

DOUBLY FED INDUCTION GENERATOR FOR WIND ENERGY SYSTEMS WITH A NOVEL SVPWM BASED INDIRECT MATRIX CONVERTERS INTERFACE

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ABSTRACT:

In this paper wind power generation is used in standalone system due to their feature of high efficiency and low maintenance cost, which was fed with smart indirect matrix converter for indirect AC-DC-AC conversion, It provides sinusoidal output waveforms with minimal higher order harmonics and no sub harmonics and also it eliminate the usage of dc-link and other passive elements. Space vector modulation (SVM) controlled technique is used for matrix converter switching which can eliminate the switching losses by selected switching states. Proposed work is often seen as a future concept for variable speed drives technology. The matrix network offers other advantages, such as lower component ratings, reduced source stress and switch count, and simpler control strategies. The generator-grid interfaces described in this paper are based on the ultra sparse matrix topology characterized by the minimum number of semiconductor switches. A unique feature of the proposed model is that it requires very less computation time and less memory compared to the power circuit realized by using actual switches. In addition, it offers better spectral performances, full control of the input power factor, fully utilization of input voltages, improve modulation performance and output voltage close to sinusoidal. The proposed model for RL load was analyzed and verified by varying the resistor and inductance value and analyzed using MATLAB simulation.

INTRODUCTION:

In proposed method Matrix converter replaced the traditional voltage source inverters and current source inverters by their effective advantages like it fulfils all the requirements of the conventionally used rectifier/dc link/inverter structures and provides an efficient way to convert electric power for motor drives, UPS, VF generators, and reactive energy control. In generation matrix converter has desirable characteristics such as bidirectional energy flow capability, it provides sinusoidal input and output waveform with minimum high order harmonics and no sub harmonics,

Minimum energy storage requirements, controllable input power factor. Furthermore, the MC has more advanced potential than conventional voltage source inverters, which are the following unity input power factor at the power supply side, availability of continuous zero speed operation because no current concentrates in any of switches, compact design and long life due to the absence of a bulky electrolytic capacitor. it also contains some limitations like the limitation in voltage transfer ratio has a maximum value of 0.866 and due to the direct connection between input and output sides it is sensitive to the power

storage distortion. A current- fed system at the input and a voltage- fed system at the output due to its inherent bi-directionality and symmetry a dual connection might be also feasible for the matrix converter. Capacitive filter on the voltage- fed side and the inductive filter on the current- fed side. Their size is inversely proportional to the matrix converter switching frequency. The space vector modulation technique is used to control the inverter output voltage and frequency. it constructs the desired sinusoidal output three phase voltage by selecting the valid switching States of a three phase matrix converter and calculating their corresponding on time duration. Implementation of SVM method involves two main procedures, switching vector selection and Vector on time calculation. PMSG is selected for wind power generation due to the advantages like the gearbox can be omitted due to low rotational speed of the PMSG. It is well known that there is a rotational speed in wind turbine for any particular wind speed. The rotational speed is called the optimum rotational speed and generates the maximum power. It operates at high power factors and high efficiencies reduce mechanical stresses.

In this paper, wind generator fed by indirect controlled matrix converter with a space vector modulated (SVM) was proposed. A complete mathematical analysis of the power circuit along with the duty cycle calculation (switching algorithm) is described for both low voltage transfer ratio (0.5) and maximum voltage transfer ratio (0.866). The whole model is then realized by using Simulink blocks such as math operators, relational operators, and delay circuits. Finally, the proposed mathematical model is validated using a passive *RL* load and active induction motor load.

