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Space Vector Modulation Based Direct Matrix Converter for Stand-Alone system

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ABSTRACT

In this paper Permanent Magnet Synchronous Generator (PMSG) is used for wind power generation in standalone system due to their feature of high efficiency and low maintenance cost, which was fed with smart direct matrix converter for direct AC-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 loses by selected switching states. Proposed work is often seen as a future concept for variable speed drives technology. The proposed model for RL load was analysed and verified by varying the resistor and inductance value and analysed using MATLAB simulation.

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1. INTRODUCTION

Generating energy through the Wind Energy Conversion System (WECS) is one of the most desired ways in the field of renewable energy like Biomass, wind, solar and hydropower because it has no major complexity on implementation. While comparing with non-renewable energy sources like thermal, nuclear power plants WECS not involve in polluting the nature. They also include standalone applications like water pumping for irrigation, power generation in remote areas and also for grid interfacing. There are mainly three types of Wind driven generators which are fixed speed and variable speed wind turbines induction generator's under the category of fixed speed and under variable speed there are two types of generators such as doubly fed induction generator (DFIG) and PMSG [2] [3]. PMSG is an attractive choice for variable-speed generation system. Due the following advantages, it can connected directly to the turbine without gearbox and do not require any external excitation current. So it can operate at low speeds and reduce again weight, losses, and costs [4].

In conventional method developed solid state power electronic converters like voltage source inverter and impedance source inverter fed wind energy conversion system has facilitated the control of the output voltage of wind turbine generators such as SEIG,DFIG,PMSG .It contains dc-link and passive components. It is important to obtain the output from an inverter with low harmonics and better efficiency. This is achieved by selecting the best control techniques to control the switches. The inverter switching pulses are controlled through various Pulse Width Modulation Techniques (PWM) [5] like Fixed PWM, Sinusoidal PWM, and Space Vector PWM. These control techniques have their specific advantages over the other. The selection of the control techniques are based on the application for the high efficiency reduced losses and reduced harmonics.

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 [7] [8]. 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 n 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 [1]. 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 [9]. 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 [2]. It operates at high power factors and high efficiencies reduce mechanical stresses.

2. CIRCUIT DIAGRAM & DESCRIPTION

In this power generation system, a horizontal axis wind turbine with a PMSG connected to the resistive load through a direct AC-AC matrix converter is considered. It consists of wind turbine, PMSG, direct matrix converter and feeding an resistive load as shown in figure 1. The permanent magnet synchronous generator is used in stand-alone energy conversion systems due to features like high efficiency and low maintenance cost. To overcome the difficulties like DC-link, AC-DC-AC conversion, energy storage elements direct matrix converter is used. Filters are used to eliminate the harmonics. The input power factor control capability is another attractive feature of matrix converters. The space vector modulation technique is used to control the inverter output voltage and frequency. By this control technique switching losses are controlled by selected switching using vector control.

