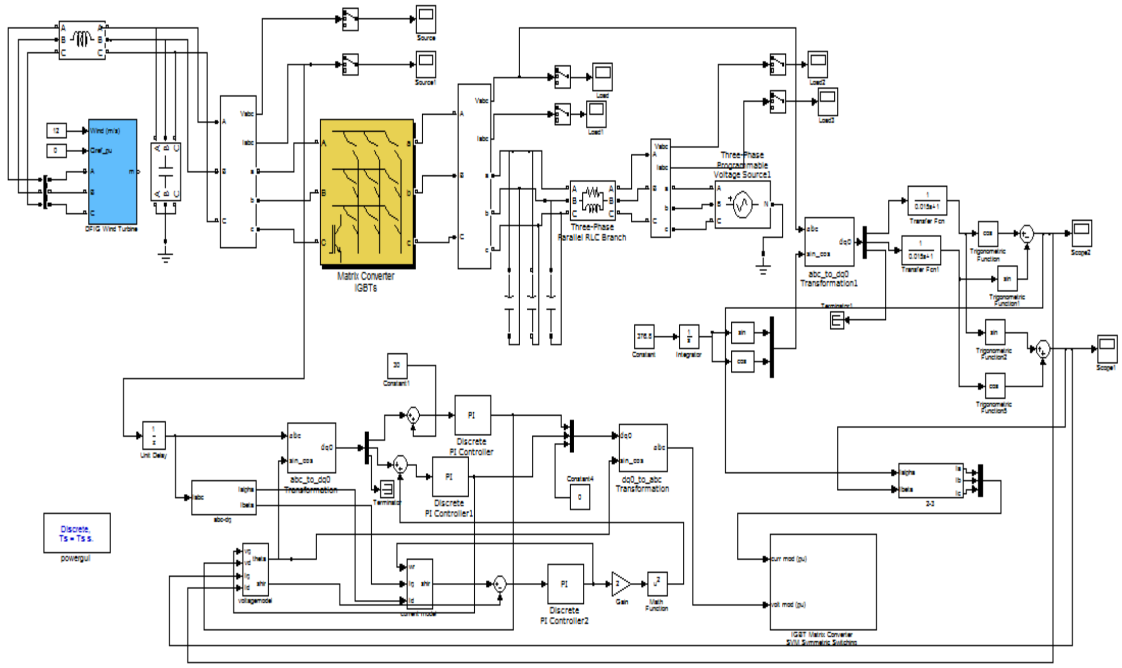

Fig. 5: Simulation diagram with MRAS Observer

4.2 Simulation Result:

The simulation results for grid connected WECS through matrix converter with and without MRAS observer is shown in figure 6&7.Input current and output voltage waveform is improved in WECS with MRAS observer compared to WECS without MRAS observer

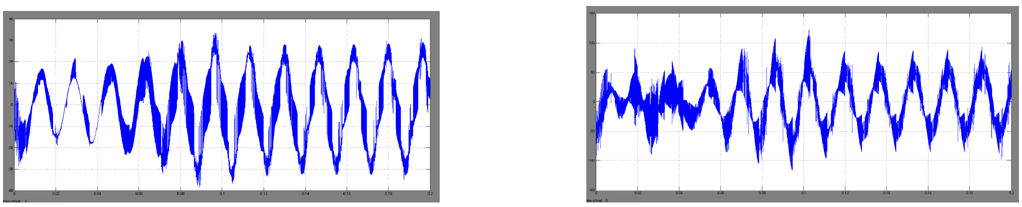

Fig. 6: Input current and output voltage with MRAS observer

Fig. 7: Input current and output voltage without MRAS Observer

4.3. Harmonics analysis of input current and output voltage with and without MRAS observer:

Table1 shows the comparision of grid connected WECS with MRAS observer and without MRAS observer. Total harmonic distortion (THD) and selective harmonics content of the input current and output voltage of the grid connected WECS with MRAS observer is better than without MRAS observer.

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Table 1: Comparison of grid connected WECS with and without MRAS observer

Parameters	With MRAS		Without MRAS	
	Input current	Output voltage	Input current	Output voltage
THD	6.76%	4.80%	19.29%	17.43%
h_5	0.52%	0.50%	1.43%	0.93%
h_7	0.77%	0.31%	0.33%	0.62%
h_{11}	0.36%	0.20%	1.59%	0.41%
h_{13}	0.17%	0.17%	0.92%	0.33%
h_{17}	0.18%	0.13%	0.89%	0.25%

Conclusion:

The performance of the grid connected WECS fed by a matrix converter has been implemented. Therefore it is concluded that the grid connected WECS fed by a matrix converter with MRAS Observer has less Total harmonics distortion (THD), selective harmonic content and better input current waveform compared to grid connected WECS fed by a matrix converter without MRAS observer.

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