MODELLING OF THE WIND TURBINE

a) Modelling of the wind turbine:

Mechanical torque developed by the wind turbine T_m is expressed as

$$T_m = 1/2 \rho \pi R^2 C_p(\lambda, \beta) V^3 / \Omega_r$$

$$(\lambda) = R \Omega_r / v$$

$C_p(\lambda, \beta)$ has been considered as

$$C_p = [0.5 - 0.00167(\beta - 2)]$$

$$\sin[\pi(\lambda + 0.1)/(12 - 0.3)(\beta - 2)]$$

β = pitch angle which is set as zero

b) Modeling of the wind generator:

When designing a wind generator, it is useful to compose a computer simulation before building a prototype. If there are N phases, then there are N stator voltages, currents, and flux linkages. Let the set of stator voltages be represented compactly as

$$V = [v_1 \ v_2 \ \dots \ v_N]^T$$

Then, applying Faraday's and Ohm's laws, the stator voltage equation may be written as

$$V = r i + d/dt(\lambda)$$

Regarding the machine as balanced, symmetrical, and magnetically linear, the flux linkage equation may be written as

$$\Lambda = L i + \lambda_{pm}$$

where

L is a symmetric $N \times N$ matrix of the appropriate self- and mutual inductances.

λ_{pm} is an $N \times 1$ vector of stator flux linkages due to the permanent magnet.

The torque equation can be derived from co energy relationships.

$$T_e = P/2 \partial/\partial \theta_r (1/2 i^T L i + i^T \lambda_{pm}) + T_{cog}$$

Where

θ_r is the electrical rotor position in radians.

P is the number of poles.

$\theta_{rm} = 2\theta_r/p$ is the Mechanical rotor position.

T_{cog} is the cogging torque.

Equations represent a simulation model of the machine provided that the resistance r , the inductance matrix $\mathbf{L}$, the cogging torque T_{cog} , and the permanent magnet flux linkage vector, λ_{pm} , are known. The parameters can be determined from direct measurement or by calculation from motor geometry (i.e., finite-element analysis). The mechanical dynamics of the system, which are not discussed here since they can widely vary, must be simulated to determine position and speed. Λ_{pm} is the function of rotor position.

The torque equation for the surface-mounted case is

$$T_{e(sm)} = P/2 i_T \frac{\partial}{\partial \theta_r} \lambda_{pm} + T_{cog}$$

The torque equation for a machine with buried magnets is

$$T_{e(BM)} = P/2 i_T (1/2 (\frac{\partial}{\partial \theta_r} L) I) + \frac{\partial}{\partial \theta_r} \lambda_{pm} + T_{cog}$$

The cogging torque may be represented as

$$T_{cog} = \sum T_q z \cos(z N_t \theta_r) + T_z d \sin(z N_t \theta_r)$$

Z is the set of natural numbers.

The Fourier series constants T_q

z and T_d

z are negligible and the constant.

N_t is the number of stator teeth.

The power in to the machine and the output is expressed as

$$P_{in} = V T_i$$

$P_{out} = T_e \omega_{rm}$ Where ω_{rm} is the mechanical rotor speed.

If the back emf is sinusoidal, then the flux linkage due the permanent magnets is as well. That is λ_{pm} may be expressed as

$$\lambda_{pm} = \lambda_m [\sin(\theta_r) \sin(\theta_r - 2\pi/3) \sin(\theta_r + 2\pi/3)] T$$

The back emf due to the permanent magnets may be stated as

$$E_{pm} = \omega_r \lambda_m [\cos(\theta_r) \cos(\theta_r - 2\pi/3) \cos(\theta_r + 2\pi/3)] T$$

Where ω_r is the electrical rotor speed and equals $P/2$ times.