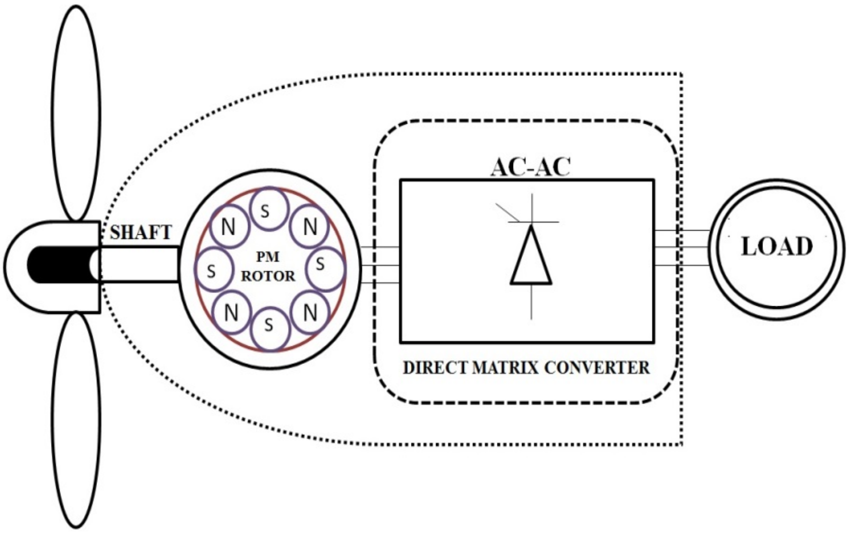


Figure 1. Circuit Diagram of the Proposed Method

3. DIRECT MATRIX CONVERTER

Direct matrix converter shown in figure 2 is direct AC-AC converter which has several advantages over traditional inverters. It provides sinusoidal input and output waveforms, with minimal higher order harmonics and no sub harmonics, it has inherent bi-directional energy flow capability; the input power factor can be fully controlled. Last but not least, it has minimal energy storage requirements, which allows to get rid of bulky and lifetime- limited energy-storing capacitors frequency converters. It consists of consists of 9 bi-directional switches that allow any output phase to be connected to any input phase. With nine bi-directional switches the matrix converter can theoretically assume 512 (2^9) different switching states combinations. But not all of them can be usefully employed. Regardless to the control method used, the choice of the matrix converter switching states combinations to be used must comply with two basic rules, they are that the converter is supplied by a voltage source and usually feeds an inductive load, the input phases should never be short-circuited and the output currents should not be interrupted. From a practical point of view by these rules imply that one and only one bi-directional switch per output phase must be switched on at any instant. By this constraint, in a three phase to three phase matrix converter 27 switching combinations are the permitted switching. no energy storage components are absent between the input and output side of the matrix converter, the output voltages and current have to be generated directly from the input voltages and current. The input power factor control capability is another attractive feature of matrix converters. The input filter acts as an interface between the matrix converter and the AC mains to prevent unwanted harmonic currents from flowing into AC mains [9] [10].

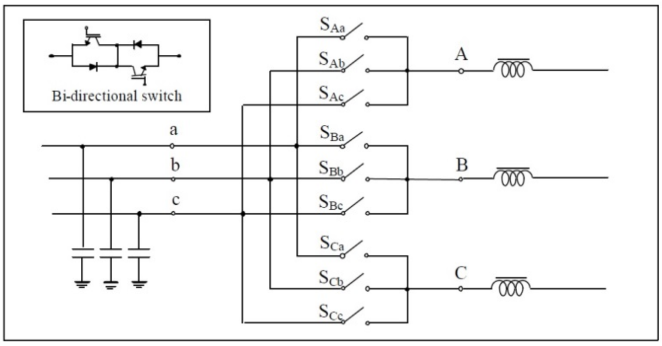


Figure 2. Direct matrix converter

4. SVM FOR DIRECT MATRIX CONVERTER

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. The valid switching states of a matrix converter are represented as voltage space vectors. Implementation of SVM method involves two main procedures, switching vector selection and Vector on time calculation.

For three phase matrix converters there are 27 valid switch combinations giving thus 27 voltage vectors. These can be divided in to three vectors, they are as follows synchronously rotating vectors, stationary vectors, zero vectors, which was in table 1

Synchronously rotating vectors :

Switching state connecting every output phase to a different input phase.
It produce voltage space vectors rotating with the input angular frequency.
Constant magnitude and angular frequency.

stationary vectors:

It use only two input voltage at a time.
It produce voltage space vectors with constant angle.
Varying magnitude

zero vectors.

All output phases are connected to same input phase.
It produce zero output voltage

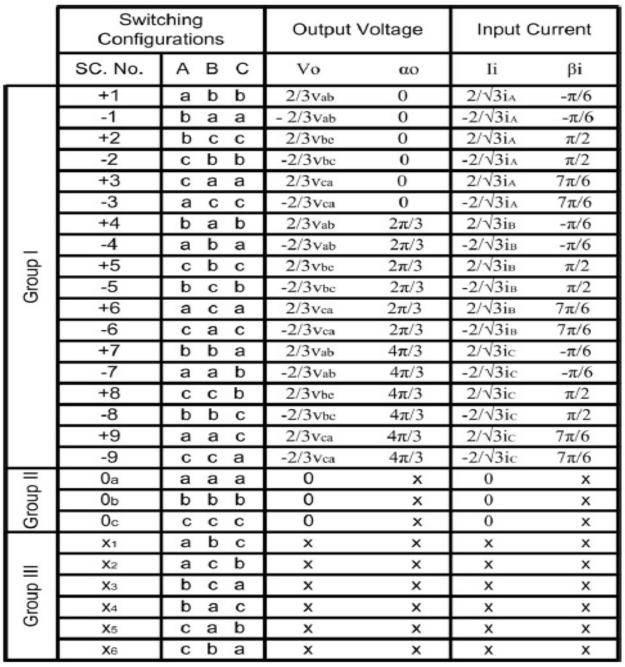
From the figure 2 the three-phase matrix converter module includes nine bidirectional switches. a, b, and c are the voltage and current at the input side of the matrix converter and the output side are denoted by A, B, and C.

