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Research Article

Grid Connected Wind Energy Conversion System Using Three Phase Matrix Converter

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Abstract: A variable speed Wind Energy Conversion System (WECS) with Permanent Magnet Synchronous Generator (PMSG) connected to grid through Matrix Converter (MC) is proposed in this study. Necessity for increased demand in electrical energy paved way for use of renewable energy sources, one of which is abundant wind energy available in ample. Various Wind Energy Conversion systems have been proposed over the decades, of which various topologies had been projected, where complex topologies are being in existence. Permanent magnet synchronous generator has substantial advantages over conventional generators like less weight and volume and exemption for separate excitation with high precision. The conventional system involves two stage of conversion involving rectification followed by inversion being coupled by a DC link capacitor before fed to a grid, which decreases the efficiency of the system due to power quality issue. To overcome this matrix converter can be utilized to transfer the power from generation stage to the grid; there by an AC-AC converter can transfer power from generator to the grid. The proposed system is designed and tested in MATALB/Simulink environment and the results are effective.

Keywords: Matrix converter, permanent magnet synchronous generator, wind energy conversion system, wind turbine

INTRODUCTION

Advancement of industrialization and increase in global population led to increase in demand for electricity day-by-day which led to need for exploitation of renewable energy sources, due to depletion of conventional resources like fossil fuels and the ecological problems caused by them.

Wind Energy Conversion System (WECS) one of the prominent renewable energy source has found noticeable worldwide growth in recent decades with the development of technology. A rapid growth in utilization of Wind Energy Conversion System's over worldwide increases constantly over the years, as shown in Fig. 1. A global installed capacity of 318.2 GW (Global Wind Report, 2013) depicts the growth in utilization of WEC system.

A minimum of 10% to a maximum of 40% growth (Global Wind Report, 2013) in every year installed capacity shows the growth of wind energy conversion utilization over the past decade alone in worldwide as shown in the following Fig. 2, which shows the every year globally installed capacity in GW. The following Table 1 portrays the global cumulative installed capacity and global annual installed capacity (Global Wind Report, 2013) from the year 1996 to 2013.

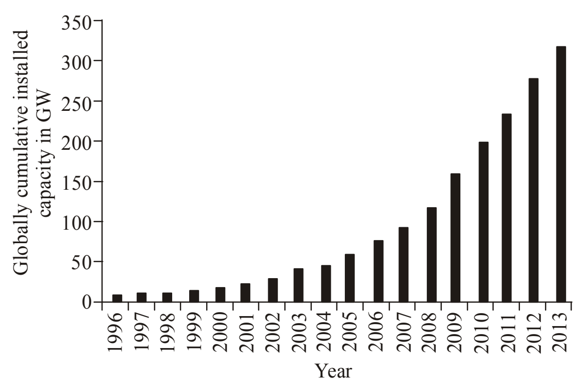

Fig. 1: Globally cumulative installed capacity in GW

The regional distribution of WEC system as shown in Fig. 3 shows that Asia plays second largest source of WECS production when compared regionally and Table 2 shows the corresponding data.

In this study a Wind Energy Conversion System (WECS) is modelled with a matrix converter and the electricity generated is fed to the grid. The following sections describe the proposed WEC system.

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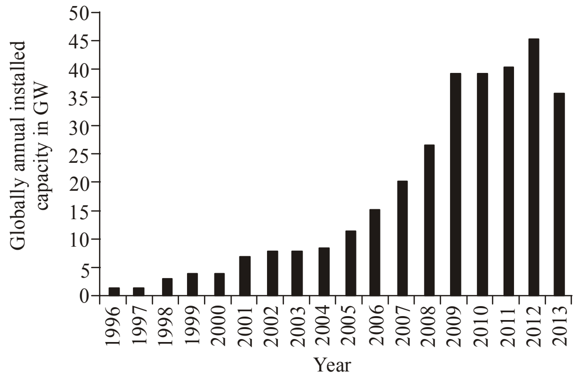

Fig. 2: Globally annual installed capacity in GW

Table 1: Global capacity of WEC system

Year	Globally cumulative installed capacity (GW)	Globally annual installed capacity (GW)
1996	6.1	1.3
1997	7.6	1.5
1998	10.2	2.5
1999	13.6	3.4
2000	17.4	3.8
2001	23.9	6.5
2002	31.1	7.3
2003	39.4	8.1
2004	47.6	8.2
2005	59	11.5
2006	74.1	14.7
2007	93.8	20.3
2008	120.3	26.9
2009	158.7	38.5
2010	194.4	39.1
2011	238.1	40.6
2012	283.1	45.2
2013	318.2	35.5

Table 2: Global capacity of WEC system

Regions	WEC System power production in GW
Africa and Middle East	1.3
Asia	115.9
Europe	121.5
Latin America and Caribbean	4.7
North America	70.9
Pacific region	3.9

NOTATION

The notation used throughout the paper is stated below:

