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# Performance Analysis of PMSG Based Wind Energy Conversion System Using Two Stage Matrix Converter

***Abstract**. This article presents a performance analysis on Permanent Magnet Synchronous Generator (PMSG) driven standalone Wind Energy Conversion System (WECS) using Two-Stage Matrix Converter (TSMC). PMSG is identified for higher efficiency due to elimination of brushes, gear transmission loss and excitation losses which makes it a viable source for wind energy conversion. Typical AC – AC conversion topologies utilized for WECS use DC link capacitor which leads to bulk circuit topology. Two-Stage Matrix Converter (TSMC) which involves direct AC – AC conversion, employs Voltage Source Rectification (VSR) and Current Source Inversion (CSI) process with virtual DC link thereby eliminating bulk DC link capacitor. In this manuscript, the design and analysis of standalone PMSG driven WECS using TSMC is carried out in MATLAB/SIMULINK environment and the results obtained exhibit robust control with low Total Harmonic Distortion (THD) and power factor higher than 0.95 for the proposed system*

***Streszczenie.** W artykule analizowano właściwości generatora synchronicznego z magnesowami trwałymi PMSG stosowanego w elektrowni wiatrowej i współpracującego z z dwustopniowym przekształtnikiem macierzowym TSMC.rzekształtnik AC-AC wykrzystuje układ prostowniczy VSR I źródło prądowe CSI I wirtualne połączenie DC eliminujace konieczność stosowania kondensatora. **Analiza właściwości generatora synchronicznego z magnesowami trwałymi stosowanego w elektrowni wiatrowej i współpracującego z z dwustopniowym przekształtnikiem macierzowym***

**Keywords:** Permanent Magnet Synchronous Generator, Two Stage Matrix Converter, Wind Energy Conversion System.
**Słowa kluczowe:** generator synchroniczny z magnesami trwałymi, przekształtnik macierzowy, elektrownia wiatrowa.

## Introduction

Advancement of energy demands, exploit the renewable energy resources to meet the requirement. A global report on energy production capacity reveals 19% share of renewable energy resources [1] among the other available resources as shown in Fig. 1. Wind Energy Conversion System (WECS) plays the major role of energy harvesting and the global installed capacity as shown in Fig. 2 ascend to 433 GW as reported by GWES 2016 [1] report. In Wind Turbine Generators (WTG) Permanent Magnet Synchronous Generator (PMSG) [2–5] plays a vital role due to gearless system, low mechanical stress and elimination of excitation losses as brushes are eliminated. Besides, PMSG is applicable for low, medium and high speed with high energy yield, higher efficiency and negligible rotor maintenance when compared to Double Fed Induction Generator (DFIG).

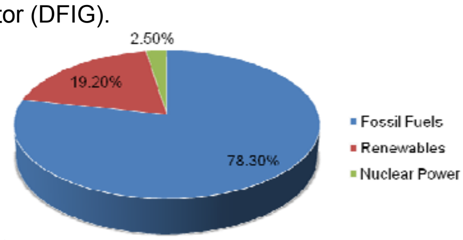


Fig.1. Share of renewable energy resources over global production capacity

WECS necessitates proficient converters for effective grid connection and the progression in semiconductor topology paved way for efficient converters such as voltage source converter (VSC), current source converter (CSC), Neutral-Point Clamped Converter (NPC), cycloconverter [6] and matrix converter (MC) [7–8]. The conventional AC – DC – AC converter topologies [6–8] as shown in Fig. 3 utilize DC link capacitor which makes the circuit bulky and yield lower efficiency. Whereas Matrix Converters (MC) [7–11] based WECS as shown in Fig. 4 involves direct AC – AC conversion and the elimination of reactive components makes it compact light weight circuit, cost effective and yield higher efficiency. In addition, matrix converters reveal higher power factor and sinusoidal input and output current waveforms.