$$V_a = V_m \cos(\omega t) \tag{1}$$

$$V_b = V_m \cos(\omega t - 2\pi/3) \tag{2}$$

$$V_C = V_m \cos(\omega t - 4\pi/3) \tag{3}$$

Table 1. Switching configuration and vectors used in matrix converter



	Switching Configurations				Output Voltage		Input Current	
	SC. No.	A	B	C	Vo	αo	Ii	βi
Group I	+1	a	b	b	$2/3v_{ab}$	0	$2/\sqrt{3}i_A$	$-\pi/6$
	-1	b	a	a	$-2/3v_{ab}$	0	$-2/\sqrt{3}i_A$	$-\pi/6$
	+2	b	c	c	$2/3v_{bc}$	0	$2/\sqrt{3}i_A$	$\pi/2$
	-2	c	b	b	$-2/3v_{bc}$	0	$-2/\sqrt{3}i_A$	$\pi/2$
	+3	c	a	a	$2/3v_{ca}$	0	$2/\sqrt{3}i_A$	$7\pi/6$
	-3	a	c	c	$-2/3v_{ca}$	0	$-2/\sqrt{3}i_A$	$7\pi/6$
	+4	b	a	b	$2/3v_{ab}$	$2\pi/3$	$2/\sqrt{3}i_B$	$-\pi/6$
	-4	a	b	a	$-2/3v_{ab}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$-\pi/6$
	+5	c	b	c	$2/3v_{bc}$	$2\pi/3$	$2/\sqrt{3}i_B$	$\pi/2$
	-5	b	c	b	$-2/3v_{bc}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$\pi/2$
	+6	a	c	a	$2/3v_{ca}$	$2\pi/3$	$2/\sqrt{3}i_B$	$7\pi/6$
	-6	c	a	c	$-2/3v_{ca}$	$2\pi/3$	$-2/\sqrt{3}i_B$	$7\pi/6$
	+7	b	b	a	$2/3v_{ab}$	$4\pi/3$	$2/\sqrt{3}i_C$	$-\pi/6$
	-7	a	a	b	$-2/3v_{ab}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$-\pi/6$
	+8	c	c	b	$2/3v_{bc}$	$4\pi/3$	$2/\sqrt{3}i_C$	$\pi/2$
	-8	b	b	c	$-2/3v_{bc}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$\pi/2$
	+9	a	a	c	$2/3v_{ca}$	$4\pi/3$	$2/\sqrt{3}i_C$	$7\pi/6$
	-9	c	c	a	$-2/3v_{ca}$	$4\pi/3$	$-2/\sqrt{3}i_C$	$7\pi/6$
Group II	0_a	a	a	a	0	x	0	x
	0_b	b	b	b	0	x	0	x
	0_c	c	c	c	0	x	0	x
Group III	x_1	a	b	c	x	x	x	x
	x_2	a	c	b	x	x	x	x
	x_3	b	c	a	x	x	x	x
	x_4	b	a	c	x	x	x	x
	x_5	c	a	b	x	x	x	x
	x_6	c	b	a	x	x	x	x

The switching function of a switch S_{ij} in figure 2 is defined as
$S_{ij}(t)$= 1(S_{ij} closed),if it is 0 (S_{ij} open)
$i\epsilon(a,b,c)$ and $j\epsilon(A,B,C)$
At any time, there is always only one switch connecting one output phase to one input phase

$$S_{aj} + S_{bj} + S_{cj} = 1 \tag{4}$$

The space vector approach is based on the instantaneous space vector representation of input and output voltages and currents. We can describe the input/output current and voltage vectors as follows:

$$V_i = 2/3(v_a + v_b e^{j2\pi/3} + v_c e^{j4\pi/3}) = V_i e^{j\alpha_i} \tag{5}$$

$$V_o = 2/3(v_A + v_B e^{j2\pi/3} + v_C e^{j4\pi/3}) = V_o e^{j\alpha_o} \tag{6}$$

$$i_i = 2/3(i_a + i_b e^{j2\pi/3} + i_c e^{j4\pi/3}) = I_i e^{j\alpha_i} \tag{7}$$

$$i_o = 2/3(i_A + i_B e^{j2\pi/3} + i_C e^{j4\pi/3}) = I_o e^{j\alpha_o} \tag{8}$$

From (5)–(8), the output voltage vector and the current vector can be determined for each switching configuration.