Constants,
P_w = Power from Wind
ρ = Air Density
R = Blade Radius
V_w = Wind Speed
C_p = Power Co-efficient
λ = Tip Speed ratio
β = Blade Pitch Angle
ω_B = Rotational Speed of Turbine
T_t = Torque Developed by Windmill

Wind energy conversion system: Wind energy is converted into electrical energy by wind turbine generators and the harnessed energy is fed to grid through power electronic converters. Various generators such as Double-Fed Induction Generator (DFIG), Synchronous Generator, Permanent Magnet Synchronous Generator (PMSG) and Induction Generator (IG) of Squirrel-Cage and Wound-Rotor type of which Permanent Magnet Synchronous Generator (PMSG). An Induction Generator (IG) with step-up gear-box has low efficiency at low speeds (Barakati *et al*., 2009; Chinchilla *et al*., 2006). A PMSG is a self-excited system, which allows operation at high power factors and high efficiencies for the PMSG (Polinder *et al*., 2006; Yamamura *et al*., 1999). A general conventional PMSG based Wind Energy Conversion System (WECS) is shown in Fig. 4 below.

In the conventional system a rectifier with inverter is used for conversion of harnessed energy to supply to grid which involves a bulky DC link capacitor, thereby reducing the efficiency of the system due to power quality issues. To elude this Matrix Converter (MC) can be used for transferring energy to the grid. A Matrix Converter is an AC-AC converter, which provides almost sinusoidal waveforms with fast dynamic

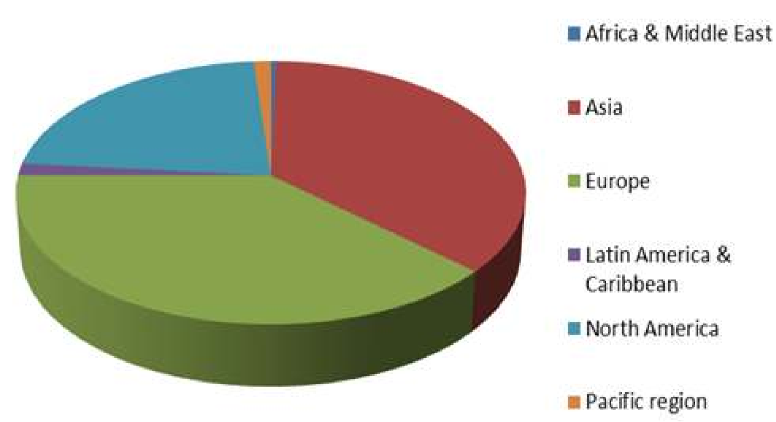

Fig. 3: Regional distribution of WEC system

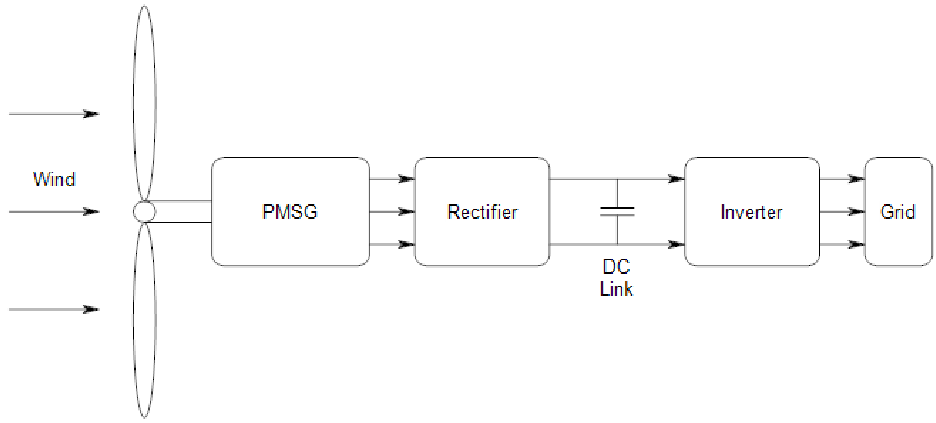

Fig. 4: PMSG based conventional WEC system

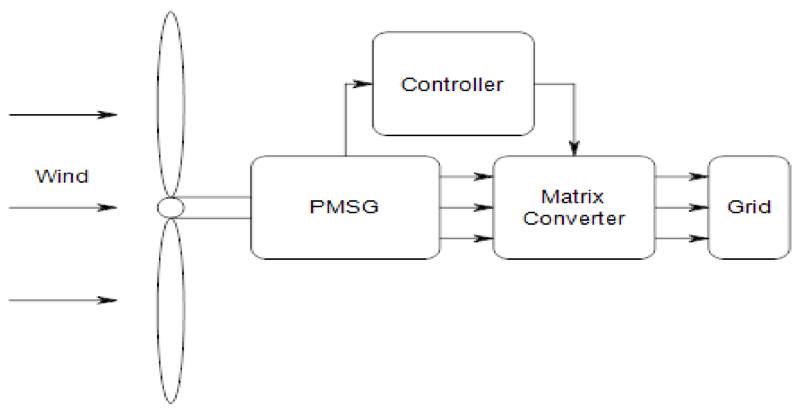

Fig. 5: Proposed PMSG based WEC system with matrix converter

response (Barakati *et al*., 2007) and high efficiency at even low switching frequencies. It has less weight and compact design (Barakati *et al*., 2007; Helle *et al*., 2004) due to absence of DC link capacitor. Hence a Wind Energy Conversion System with a Permanent Magnet Synchronous Generator combined with Matrix Converter connected to grid is being proposed as shown in following Fig. 5.

