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Ultra Sparse Matrix Converter based Wind Energy Conversion System

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Abstract: The Paper presents the ultra-sparse matrix based AC/AC conversion system. Here the implementation of the z-source in DC side improves the voltage boost by its shoot through capability. The inrush current and capacitor voltage stress is also limited to a certain value compared to the conventional system. In the Proposed System, the Sinusoidal Pulse Width Modulation is used for controlling the switches in the rectifier, while the Space Vector Pulse Width Modulation is used for controlling the inverter switches. Thus the Proposed Matrix Converter System is connected to a three phase RL Load and verified using the MATLAB/SIMULINK software.

Keywords: SVPWM, Clarke Transformation, Park Transformation.

1. INTRODUCTION

The Matrix based Converters are having the advantages of less number of required switching devices and it is less complex compared to the conventional converter systems [1]. Sparse matrix converters eliminate the use of multi-step commutation procedure used in the conventional matrix converter systems. Matrix Converters consists of several industrial applications including AC drives for reliable operations. Matrix Converter not only reduces the number of switching devices, but also reduces the number of isolated Driver Potentials.

The Space Vector Pulse Width Modulation is used for controlling inverter side switches. The Clarke and Park Transformations are used for the transformation of the "abc" into "dq" Parameters and vice-versa. The Sinusoidal signal is compared with the carrier wave and the resulting pulse output is given to rectifier switches. The Power Electronic Configurations vary according to the type of generator used. Wind energy systems with induction generator uses two types of AC/AC power configurations, including Full Power Back-to-Back Configuration and Half Power Back-to-Back or for Reactive Power Compensation. These Indirect AC/AC Power Configurations use both AC/DC and DC/AC converters with DC link between the two power configurations. The DC link is not present in the case of Direct AC/AC Conversion Systems [8].

The Closed Loop Converter can be implemented for the proposed type of Ultra Sparse Matrix Converter system [2]. Thus the LC Filter is used in the Wind Energy System in order to connect it with the AC-AC Converter System. Thus the DC link side consists of the z-source for the purpose shoot through for the inverter side switches. The requirement of high frequency Transformer can be eliminated in this type of Systems [3]. Thus the Ultra-Sparse Matrix based Converter can also be used for the Induction Heating applications without any energy storage elements [4].

2. TYPES OF MATRIX CONVERTERS

Thus the Matrix Based Converter system consists of the two major types: 1. Direct Matrix Converter and 2. Indirect Matrix Converter. The Direct Matrix Converter is in turn classified as the Voltage Source (VSC) and Current Source Converter (CSC). The Indirect Matrix Converter is broadly classified as the Conventional Indirect

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Matrix converter (CIMC), Sparse Matrix Converter (SMC), Very Sparse Matrix Converter (VSMC), Ultra Sparse Matrix Converter configurations (USMC), Inverter Link Matrix Converter (ILMC), Multi-Step Commutation, Zero DC-Link current commutation.

The z-source converter has the series and cascaded configurations. Thus the series connected z-source configuration is proved to have a reduced capacitor voltage and inrush current at the startup than compared to the cascaded z-source based configuration [2, 1]. Very Sparse based Configurations consists of the 12 Transistors, 30 Diodes and 10 Driver Potentials which makes the system more bulky and complex compared to the other matrix converter topologies.

In order to overcome this problem, the Ultra-Sparse Matrix Converter is implemented. The Series z-source converter topologies are proved effective way of improving the boost factor for the Voltage Source Matrix Converters compared to the Cascaded Z – source Configurations [5].

Active Clamp Circuit can be used along with the matrix converter for both purposes:

(1) To produce the sinusoidal currents of high quality at both input and the output of the converter.

(2) To protect the converter from over voltages.

(3) To interface a source with a power converter circuitry [6].