The rotor position-dependent terms can be eliminated by transforming the variables into a reference frame fixed in the rotor. Only the results of this long process are given here. The transformation is applied as.

$$V_{qdo} = K v$$

$$V_{qdo} = [V_q V_d V_o] T$$

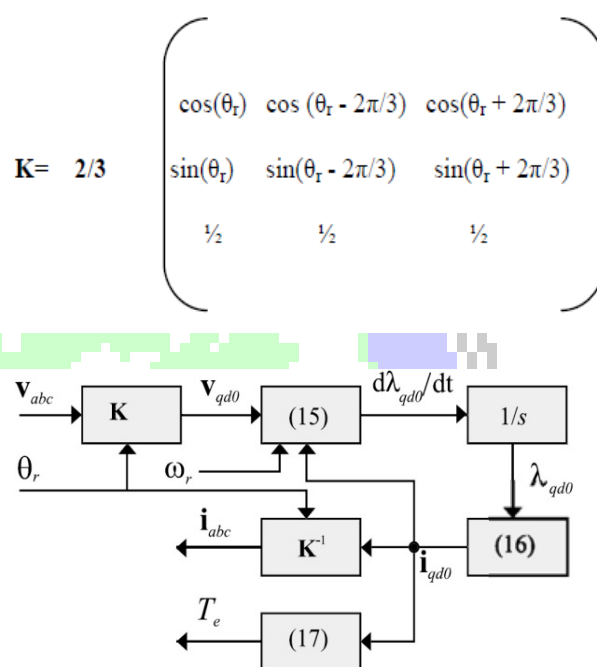


Figure 1. Diagram of control loop model

After transforming the equations into the rotor reference frame with the following relationships hold.

$$V_q = r i_q + \omega_r \lambda_d + d/dt (\lambda_q)$$

$$V_d = r i_d - \omega_r \lambda_q + d/dt (\lambda_d)$$

$$V_o = r i_o + d/dt (\lambda_o)$$

$$\Lambda_q = L_q i_q$$

$$\Lambda_d = L_d i_d + \lambda_m$$

$$\Lambda_o = L_o i_o$$

$$T_e = 3/2 P/2 \lambda_m i_q + (L_d - L_q) i_d i_q$$

SPACE VECTOR MODULATION:

Space Vector Modulation refers to a special switching sequence which is based on the upper switches of a three phase matrix converter. Theoretically, SVM treats a sinusoidal voltage as a phasor or amplitude vector which rotates at a constant angular frequency, ω . This amplitude vector is represented in $d-q$ plane where it denotes the real and imaginary axes. As SVM treats all three modulating signals or voltages as one single unit, the vector summation of three modulating signals or voltages are known as the reference voltage, V_{ref} which is related to the magnitude of output voltage of the switching topologies. The aim of SVM is to approximate the reference voltage vector, V_{ref} from the switching topologies. For a balanced three phase sinusoidal system the instantaneous voltages maybe expressed as

$$\begin{bmatrix} V_u(t) \\ V_v(t) \\ V_w(t) \end{bmatrix} = V_o \begin{bmatrix} \cos \omega_0 t \\ \cos(\omega_0 t - 120^\circ) \\ \cos(\omega_0 t - 240^\circ) \end{bmatrix}$$

This can be analyzed in terms of complex space vector

$$\vec{V}_o = \frac{2}{3} \left[V_u(t) + V_v(t)e^{\frac{j2\pi}{3}} + V_w(t)e^{\frac{j4\pi}{3}} \right] = V_o e^{j\omega_0 t}$$

$$\vec{V}_i = \frac{2}{3} \left[V_a(t) + V_b(t)e^{\frac{j2\pi}{3}} + V_c(t)e^{\frac{j4\pi}{3}} \right] = V_i e^{j\omega_i t}$$

Where V_i is the amplitude and ω_i is the constant input angular velocity. If a balanced three phase load is connected to the output terminals of the converter, the

space vector forms of the three phase output and input currents are given by

$$\vec{I}_o = \frac{2}{3} \left[I_u(t) + I_v(t)e^{\frac{j2\pi}{3}} + I_w(t)e^{\frac{j4\pi}{3}} \right] = I_o e^{j(\omega_0 t - \phi_o)}$$

$$\vec{I}_i = \frac{2}{3} \left[I_a(t) + I_b(t)e^{\frac{j2\pi}{3}} + I_c(t)e^{\frac{j4\pi}{3}} \right] = I_i e^{j(\omega_i t - \phi_i)}$$

Respectively, where theta 0 is the lagging phase angle of the output current to the output voltage and theta I is that of the input current to the input voltage.