The mechanical power (P_w) available from wind turbine is given by the following Eq. (1):

$$P_w = 0.5\rho\Pi R^2 V_w^3 C_p\left(\lambda,\beta\right) \tag{1}$$

where,

ρ = The air density
R = The blade radius
V_w = The wind speed
C_p = The power co-efficient which is a non-linear function of tip speed ratio λ and blade pitch angle β

The power co-efficient is given by the Eq. (2):

$$C_p = \frac{1}{2}\times\left(\lambda - 0.022\times\beta^2 - 5.6\right)\times e^{-0.17\lambda} \tag{2}$$

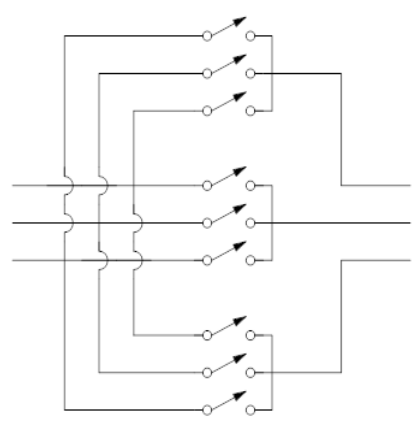

Fig. 6: Structure of three-phase matrix converter switch

And the tip speed ratio is given by the Eq. (3):

$$\lambda = \frac{V_w}{\omega_B} \tag{3}$$

where, ω_B is the rotational speed of the turbine. The torque developed by the windmill is given by the Eq. (4):

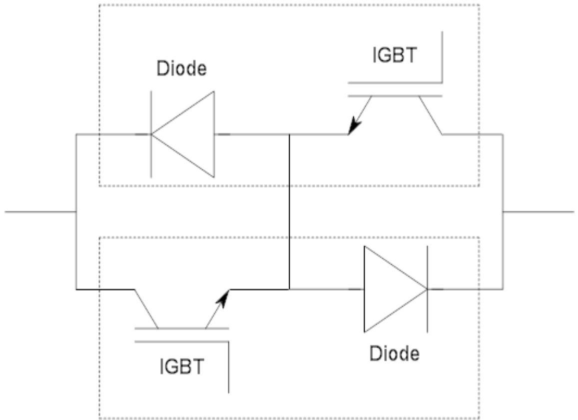

Fig. 7: Structure of bidirectional matric converter single switching element

$$T_t = 0.5\mu\left(\frac{C_P}{\lambda}\right)\square uR^2V_w^3 \qquad (4)$$

Matrix converter: A three-phase Matric Converter (MC) is an array of nine bidirectional switches connecting each phase of input to each phase of output as shown in following Fig. 6. By operating these switches desired output frequency, output voltage and input displacement angle can be obtained. The development of high frequency control (Venturini and Alesina, 1980; Venturini, 1980) was proposed with PWM modulation control technique (Ziogas *et al.*, 1986) provides low distortion sinusoidal input-output waveforms. The structure of a single bidirectional switch with IGBT is shown in Fig. 7 above.

PROPOSED WECS METHODS

The proposed WECS MATLAB/simulink model is as shown in following Fig. 8.

In the proposed WECS model the rating of PMSG is 730V, 1.5MVA, 60 Hz generator for a wind turbine of 2 MW output mechanical power is considered for design purpose. The output of the PMSG generator for variable wind speed from 6 m/s to 12 m/s as shown in Fig. 9 is simulated through MATLAB/Simulink model and the output of the generator is fed to Matrix Converter (MC), whose output is connected to load and the grid through filters. The structure of Matrix Converter switches in simulink model is shown in following Fig. 10.