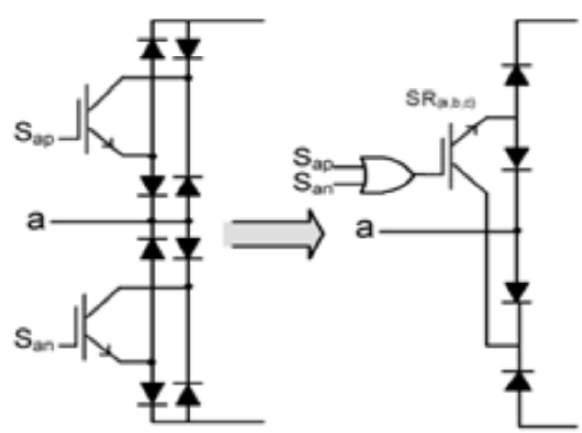
3. ULTRA SPARSE MATRIX CONVERTER

Thus the Ultra Sparse Matrix converter consists of the 9 Transistors, 18 Diodes and 7 Isolated Driver Potentials [12]. The Maximum Phase displacement between the input voltage and input current is restricted to ± 30° [14]. Thus the Figure 1 shows the Ultra-Sparse based Matrix Converter System using "OR" operator in comparison with the Sparse Matrix based Converter configuration [9].

In the Proposed type of Matrix Converter System the OR function is processed by using the Relational operator ">=", "greater than or equal to". The Sinusoidal Pulse Width Modulation Technique is used in order to initiate the pulses for the Switches M1, M2 and M3 of the rectifier. The Sinusoidal Pulse Width Modulation is used to initiate the pulses in the Six Inverter side Switches.

Indirect type of Matrix Converters could achieve the highest semiconductor Power Efficiencies [10]. The Ultra Sparse Matrix Converter is best suitable for Unidirectional Power Flow Applications and by adding three more switches it can be converted into a sparse matrix type of converter. The Matrix Converters not only reduce the number of switching devices, but also it reduces the number of conversion stages.

The harmonics present in the Matrix Converter is also low compared to the Static type of Converters [11]. In some applications including aircraft actuators and elevator drives, specialist machines are required and thus the



(a) (b)

Figure 1 (a) represents the Sparse Matrix based converter and Figure 1 (b) represents the Ultra Sparse based Matrix converter using OR gate.

Sparse Matrix Converters are suitable for those applications. The Ultra Sparse Matrix Converters are best suited for those applications instead of the Conventional Direct Matrix Converter topologies [12].

4. BLOCK DIAGRAM OF PROPOSED CONVERSION SYSTEM

Thus the block diagram is shown in the Figure 2, which consists of the Wind Energy System as the input source and it is connected to the AC/AC Converter using an LC Filter circuit. Thus, both rectifiers and the inverter bridges are connected via DC link Capacitor and Series Z-Source Configuration. Here the conversion takes place by boosting the DC voltage through the z-source configuration and fed to the inverter circuit. The Star Connected "RL" Load is connected to the load side inverter. Thus, from the Figure 2, the input side rectifier is controlled using the Sinusoidal Pulse Width Modulation Technique, where the three sinusoidal inputs with 120 degree phase displacement to each other is used, while the Load side Inverter is controlled using the Space Vector Pulse Width Modulation Technique.

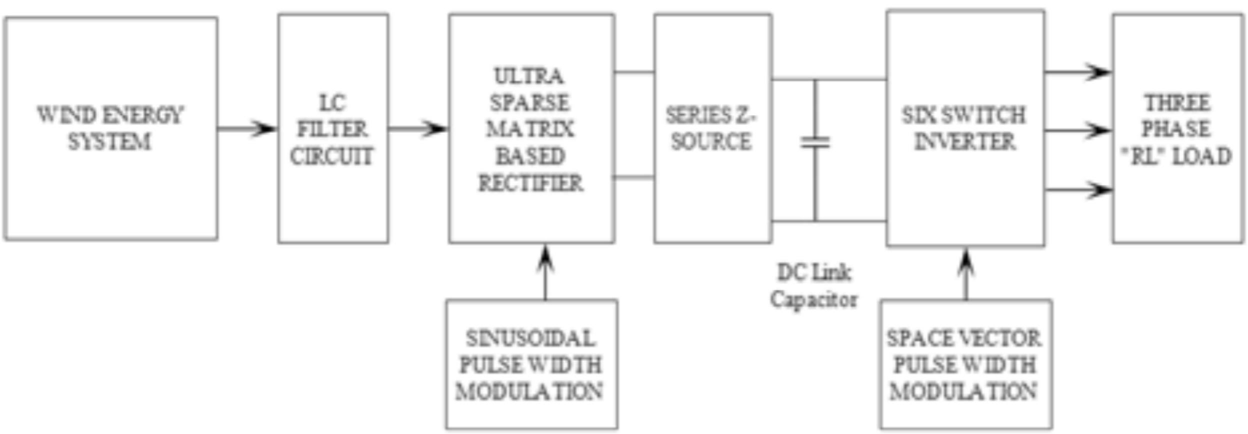


Figure 2: Proposed Ultra Sparse Matrix Converter based Wind Energy Conversion System