Switching Principle

The three phase matrix converter (MC) topology is shown in Figure 2.

Since MC connects load directly to the voltage source by using nine bidirectional switches, the input phases must never be shorted, and due to the inductive nature of the load, the output phases must not be left open. If the switching function of a switch, in Figure 2, is defined as

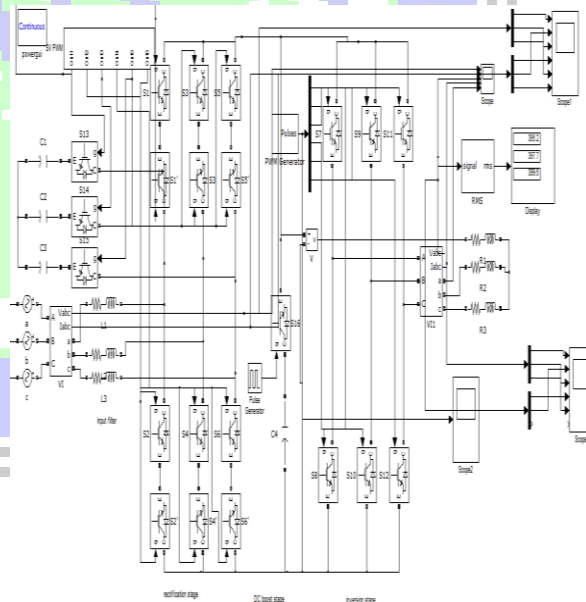


Figure 2: Three phase indirect SVPWM based matrix converter

$$S_{ij} = \begin{cases} 1, & S_{ij} \text{ close} \\ 0, & S_{ij} \text{ open} \end{cases} \quad i \in \{u, v, w\}, j \in \{a, b, c\}$$

The constraints can be expressed as

$$S_{ia} + S_{ib} + S_{ic} = 1,$$

For a three phase MC there are 27 valid switch combinations giving thus 27 voltage vectors as

shown in Table 1. The switching combinations can be classified into three groups which are, synchronously rotating vectors, stationary vectors and zero vectors.