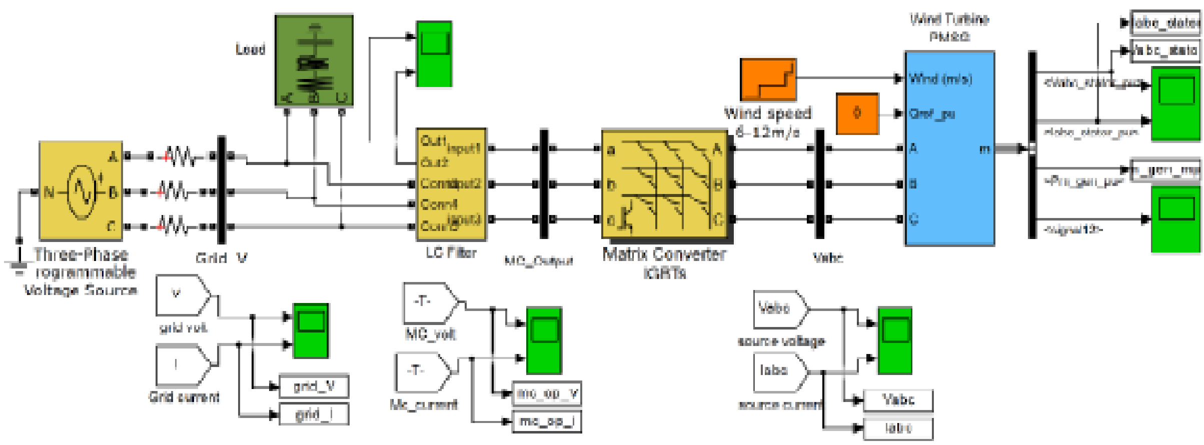

Fig. 8: Proposed wind energy conversion system with matrix converter simulink model