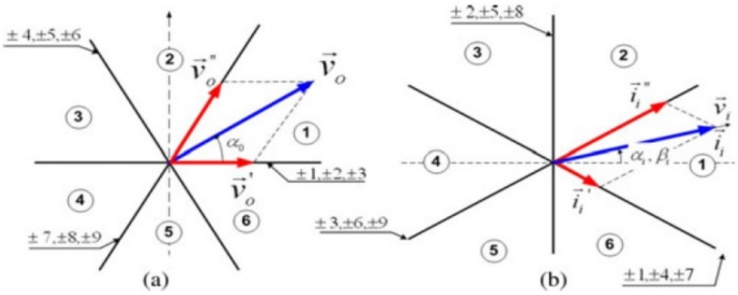


Figure 3. (a) Output line-to-neutral voltage vector. (b) Input line current vector

5. MODELLING OF THE WIND TURBINE

a) Modelling of the wind turbine:
Mechanical torque developed by the wind turbine Tm is expressed as
Tm=1/2ρπRt2Cp(λβ)V3/Ωr
(λ)=RtΩr/v
Cp(λ,β) has been considered as
Cp=[0.5-0.00167(β-2)]
sin[π(λ+0.1)/(12-0.3)(β-2)]
β=pitch angle which is set as zero

b) Modelling of the PMSG:
When designing a PMSM drive, 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

$$V=[\, v_1 \;\; v_2 \;\; \ldots\ldots \;\; v_N \,]^T$$

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

$$V= ri + d/dt(\lambda) \tag{9}$$

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

$$\Lambda = Li + \lambda_{pm} \tag{10}$$

where
L is a symmetric *N*N* matrix of the appropriate self- and mutual inductances.
Λpm is an *N**1 vector of stator flux linkages due to the permanent magnet.
The torque equation can be derived from coenergy relationships.

$$T_e= P/2 \;\; \partial/\partial\theta_r \,(1/2\; i^T\, Li + i^T\, \lambda_{pm}) + T_{cog} \tag{11}$$

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.

Equation 1,2,3 represent a simulation model of the machine provided that the resistance r, the inductance matrix **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

$$T_{e(sm)} = P/2\ i^T\ \partial/\partial\theta_r\ \lambda_{pm} + T_{cog} \tag{12}$$

The torque equation for a machine with buried magnets is

$$T_{e(BM)}=P/2\ i^T(1/2(\partial/\partial\theta_r\ L)I+ \partial/\partial\theta_r\ \lambda_{pm})+T_{cog} \tag{13}$$

The cogging torque may be represented as

$$T_{cog} = \sum T_q^{\ z} \text{Cos}\ (z\ N_t\ \theta_r) + T^z{}_d\ \text{Sin}\ (z\ N_t\ \theta_r) \tag{14}$$

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

$$P_{in} = V^T i \tag{15}$$

$P_{out} = T_e\ \omega_{rm}$ 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

$$\Lambda_{pm} = \lambda_m\ [\sin(\theta_r)\ \sin(\theta_r - 2\pi/3)\ \sin(\theta_r + 2\pi/3)\ ]^{\ T} \tag{16}$$

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

$$E_{pm} = \omega_r\lambda_m\ [\cos(\theta_r)\ \cos\ (\theta_r - 2\pi/3)\ \cos(\theta_r + 2\pi/3)\ ]^{\ T} \tag{17}$$

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

$$V_{qdo} = Kv \tag{18}$$

$$V_{qdo} = [\ V_q\ V_d\ V_o]^{\ T} \tag{19}$$

$$\mathbf{K=}\quad \mathbf{2/3} \begin{pmatrix} \cos(\theta_r) & \cos\ (\theta_r - 2\pi/3) & \cos(\theta_r + 2\pi/3) \\ \sin(\theta_r) & \sin(\theta_r - 2\pi/3) & \sin(\theta_r + 2\pi/3) \\ ½ & ½ & ½ \end{pmatrix} \tag{20}$$