Table 1: Matrix converter switching vectors

Group	ON Switch	V_u	V_v	V_w	I_a	I_b	I_c	V_0	ω_0	I_0	α_0
I	S_{uv}, S_{vu}, S_{ww}	V_u	0	$-V_u$	I_a	$-I_a$	0	$2/3V_u$	0	$2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	0	V_u	$-I_a$	I_a	0	$-2/3V_u$	0	$-2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	V_u	0	$-V_u$	0	I_a	$-I_a$	$2/3V_u$	0	$2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	0	V_u	0	$-I_a$	I_a	$-2/3V_u$	0	$-2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	V_u	0	$-V_u$	$-I_a$	0	I_a	$2/3V_u$	0	$2/\sqrt{3}V_u$	$7\pi/6$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	0	V_u	I_a	0	$-I_a$	$-2/3V_u$	0	$-2/\sqrt{3}V_u$	$7\pi/6$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	V_u	0	I_a	$-I_a$	0	$2/3V_u$	$2\pi/3$	$2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	V_u	$-V_u$	0	$-I_a$	I_a	0	$-2/3V_u$	$2\pi/3$	$-2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	V_u	0	0	I_a	$-I_a$	$2/3V_u$	$2\pi/3$	$2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	V_u	$-V_u$	0	0	$-I_a$	I_a	$-2/3V_u$	$2\pi/3$	$-2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	V_u	0	$-I_a$	0	I_a	$2/3V_u$	$2\pi/3$	$2/\sqrt{3}V_u$	$7\pi/6$
	S_{uv}, S_{vu}, S_{ww}	V_u	$-V_u$	0	I_a	0	$-I_a$	$-2/3V_u$	$2\pi/3$	$-2/\sqrt{3}V_u$	$7\pi/6$
	S_{uv}, S_{vu}, S_{ww}	0	$-V_u$	V_u	I_a	$-I_a$	0	$2/3V_u$	$4\pi/3$	$2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	0	V_u	$-V_u$	$-I_a$	I_a	0	$-2/3V_u$	$4\pi/3$	$-2/\sqrt{3}V_u$	$-\pi/6$
	S_{uv}, S_{vu}, S_{ww}	0	$-V_u$	V_u	0	I_a	$-I_a$	$2/3V_u$	$4\pi/3$	$2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	0	V_u	$-V_u$	0	$-I_a$	I_a	$-2/3V_u$	$4\pi/3$	$-2/\sqrt{3}V_u$	$\pi/2$
	S_{uv}, S_{vu}, S_{ww}	0	$-V_u$	V_u	$-I_a$	0	I_a	$2/3V_u$	$4\pi/3$	$2/\sqrt{3}V_u$	$7\pi/6$
	S_{uv}, S_{vu}, S_{ww}	0	V_u	$-V_u$	I_a	0	$-I_a$	$-2/3V_u$	$4\pi/3$	$-2/\sqrt{3}V_u$	$7\pi/6$
II	S_{uv}, S_{vu}, S_{ww}	0	0	0	0	0	0	0	-	0	-
	S_{uv}, S_{vu}, S_{ww}	0	0	0	0	0	0	0	-	0	-
	S_{uv}, S_{vu}, S_{ww}	0	0	0	0	0	0	0	-	0	-
III	S_{uv}, S_{vu}, S_{ww}	V_u	V_v	V_w	I_a	I_b	I_c	V_0	$\omega_0 t$	I_0	$\alpha_0 t$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	$-V_v$	$-V_w$	I_a	I_b	I_c	$-V_0$	$-\omega_0 t$	$-I_0$	$-\alpha_0 t$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	$-V_v$	$-V_w$	I_a	I_b	I_c	$-V_0$	$-\omega_0 t$	$-I_0$	$-\alpha_0 t$
	S_{uv}, S_{vu}, S_{ww}	V_u	V_v	V_w	I_a	I_b	I_c	V_0	$\omega_0 t$	I_0	$\alpha_0 t$
	S_{uv}, S_{vu}, S_{ww}	V_u	V_v	V_w	I_a	I_b	I_c	V_0	$\omega_0 t$	I_0	$\alpha_0 t$
	S_{uv}, S_{vu}, S_{ww}	$-V_u$	$-V_v$	$-V_w$	I_a	I_b	I_c	$-V_0$	$-\omega_0 t$	$-I_0$	$-\alpha_0 t$

SIMULATION RESULTS

The simulation and practical results obtained for the matrix converter circuit are presented in this chapter. The chapter is divided into two main sections; a section that presents the simulation results of both the direct and the indirect matrix converter topologies, while the other section presents the practical results of the 3phase to 3 phase AC/DC/AC direct matrix converter topology. Practical results of the indirect matrix converter topology are not included in this section, since this topology is not part of the thesis.

The simulation results of this topology are presented to show a comparison of the advantages and disadvantages, as well as to verify whether the desired characteristics of the indirect matrix converter topology can be achieved by this topology. Some practical results obtained from the direct matrix converter are presented. Fixed duty cycles that results only 50 Hz output frequency and controllable voltage level, and variable duty cycles calculated based on the transfer function proposed, were applied. These variable duty cycles used generate a controlled output frequency range and a controlled output voltage level. The simulation results of the direct matrix converter topology will be examined and are followed by presenting the results of the indirect matrix converter topology. Finally, some of the practical results of the indirect matrix will be presented.