5. PULSE WIDTH MODULATION TECHNIQUES

5.1. Sinusoidal Pulse Width Modulation

The Sine Wave Pulse Width Modulation technique uses the Sine wave with a phase shift of 120° with each other with amplitude of 0.8. Sinusoidal wave is compared with a triangular signal to generate the pulses for the input side

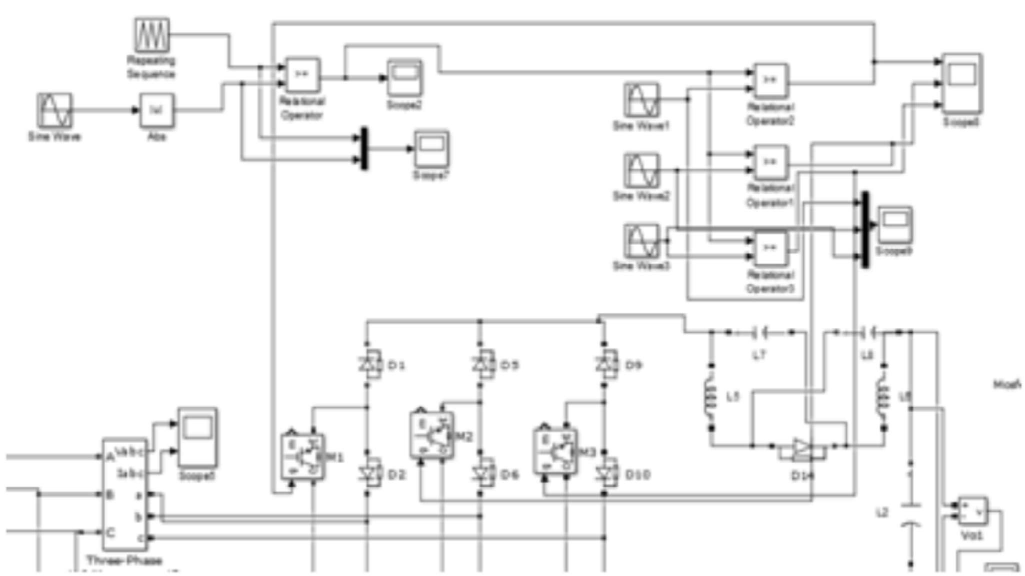


Figure 3: Implementation of Sinusoidal Pulse Width Modulation with 120° phase shift with each other.

rectifier. Figure 3 represents the circuit configuration of the Sinusoidal Pulse Width Modulation technique where the sinusoidal signal acts as the reference signal and the triangle signal acts as the carrier wave represented by the repeating table in Figure 3.

5.2. Space Vector Pulse Width Modulation Technique

The Space Vector Pulse Width Modulation Technique consists of the transformation of the "abc" three phase into two phase quantities such as the direct axis 'd' and the quadrature axis 'q' components and vice versa [2]. The transformation of balanced three-phase quantities into balanced two-phase quadrature quantities is known as the Clarke's transformation and the conversion of balanced two-phase stationary reference frame into the rotating reference frame is known as the Park's Transformation.

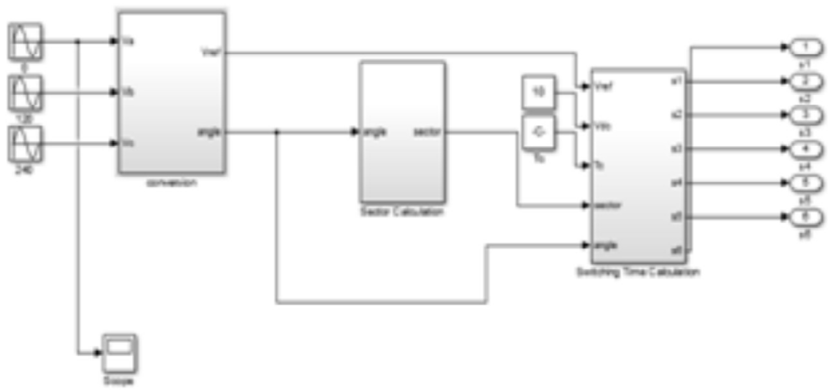


Figure 4: Implementation of the Space Vector Pulse Width Modulation using the Reference Frame theory.