The Simulation model is shown in figure 2

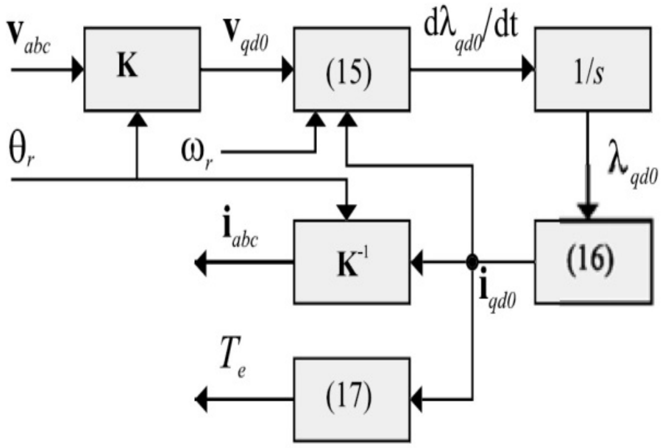


Figure 4. Diagram of simulation model

After transforming the equations into the rotor reference frame with Eq 13 the following relationships hold.

$$V_q = ri_q + \omega_r\lambda_d + d/dt\,(\lambda_q)$$
$$V_d = ri_d - \omega_r\lambda_q + d/dt\,(\lambda_d) \qquad (15)$$
$$V_q = ri_q + d/dt\,(\lambda_0)$$

$$\Lambda_q = L_q i_q$$
$$\Lambda_d = L_d i_d + \lambda_m \qquad (16)$$
$$\Lambda_o = L_o i_o$$

$$T_e = 3/2\ P/2\ \lambda_m\, i_q + (L_d - L_q)\, i_d i_q \qquad (17)$$

6. SIMULATION & RESULTS

The Matlab/Simulink model of the PMSG fed resistive and inductive load through AC to AC matrix converter converter controlled using SVM are shown in Figure 5 respectively. Modelling of PMSG is used for power generation which was connected as source. The variable wind speed is set to be 12m/s and the model was designed by using equ (9) – (20). The Simulink model of PMSG is shown in fig 6.