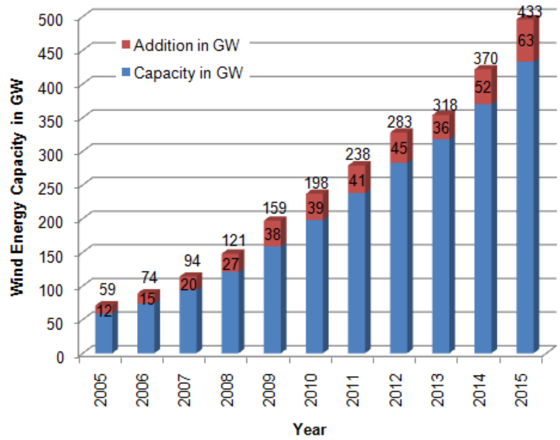


Fig.2. Global installed capacity of WECS

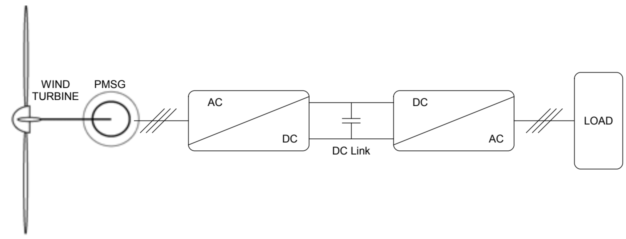


Fig.3. Conventional AC – DC – AC conversion system

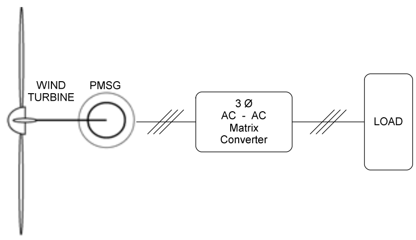


Fig.4. Matrix Converter based Wind Energy Conversion System

The complexity in modulation control strategy of a direct matrix converter led to the development of Two-Stage Matrix Converter (TSMC) topology [9 –11] which has all the features of direct matrix converter together with simplified commutation strategy. As a result a PMSG based WECS with MC is modeled for a standalone system in this article and the performance analysis of standalone PMSG based WECS with Two-Stage Matrix Converter (TSMC) is evaluated in MATLAB/SIMULINK environment and the results obtained for various loading conditions were presented in the following sections.

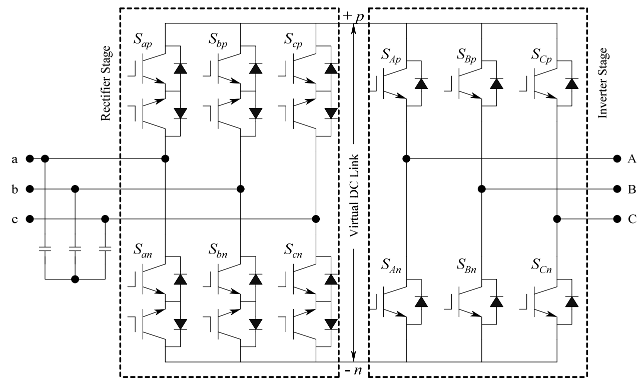


Fig.5. Schematic view of Two Stage Matrix Converter (TSMC)

### Two-Stage Matrix Converter (TSMC)

The Two-Stage Matrix Converter (TSMC) [9–11] is a unidirectional indirect matrix converter consisting of two stages namely rectifier stage and inverter stage which has fictitious DC coupling between the stages and the absence of reactive DC link capacitor and inductor results in compact design of the converter with low losses. The main advantage of TSMC is the Zero Current Switching (ZCS) at the input side switches of the converter with simple computation. The rectifier stage of Two-Stage Matrix Converter (TSMC) is a Voltage Source Rectifier (VSR) comprising of six bidirectional switches connected in common emitter mode with protective diodes which acts as a three phase rectifier and is coupled to the Current Source Inverter (CSI) through a virtual DC link. The CSI connected to the load consists of six unidirectional switches which act as three phase inverter as shown in Fig. 5. The input voltages of Voltage Source Rectifier (VSR) are represented by the set of equations given in Eq. (1) and the output currents of Current Source Inverter (CSI) are represented by the set of equations given in Eq. (2) below.

$$\begin{cases} v_a = V_i \cos\left(\alpha_i(t)\right) \\ v_b = V_i \cos\left(\alpha_i(t) - 2\pi/3\right) \\ v_c = V_i \cos\left(\alpha_i(t) + 2\pi/3\right) \end{cases} \quad (1)$$

$$\begin{cases} i_A = I_o \cos\left(\alpha_o(t)\right) \\ i_B = I_o \cos\left(\alpha_o(t) - 2\pi/3\right) \\ i_C = I_o \cos\left(\alpha_o(t) + 2\pi/3\right) \end{cases} \quad (2)$$

where $V_i$ is the source voltage amplitude; $I_o$ is the current source amplitude; $\alpha_i(t)$ is the phase angle of the voltage source and $\alpha_o(t)$ is the phase angle of the current source.