Clarke and Park Transformations are used in the vector control schemes for the permanent magnet synchronous and the Asynchronous Machines. Figure 4 represents the implementation of the Space Vector Pulse Width Modulation for the inverter side. The Commutation is less Complex in the case of Matrix Converter compared to the conventional converters. The switches can also be turned on and off at the zero current in the case of matrix Converters [15].

5.3. Clarke Transformation

In this transformation, the three phase quantities are transformed into the two phase quadrature quantities [7]. Thus, Clarke transformation is represented by,

$$I_\alpha = \frac{2}{3}(I_a) - \frac{1}{3}(I_b - I_c) \tag{1}$$

$$I_\beta = \frac{2}{\sqrt{3}}(I_b - I_c) \tag{2}$$

Here, *Ia*, *Ib*, and *Ic* are three-phase quantities. Figure 5 gives the graphical representation of the Clarke's Transformation. Here $I\alpha$ and $I\beta$ are stationary orthogonal reference frame quantities. $I\alpha$ is superposed with *Ia* and $Ia + Ib + Ic$ is zero, *Ia*, *Ib*, and *Ic* can be transformed to $I\alpha$ and $I\beta$ as:

$$I_\alpha = I_a \tag{3}$$

$$I_\beta = \frac{1}{\sqrt{3}}(I_a + 2I_b) \tag{4}$$

$$I_a + I_b + I_c = 0 \tag{5}$$

Here $I\alpha$ and $I\beta$ are the two phase quadrature components. There exist several types of Clarke's Transformations.

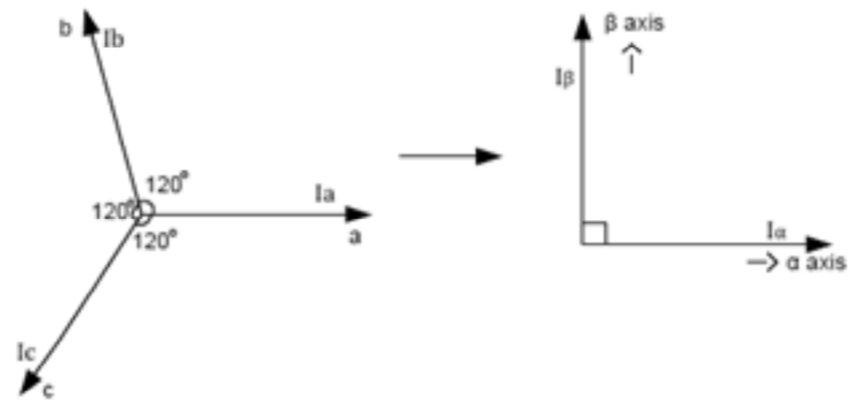


Figure 5 Clarke's transformation

5.4. Park's Transformation

The two-axis stationary reference frame quantities (*q*,*d*) are transformed into rotating reference frame quantities (*a*, *b*, *c*) [7]. Thus the Park's Transformation is expressed using the following equations:

$$I_d = I_\alpha \cos(\theta) + I_\beta \sin(\theta) \quad (6)$$

$$I_q = I_\beta \cos(\theta) - I_\alpha \sin(\theta) \quad (7)$$

where,

Id, *Iq* are rotating reference frame quantities

*I*α, *I*β are orthogonal stationary reference frame quantities

θ is the rotation angle

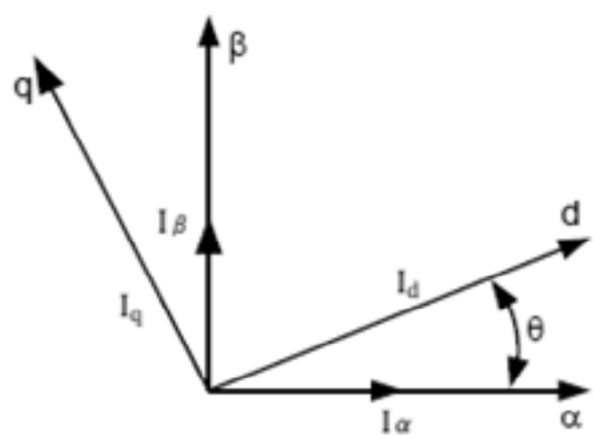


Figure 6 Park's Transformation

Figure 6 represents the transformation of the quadrature quantities into three phase rotating reference quantities using park's Transformation.