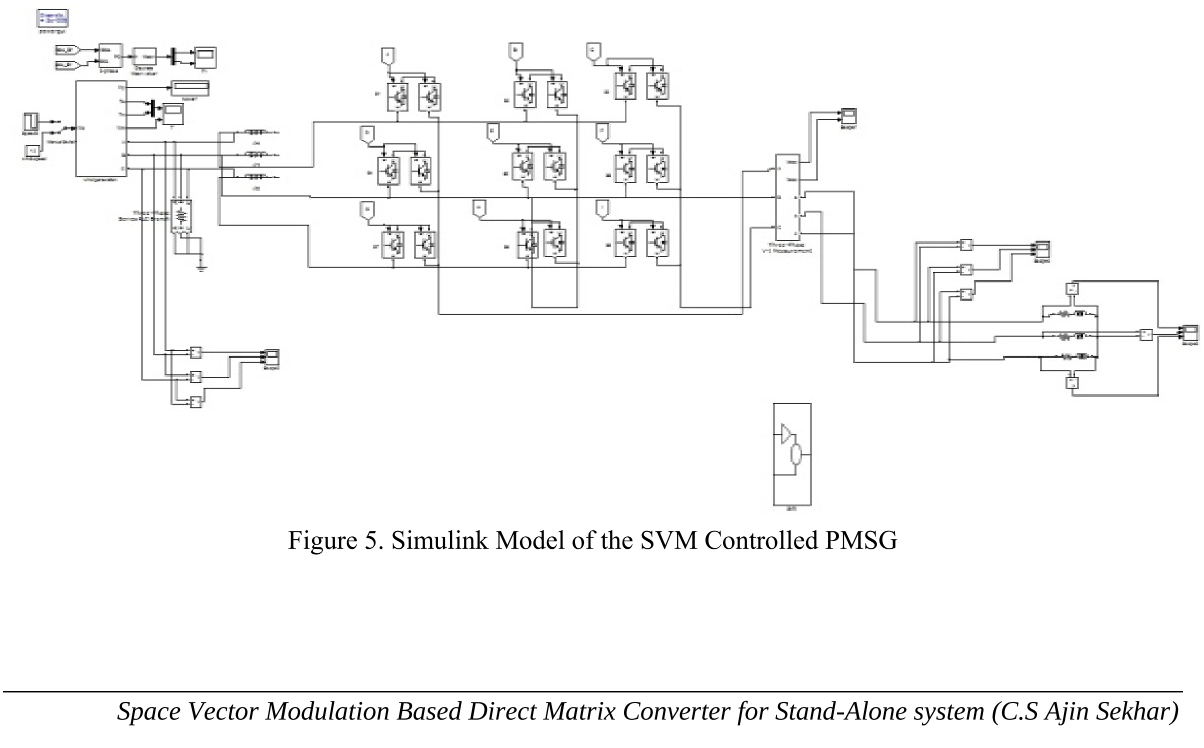


Figure 5. Simulink Model of the SVM Controlled PMSG

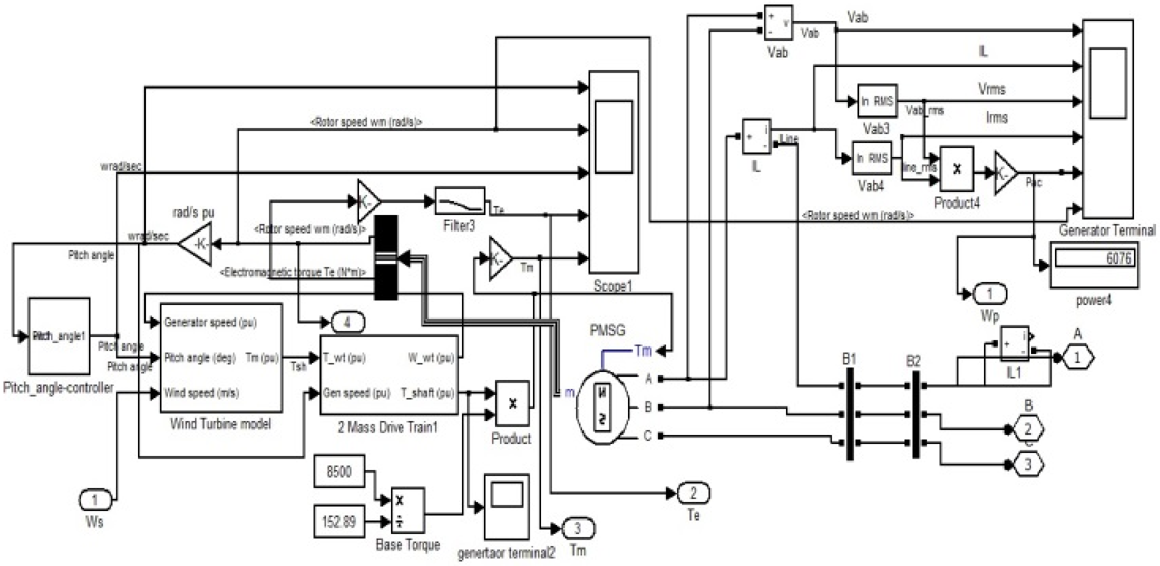


Figure 6. Simulink model of PMSG

The operating point (P and ω) is moved along a corresponding turbine power-speed characteristic (power curve) and is tracked by the controller of the machine-side converter until the point of maximum power is achieved. These traces are parts of the turbine characteristics shown in Figure 7.