Simulation Results of the Indirect Matrix Converter

The converter circuit of the 3phase to 3 phase AC/DC/AC indirect matrix converter setup is shown in Figure 3. Four different modulation transfer functions of generating the control switching signals were applied to the ideal switches of the converter. These are a forward transfer function, a reversed

transfer function, a combined transfer function with 50% maximum gain, which can able to control the input phase shift of the converter to unity, and the final transfer function with 86.67% maximum gain, as well able to control the input phase shift of the converter to unity. All four-transfer functions are proposed. Table 2 shows the specification of the three-phase-to-three-phase indirect matrix converter circuit.

Table 2 Input/output specifications of the indirect matrix converter

Symbol	Parameter	Value	Unit
$3\phi V_i$	Input supply Voltage	400	V
f_{in}	Input frequency	50	Hz
L_{in}	Input inductance	200	μH
C_{in}	Input capacitance	50	μF
R_{in}	Input resistance	0.02	Ω
$3\phi V_o$	Output Voltage	0.200	V
f_o	Output frequency	0.200	Hz
I_o	Output current	0.10	A
R_L	Resistive load	10	Ω
L_o	Output inductance	2000	μH
C_o	Output capacitance	50	μF
f_s	Switching frequency	5	kHz

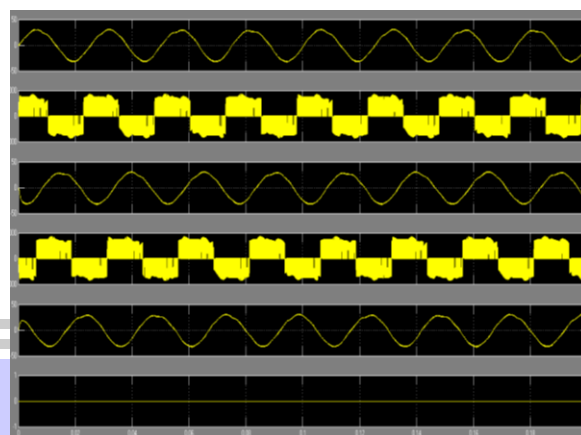
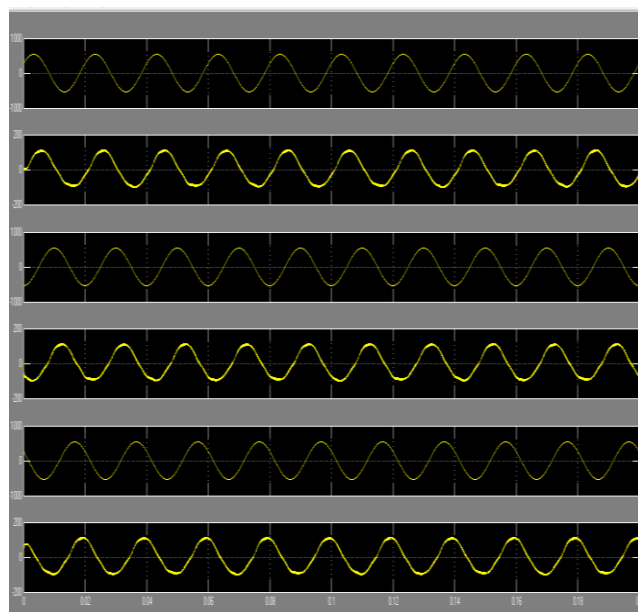