6. SIMULATION RESULTS

Simulation Parameters:

Wind Output Voltage (Peak): 51 Volts.

Wind Output Current (Peak): 3 Amperes.

Wind Speed: 10 m/s.

LC Filter Parameters:
Inductance (per phase): 80 mH.
Capacitance (per phase): 55 µH.

Series Z-Source parameters:
Inductance: 2 mH.
Capacitance: 1000 µF.
DC Link Parameters: 1000 µF.

Load Parameters:
Three Phase RL Load:
Resistance = 50 ohms, Inductance = 10 mH.

Repeating Table (Carrier Signal) Parameters:
Time Values: 0, 0.5e-4, 1e-4.
Output Values: 0, 1, 0.

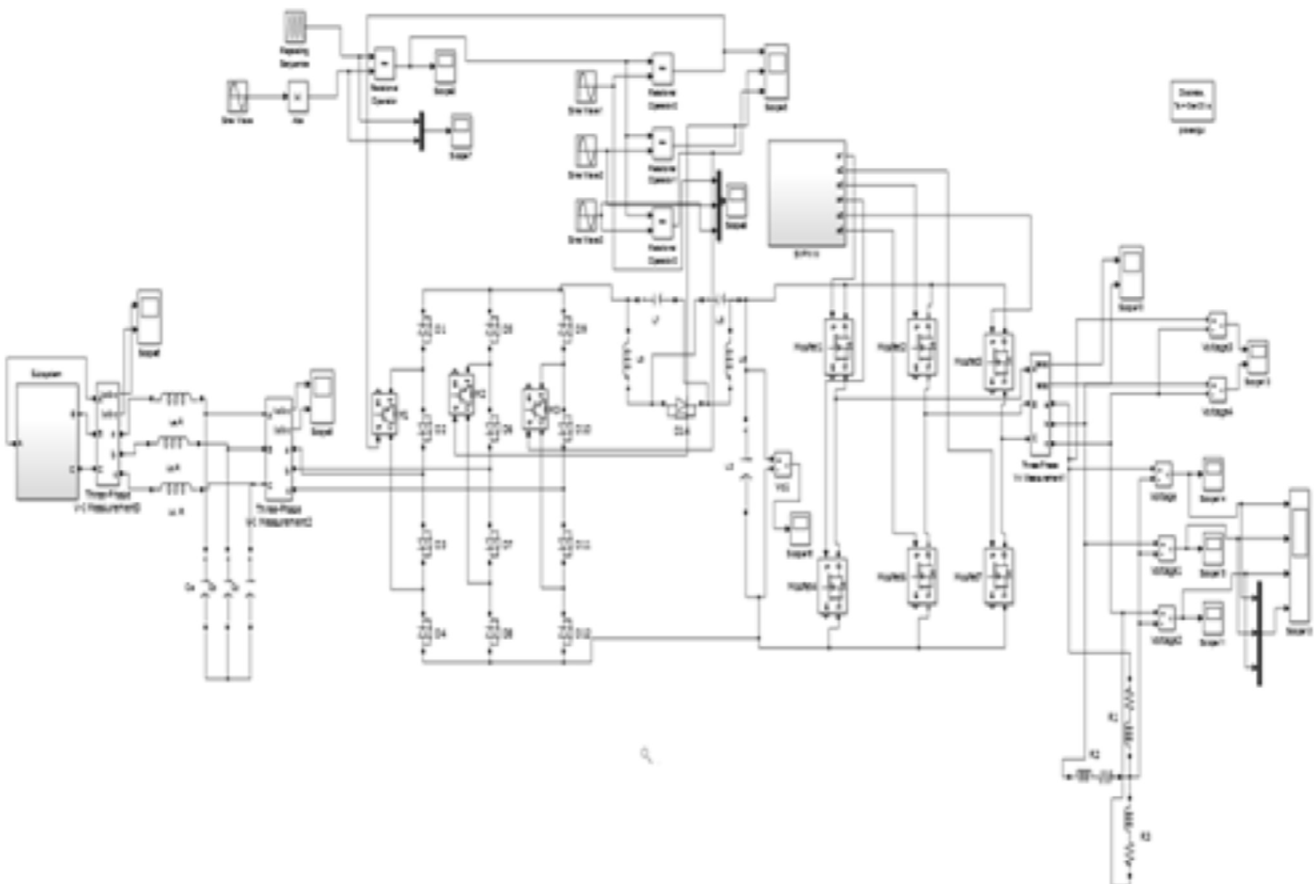


Figure 7: Simulation of the proposed ultra-sparse matrix based Wind Energy Conversion System with "RL" load

Thus the Figure 7 represents the proposed wind energy conversion system using Ultra-Sparse matrix Conversion Technique. The Wind Turbine with 2-mass Drive Train Model along with the Permanent Magnet Synchronous Machine is used for the Proposed System which is represented in Figure 8. It also implements the pitch angle controller.

The Net Torque T and the Motor Speed ω_m are represented by the Figure 9. The generator used in the Wind Energy System is a Permanent Magnet Synchronous Generator and is controlled by a pitch angle controller.