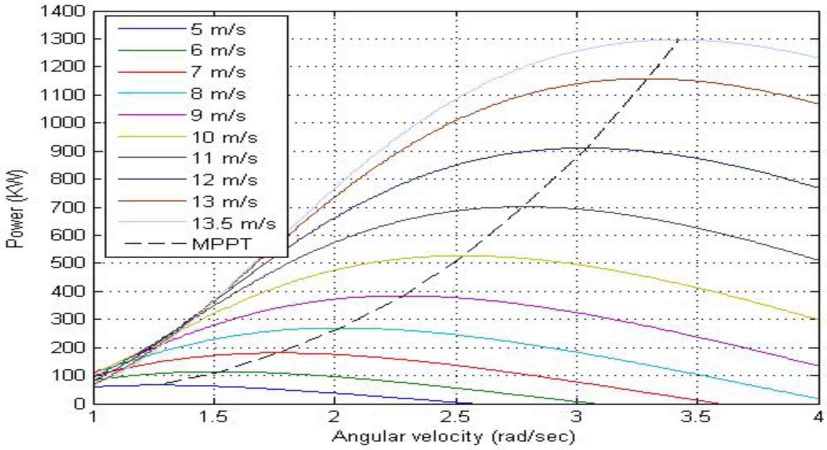


Figure 7. Characteristics of the wind turbine

Dynamic performance of wind driven PMSG wind moderate wind velocity is shown in figure 8 and Figure 9 shows the variable speed Permanent Magnet Generator output voltages for different values of wind velocities. The generated voltage reaches steady state at t=3milliseconds

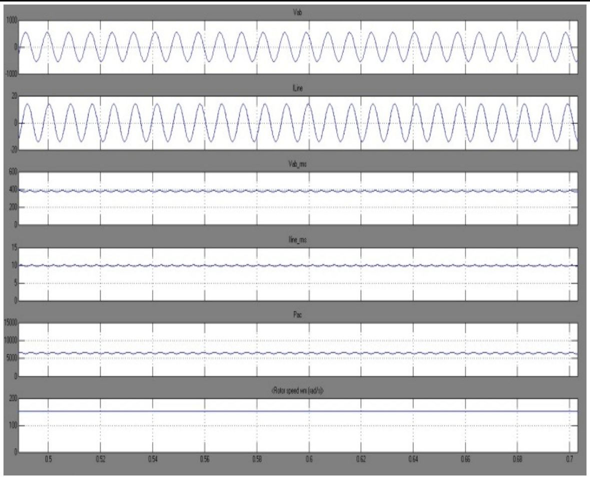


Figure 8. Dynamic performance of wind driven PMSG

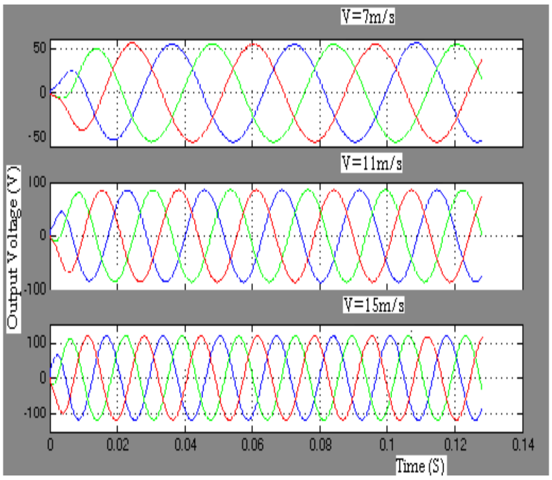
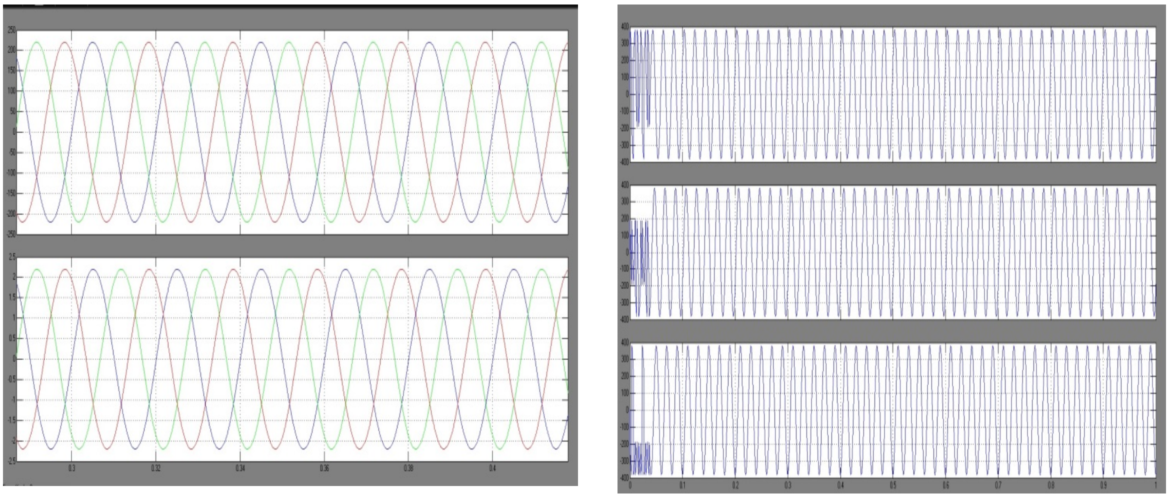