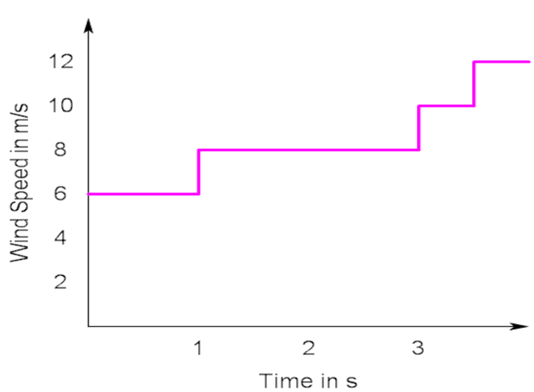

Fig. 9: Wind speed simulated in simulink model

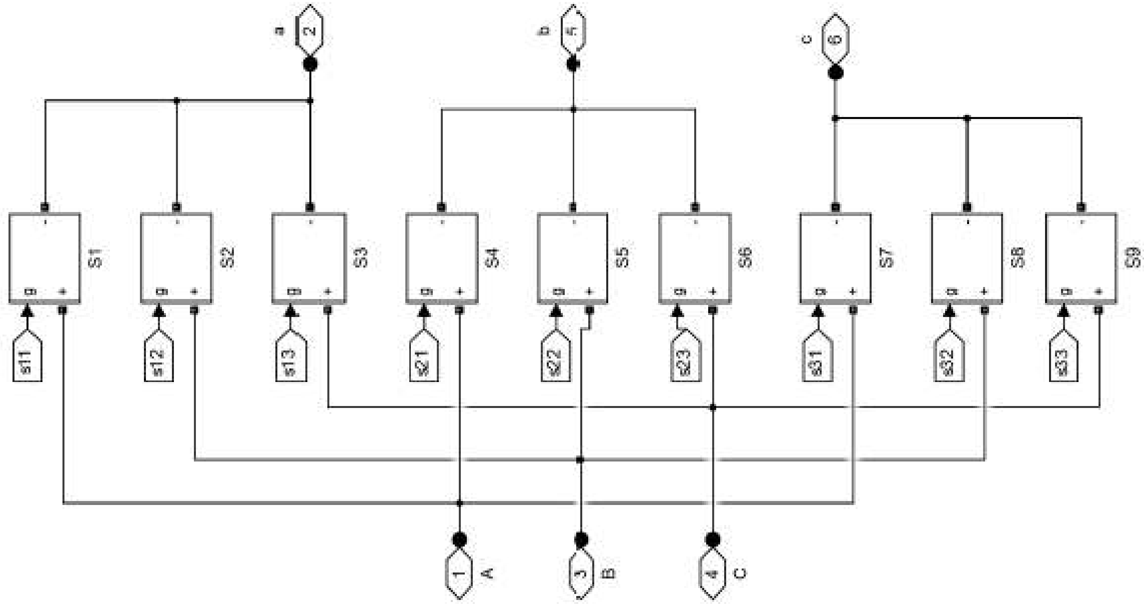

Fig. 10: Matrix converter switches in simulink model

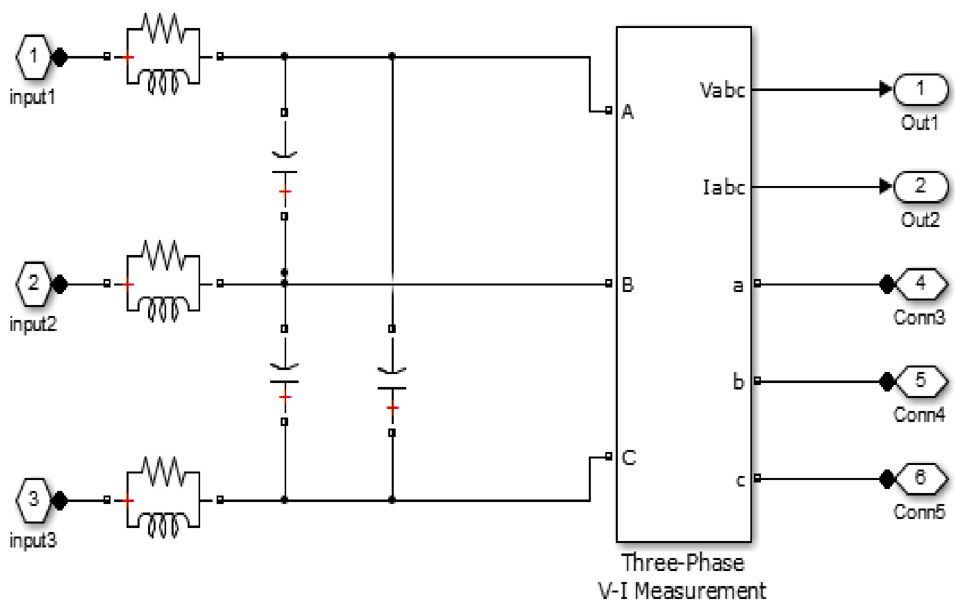

Fig. 11: Simulink filter model

The MATLAB/Simulink model of filter circuit of 500 Ω, 1 mH and 1 μF is shown in Fig. 11 above.

Due to variation in wind speed the output voltage of the Wind turbine driven PMSG varies with turbine speed. As a result the Matrix Converter output varies with the variation of PMSG output. To obtain the desired output the Matrix Converter is controlled by SPWM technique generated by a controller to obtain a closed-loop control over the output. The output obtained from the Matrix Converter has to be filtered by the filter module before the output is fed to the load and grid.

RESULTS AND DISCUSSION

The output of the generator voltage and current are shown in the Fig 12 and 13 below. The output voltage and current waveform of the Matrix Converter is shown in Fig. 14 and 15 below.

The output obtained from the Matrix Converter is filtered by the filter module and fed to the grid and load. The filtered output or the grid voltage and grid current waveforms are given in Fig. 16 and 17 below. The Total Harmonic Distortion (THD) measured from the input side and output side of the Matrix Converter is shown in following Fig. 18 and 19.