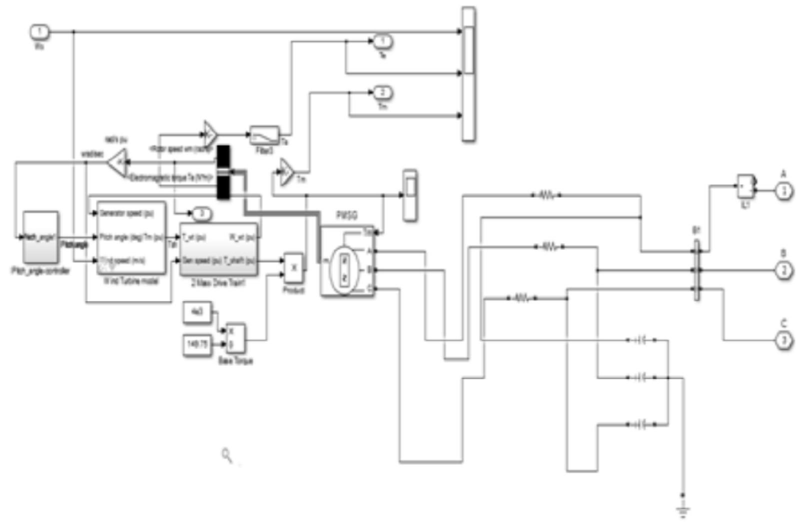


Figure 8: Two-mass Drive Train Model of Wind Energy system

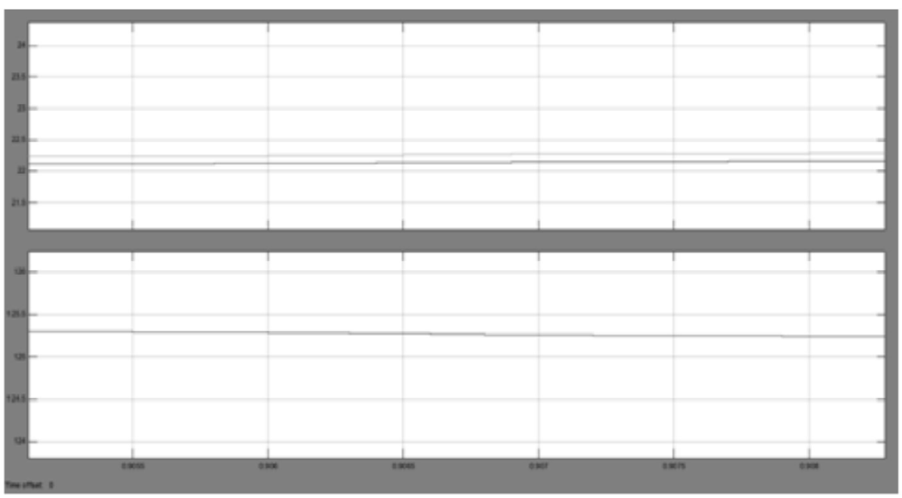


Figure 9: Torque and Motor Speed Characteristics

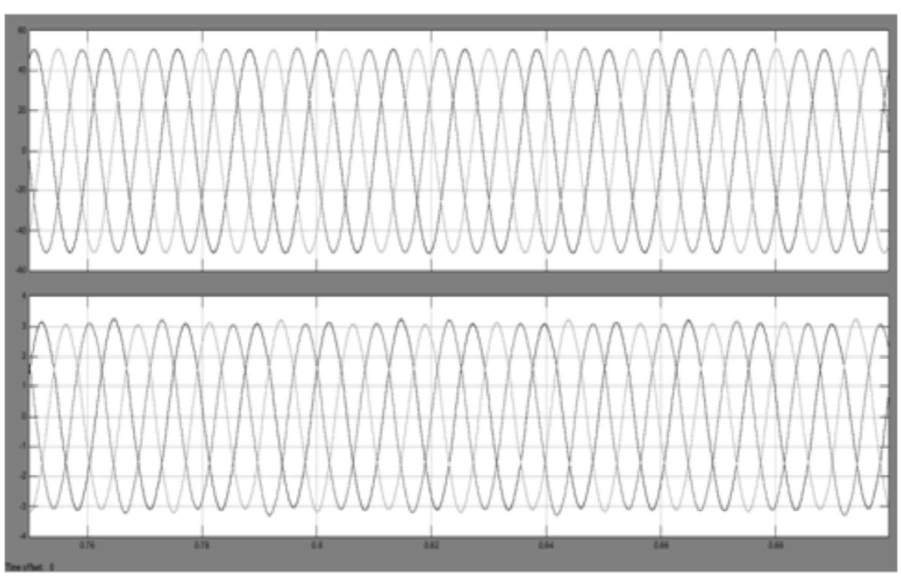