The transfer function of the TSMC is given by the following equation Eq. (3)

$$T = I \bullet R \quad (3)$$

where $T$ is the transfer function of the TSMC and $I$ is the transfer function of the CSI and $R$ is the transfer function of the VSR which can be rewritten in the following equation form as Eq. (4)

$$\begin{bmatrix} S_{aA} & S_{bA} & S_{cA} \\ S_{aB} & S_{bB} & S_{cB} \\ S_{aC} & S_{bC} & S_{cC} \end{bmatrix} = \begin{bmatrix} S_{Ap} & S_{An} \\ S_{Bp} & S_{Bn} \\ S_{Cp} & S_{Cn} \end{bmatrix} \bullet \begin{bmatrix} S_{ap} & S_{bp} & S_{cp} \\ S_{an} & S_{bn} & S_{cn} \end{bmatrix} \quad (4)$$

The output voltage matrix can be represented in the following form of equation Eq. (5)

$$\begin{bmatrix} V_A \\ V_B \\ V_C \end{bmatrix} = \begin{bmatrix} S_{Ap} & S_{An} \\ S_{Bp} & S_{Bn} \\ S_{Cp} & S_{Cn} \end{bmatrix} \bullet \begin{bmatrix} S_{ap} & S_{bp} & S_{cp} \\ S_{an} & S_{bn} & S_{cn} \end{bmatrix} \bullet \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

The switching waveforms for the voltage source rectifier with six bidirectional switches ($S_{ap}$ – $S_{cn}$) is represented by the following figure Fig. 6 and the switching waveforms for the current source inverter with six unidirectional switches ($S_{Ap}$ – $S_{Cn}$) is represented by the following figure Fig. 7.

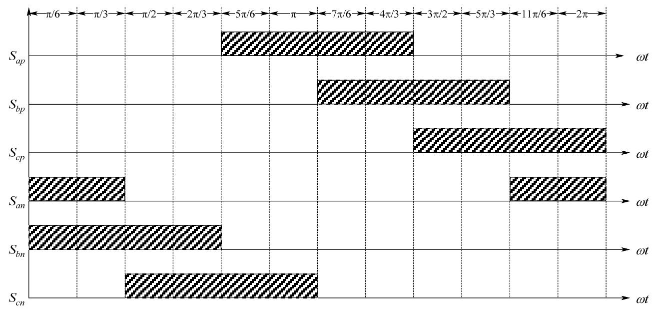


Fig.6. Switching waveforms of the voltage source rectifier

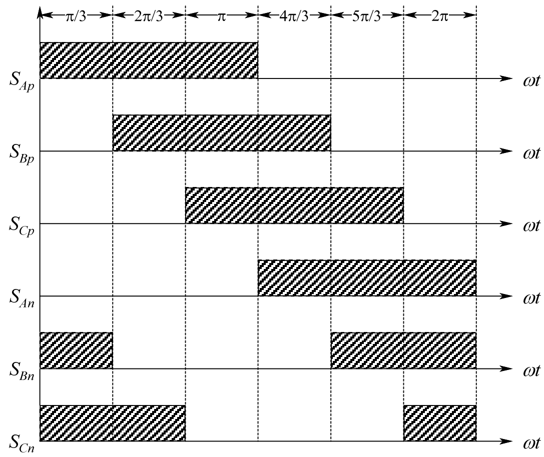


Fig.7. Switching waveforms of the current source inverter

### Modelling of PMSG driven WECS with TSMC

The simulink model of Permanent Magnet Synchronous Generator driven wind energy conversion system with two-stage matrix converter is shown in the following figure Fig.8 in which the Wind Turbine Generator (WTG) comprising of turbine and PMSG is connected to the Two-Stage Matrix Converter (TSMC) through a LC filter of 5.5mH and 60μF. The output of TSMC is connected to the three phase series RL branch load of 5Ω and 5mH. The TSMC simulink model consists of VSR and CSI coupled by virtual DC link and the pulse width modulated (PWM) switching signal generated for VSR and CSI is fed to the converter (rectifier) and inverter module switches. Fig. 9 shows the voltage source rectifier subsystem components which consists of six bidirectional switches and Fig. 10 shows the bidirectional switching connection in common emitter mode configuration.