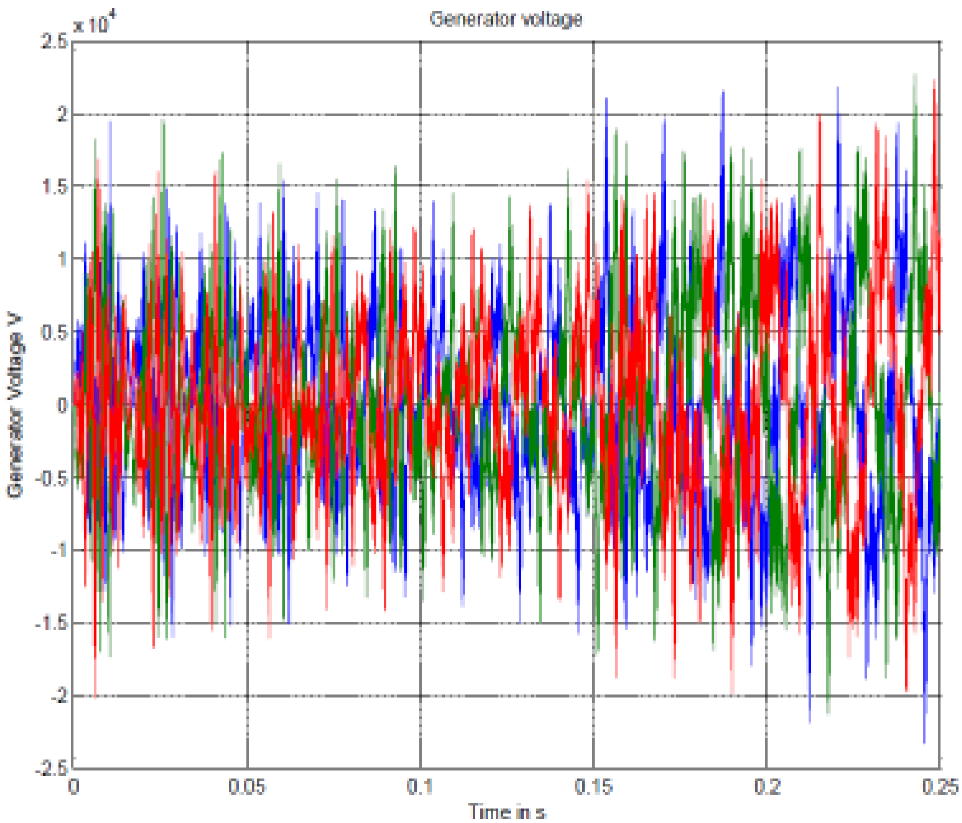

Fig. 12: Generator output voltage waveform

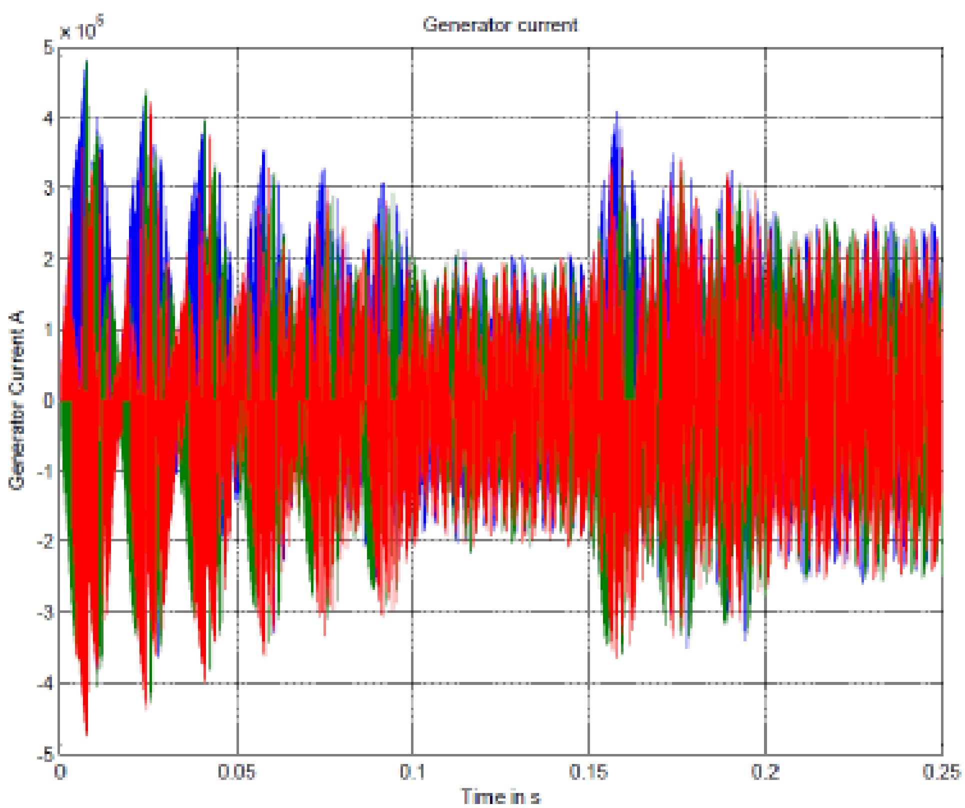

Fig. 13: Generator output current waveform

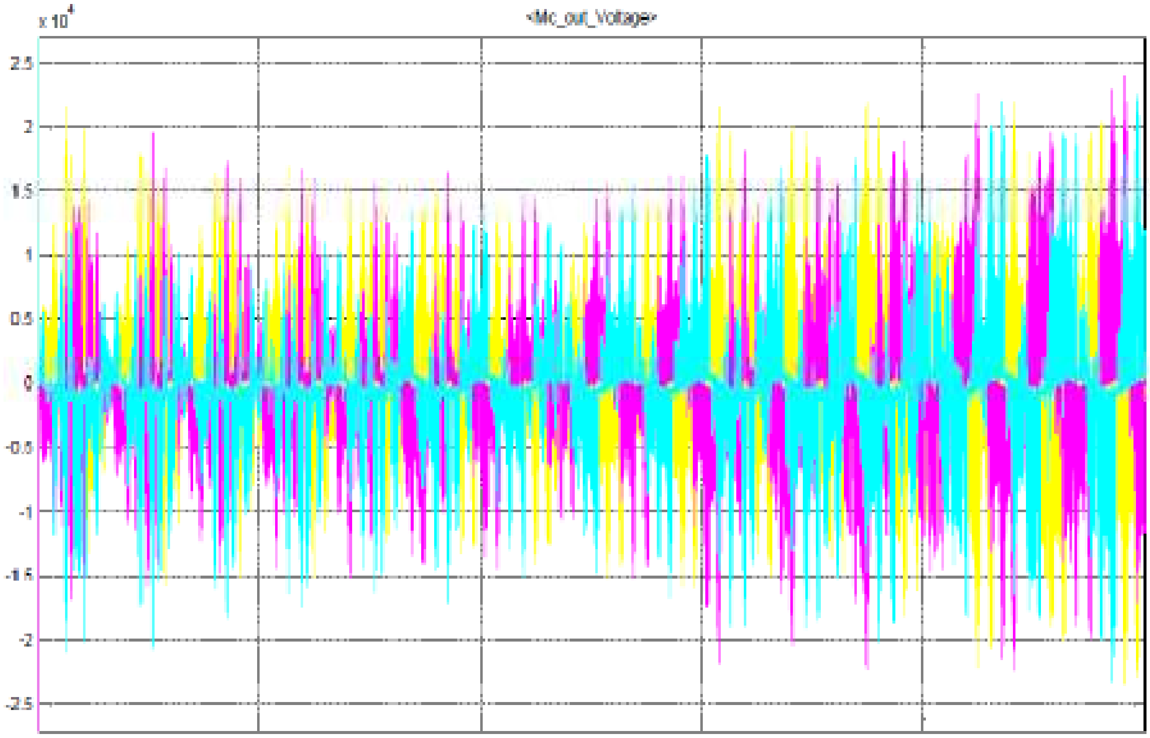

Fig. 14: Matrix converter output voltage waveform

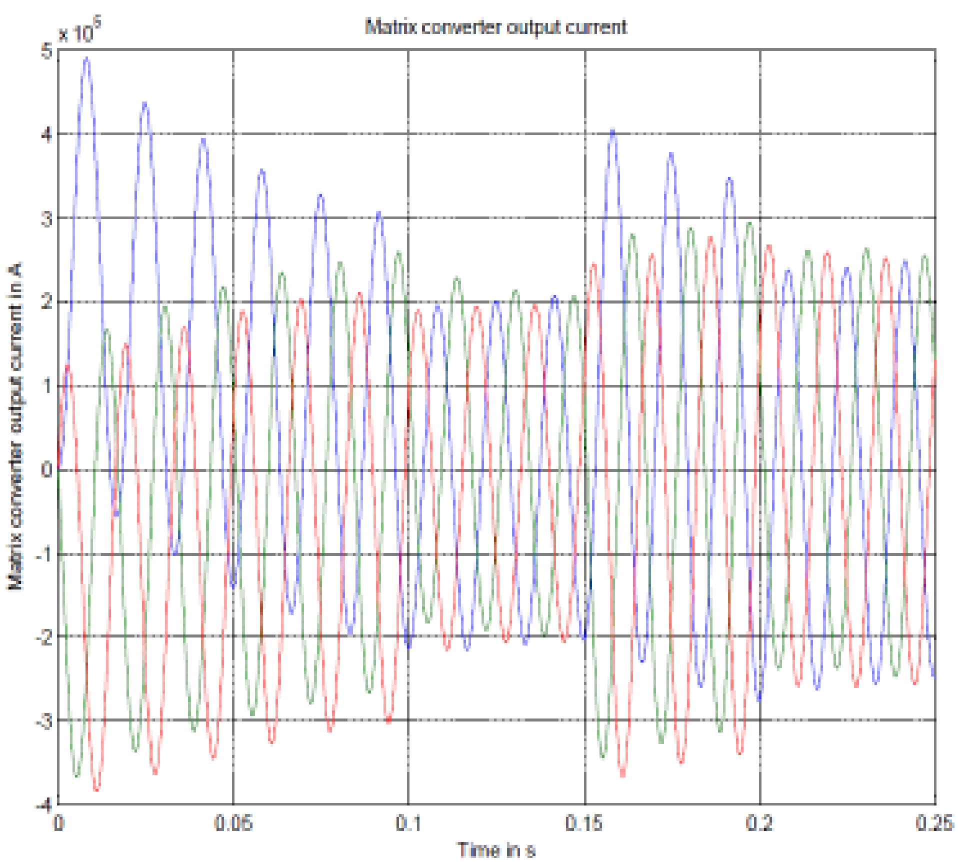

Fig. 15: Matrix converter output current waveform

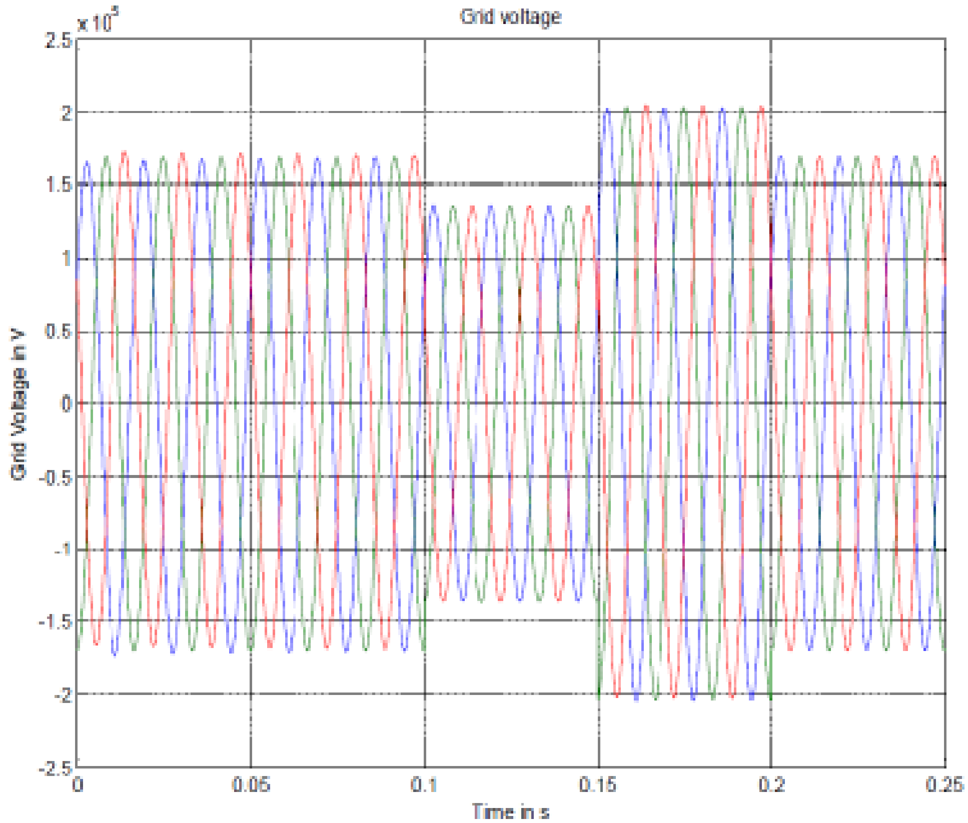

Fig. 16: Grid voltage waveform

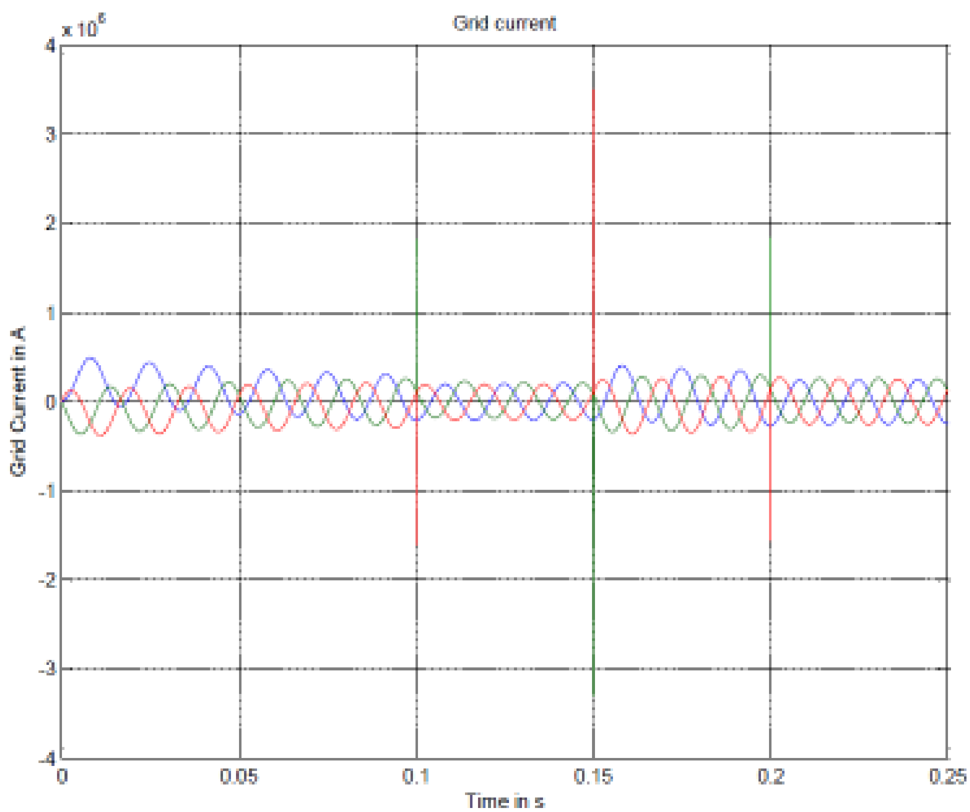

Fig. 17: Grid current waveform