Figure 10: Wind System Voltage and Current waveforms

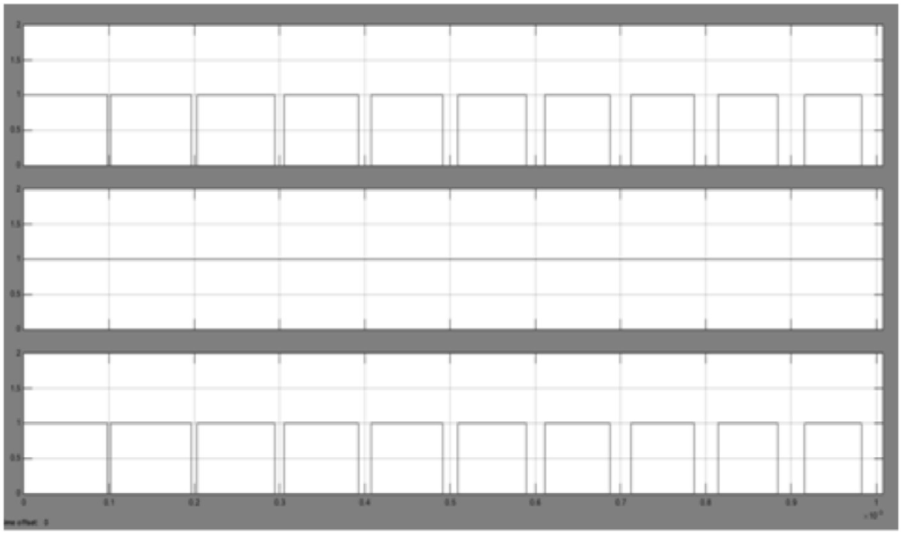


Figure 11: Input Pulses to Rectifier Switches

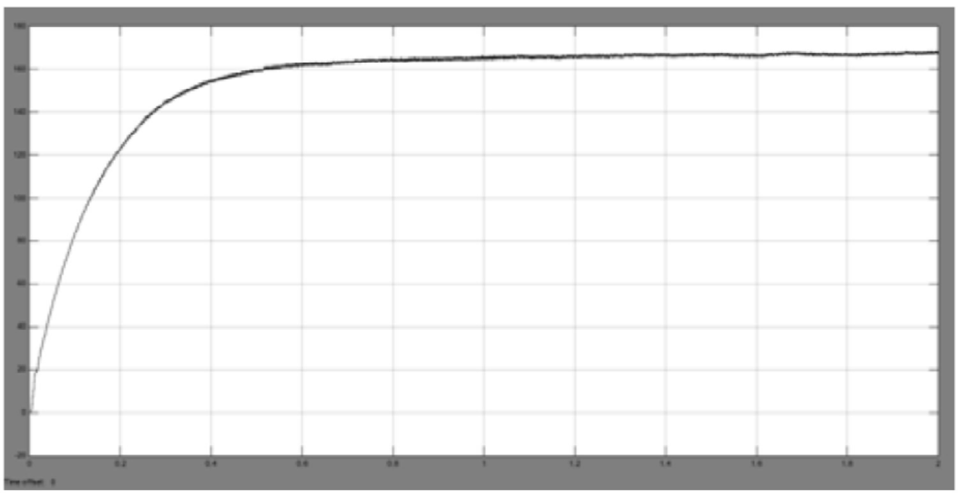