Figure 4 Output voltage and current, Line-line voltage, Phase-line voltage

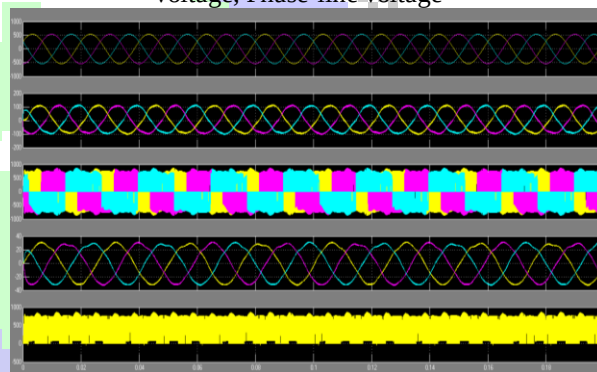
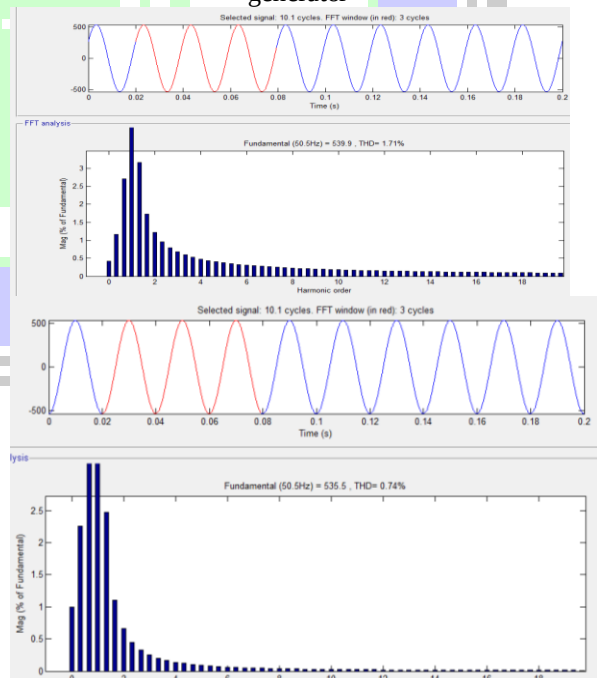


Figure 5. Output 3 phase voltages & currents of wind generator



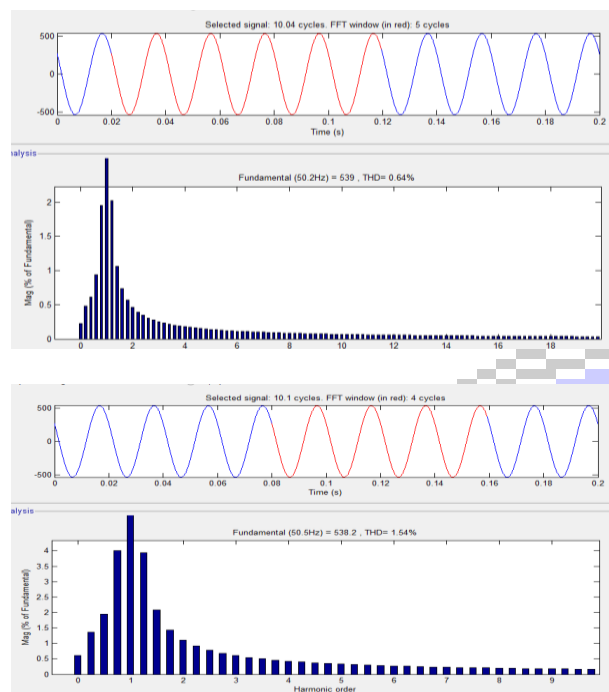


Fig.6 T.H.D analysis of line current & phase voltages

CONCLUSION

The proposed work demonstrated the comparative analysis for varying resistance and inductance using Space Vector Modulation Techniques. The wind generator connected to a indirect AC-DC-AC matrix converter without the need of energy storage elements fed to RL load. It is observed that SVPWM is more efficient compared to the other PWM techniques. The efficiency of the proposed converters is expected to be high due to reduced number of power electronic switches.

Furthermore, the shoot-through state is no longer a hazard, which improves the reliability of the proposed converters. The THD analysis of input and output currents & line currents & phase voltages has shown (1.73%,0.74%,0.64%,1.54%) highly superiority of the proposed converter over the QZMC with respect to the quality of

input currents. By using matrix converter conventional DC-link are eliminated to attain high efficiency and low cost. In future the work is extreme with modeling agricultural motor for water pumping and also for variable speed drives.

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