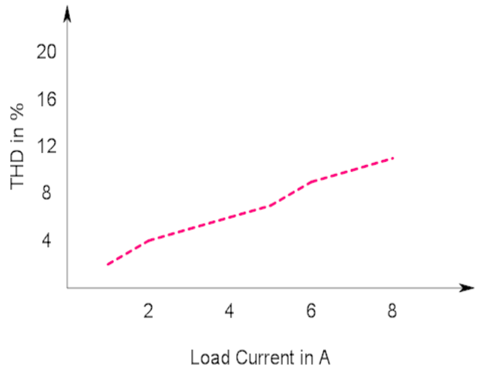

Fig. 18: Input current THD of matrix converter

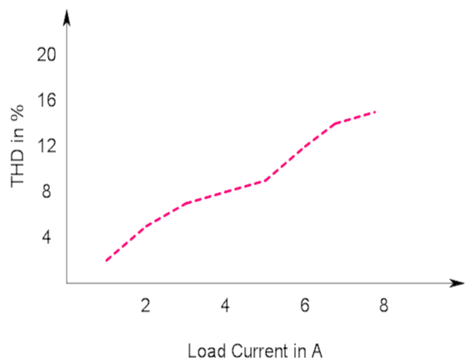

Fig. 19: Output current THD of matrix converter

Thus the THD measured for various load currents as shown in Fig. 18 and 19 shows very low THD when compared to conventional WECS. By reducing the harmonic distortion the efficiency of this system is being improved.

CONCLUSION

The Permanent Magnet Synchronous Generator driven by wind turbine with Matrix Converter to control the power fed to grid is modelled in MATLAB/Simulink and simulated for varying wind conditions and loading arrangement. With variation in wind, the output of the generator varies and the output is controlled by the Matrix Converter. When compared with conventional rectifier-inverter fed system, the proposed Matrix Converter fed system has lower Total Harmonic Distortion (THD) which improves the efficiency of the system.

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