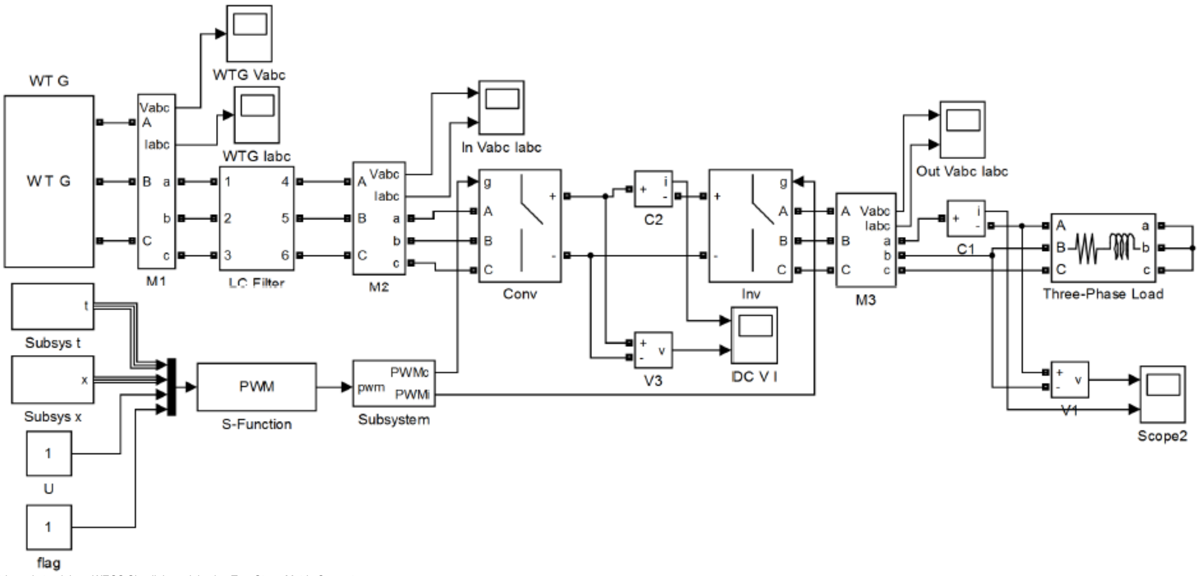


Fig.8. PMSG based standalone WECS Simulink model using Two Stage Matrix Converter

Fig. 11 shows the current source inverter subsystem module with six unidirectional switches and the output ports for connecting the load.

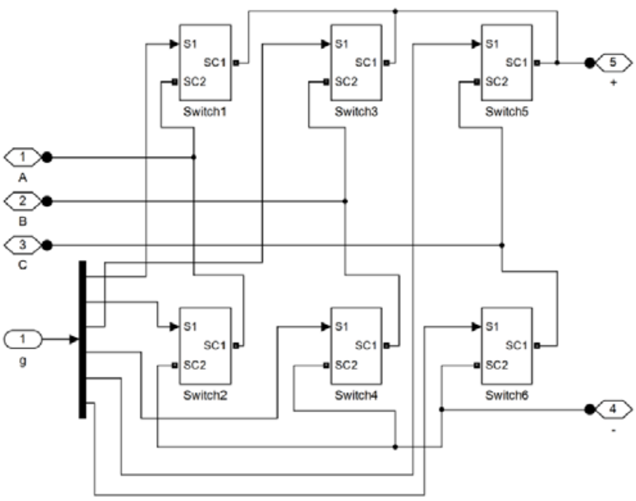


Fig.9. Voltage source rectifier stage of TSMC

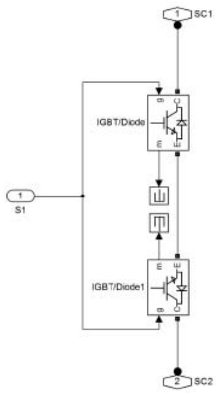


Fig.10. Single bidirectional switch module of TSMC-voltage source rectifier

**Results and Discussion**

The simulation results for various loading conditions obtained from the performance analysis of PMSG driven WECS using Two-Stage Matrix Converter (TSMC) from simulink environment were shown in following figures from Fig. 12 to Fig. 27. Fig. 12 shows the PWM switching waveform for the six bidirectional switches $S_{ap}$, $S_{an}$, $S_{bp}$, $S_{bn}$, $S_{cp}$ and $S_{cn}$ of the voltage source rectifier for time period 20ms to 40 ms. Fig. 13 shows the PWM switching pulse signal for the six unidirectional switches $S_{Ap}$, $S_{An}$, $S_{Bp}$, $S_{Bn}$, $S_{Cp}$ and $S_{Cn}$ of the current source inverter for time period 20ms to 40ms.