Figure 9. Output voltage of variable speed PMSG

The parameters used for proposed RL load are tabulated below,

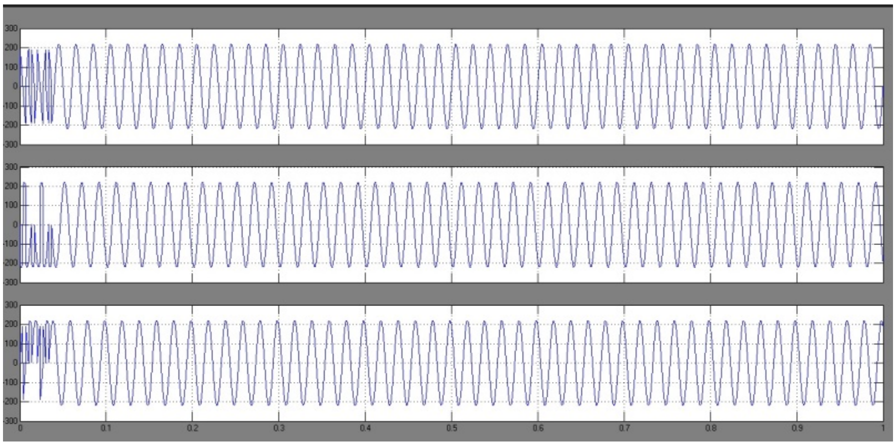
Resistor	100 ohms
Inductor	10e-3
Wind speed	12ms
Switching Frequency	50Hz
Output voltage	220V
Output current	2.2A
Line-Line Voltage	400v

The Output of the PMSG with wind velocity of 12 m/s and the rotor rotates at 170 rad/sec to attain Output voltage of 220 Volts matrix converter is given to fully controlled converter. The results analysis using proposed work in matlab are shown in Figure 10 (a) (b) (c).



(a)

(b)



(c)

Figure 10. (a) Output voltage and current (b) Line-line voltage (c) Phase-line voltage

For RL load by varying the inductance value we attain constant output voltage 220V but there is a changes in current which was represented graphically in Figure 11 and figure 12.

Inductance(H)	Output current(A)
10	2.2
15	1.5
20	1.2
25	1

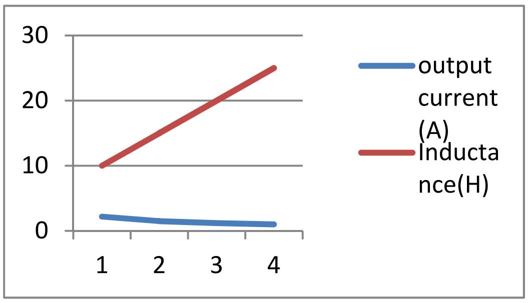


Figure 11. Waveform for output current and variable inductance

Resistor(ohms)	Inductance(H)	Output Voltage(V)
100	10	220
150	15	220
200	20	220
250	25	220

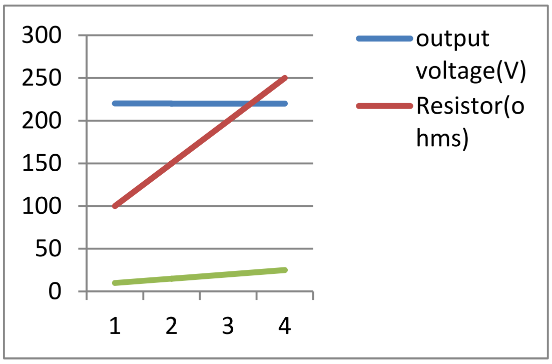


Figure 12. Waveform for output Voltage with variable inductance
And resistance

7. CONCLUSION

The proposed work demonstrated the comparative analysis for varying resistance and inductance using Space Vector Modulation Techniques. The PMSG connected to a direct AC-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. Modelling of PMSG is discussed with moderate windspeed of 12ms .By using matrix converter conventional DC-link are eliminated to attain high efficiency and low cost. In future the work is extremed with modelling agricultural motor for water pumping and also for variable speed drives.

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