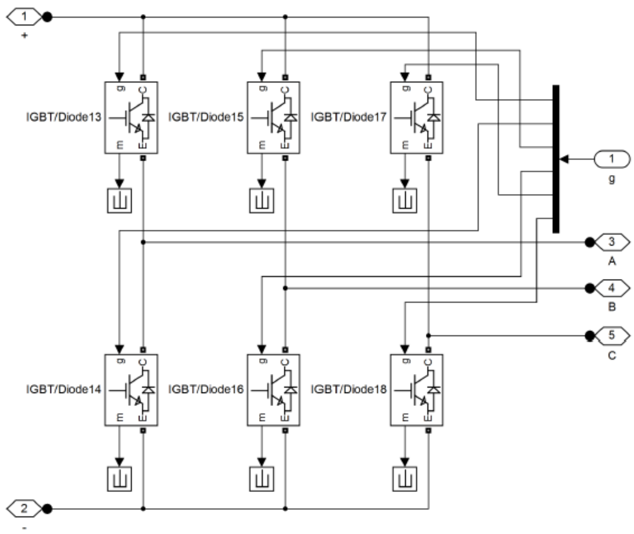


Fig.11. Current source inverter stage of TSMC

The output of voltage source rectifier is fed to the current source inverter termed as virtual DC link and the voltage waveform of the virtual or fictitious DC link for time period 40ms to 60ms is shown in the following figure Fig. 14. The current waveform of the virtual DC link for time period 40ms to 60ms is shown in the following figure Fig. 15.

The line-line output voltage waveform of the load for three phase system is shown in the following figure Fig. 16 and Fig. 17 shows the line-line output voltage waveform across $V_{AB}$ of the system. Fig. 18 shows the output load current waveform for 25% load.

Fig.19 shows the Total Harmonic Distortion (THD) of the output current for 25% load. Fig. 20 shows the output load current waveform for 50% load and corresponding THD measured is shown in figure Fig. 21.

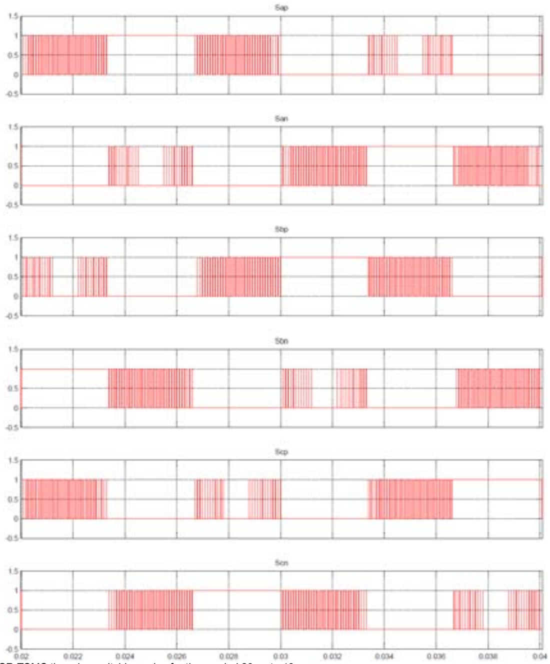


Fig.12. VSR-TSMC three leg switching pulse for time period 20ms to 40ms

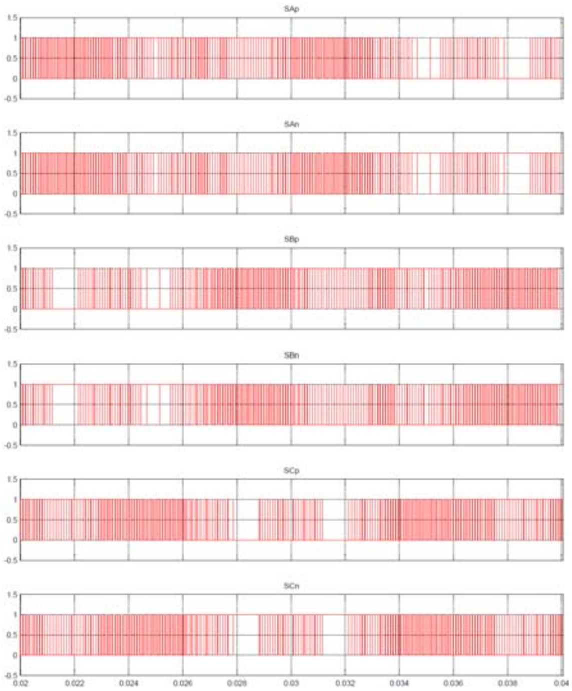


Fig.13. CSI-TSMC three leg switching pulse for time period 20ms to 40ms

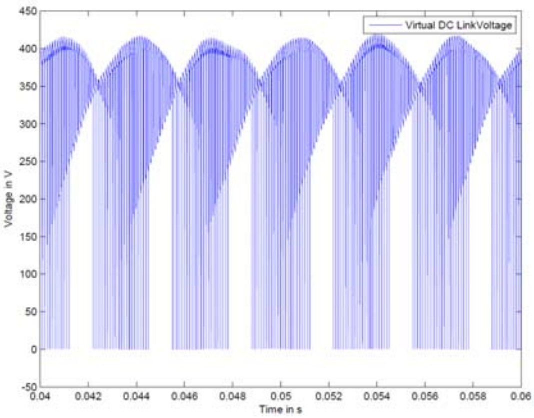


Fig14. Virtual DC link voltage waveform for time period 40ms to 60ms

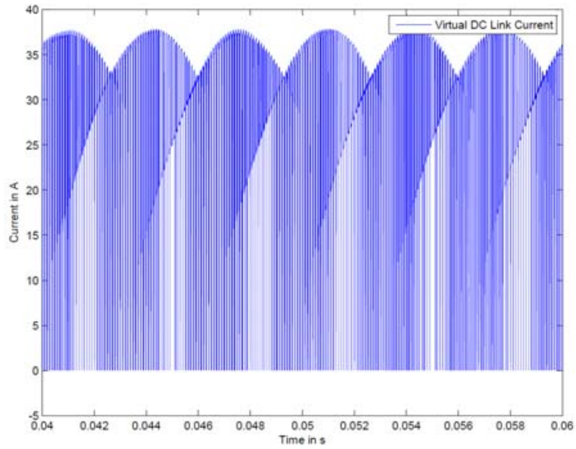


Fig.15. Virtual DC link current waveform from time period 40ms to 60ms

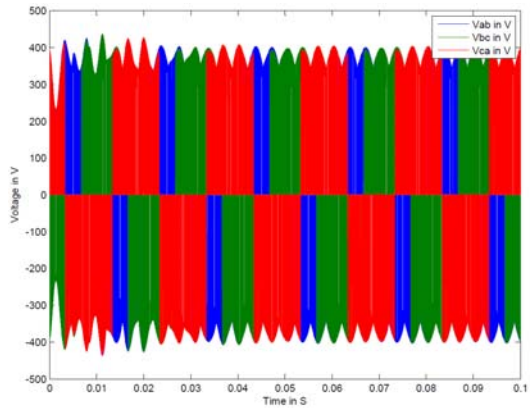


Fig.16. Line-Line output three phase load voltage waveform

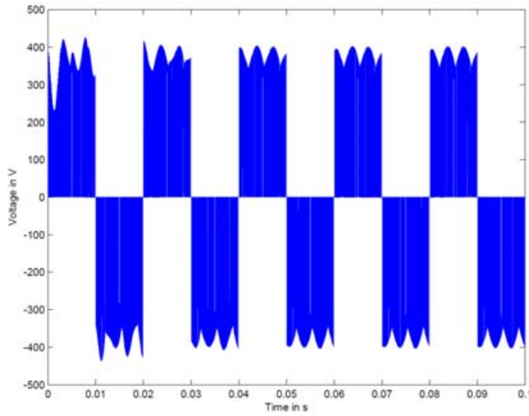


Fig.17. Line-line output load voltage waveform of $V_{AB}$

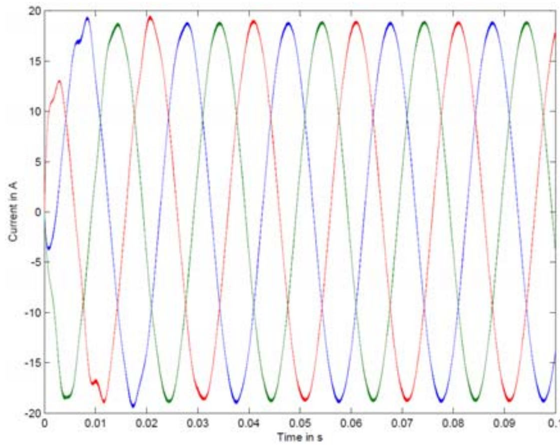


Fig.18. Output load current waveform for 25% load

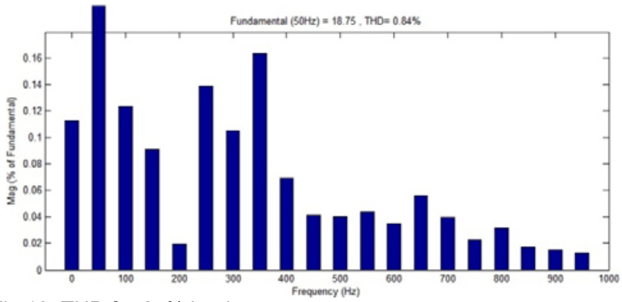


Fig.19. THD for 25% load

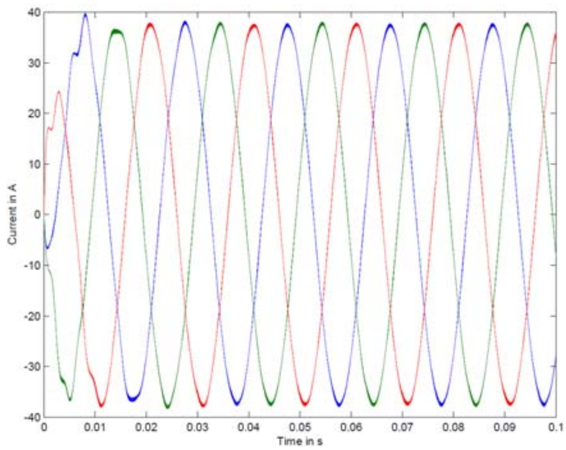


Fig.20. Output load current waveform for 50% load

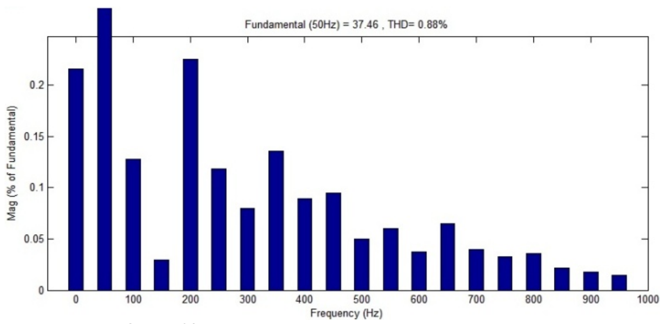


Fig.21. THD for 50% load

Fig. 22 shows the output load current waveform for 75% load and corresponding THD is shown in figure Fig. 23. Following Fig. 24 shows the output full load current.

Following figure Fig. 25 shows the THD value measured for full load current.

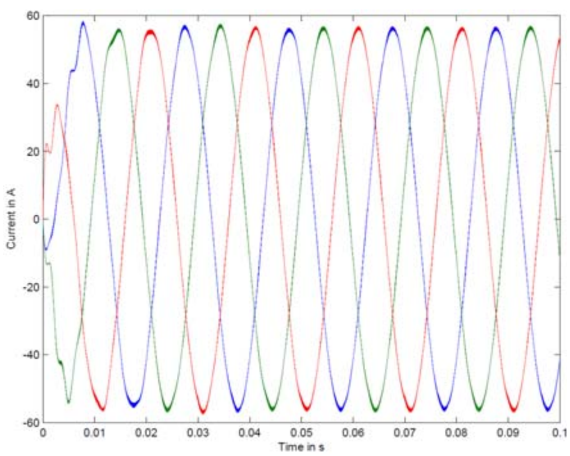


Fig.22. Output load current waveform for 75% load

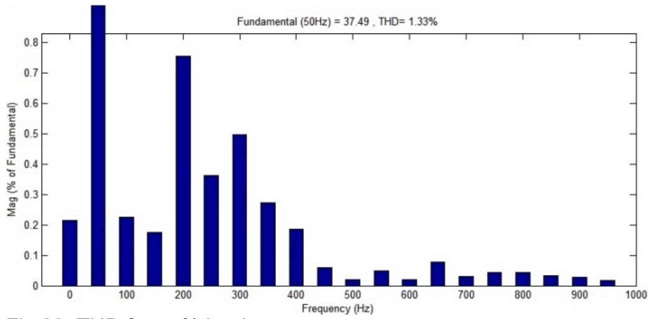


Fig.23. THD for 75% load

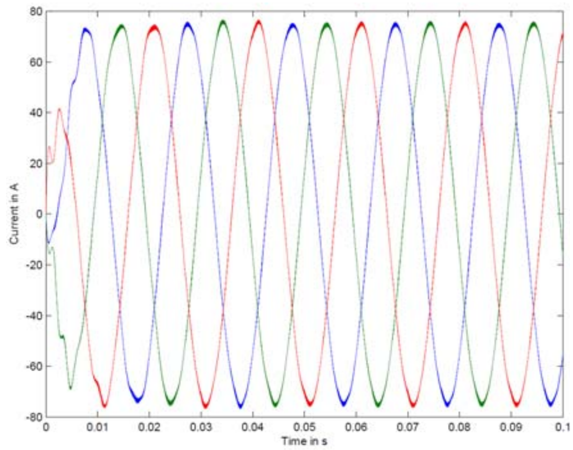


Fig.24. Output load current waveform for full load

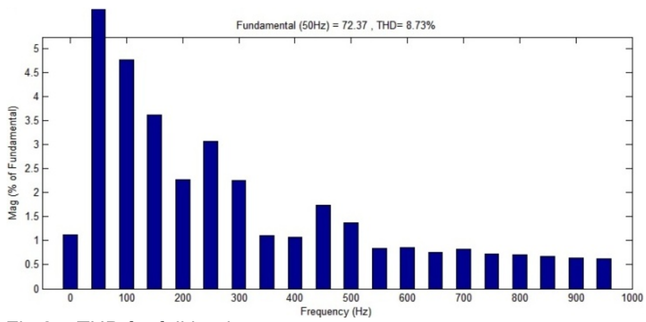


Fig.25. THD for full load

The power factor measured for the above various loading conditions is measured and the value was higher than 0.95 for all the loading conditions as shown in figure Fig, 26 which exhibit a good power quality of the proposed system. The THD value measured under various loading conditions is depicted by the following figure Fig. 27 shows very low THD values which meet the international standards.

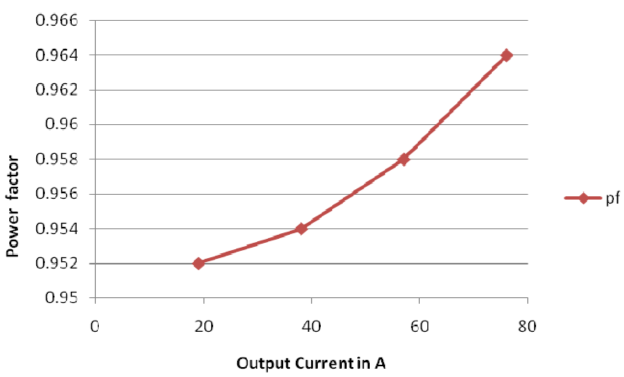


Fig.26. Power factor Vs load current

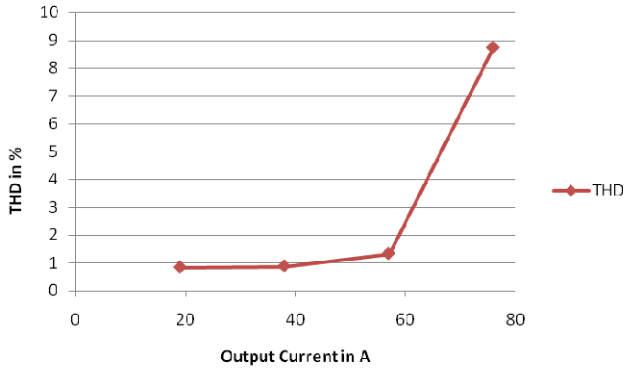

Fig.27. THD Vs load current

**Conclusion**

The Wind Turbine Generator (WTG) driven by Permanent Magnet Synchronous Generator (PMSG) is designed for a standalone system using Two-Stage Matrix Converter (TSMC) and the performance of the system for various loading conditions was analyzed and results obtained from MATLAB/SIMULINK were presented in this manuscript. The above results exhibit very low Total harmonic Distortion (THD) and high power factor (>0.95) resulting in good power quality which meets the international standard. Thus improved power quality resulting in higher efficiency confirms the robust operation of the designed system.

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