Figure 12: DC Output voltage across the DC Link Capacitor

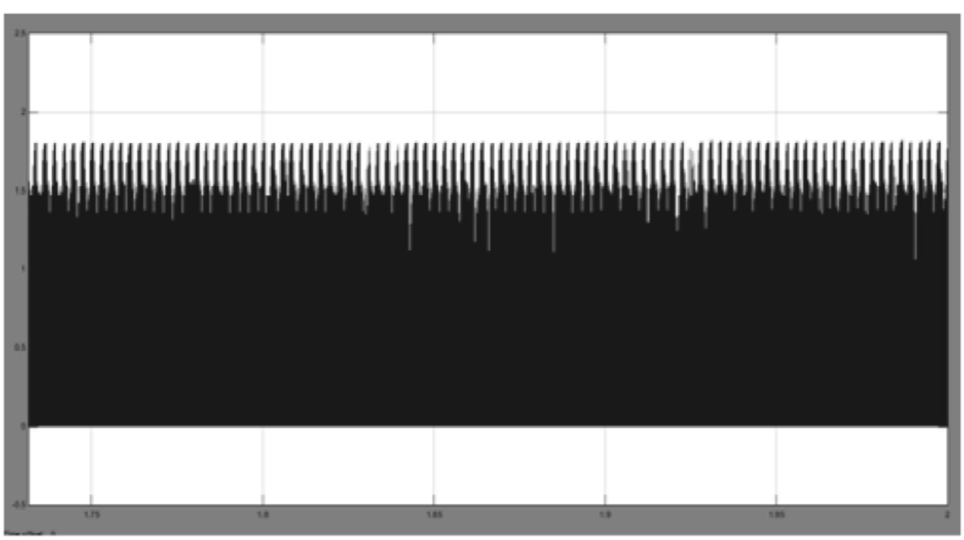


Figure 13: DC Link Current Waveform

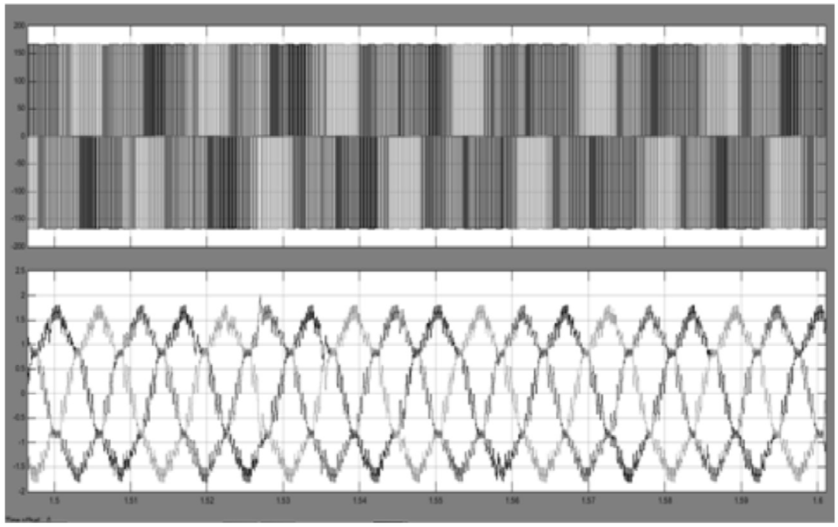


Figure 14: Three Phase Output Voltage and Current Waveforms

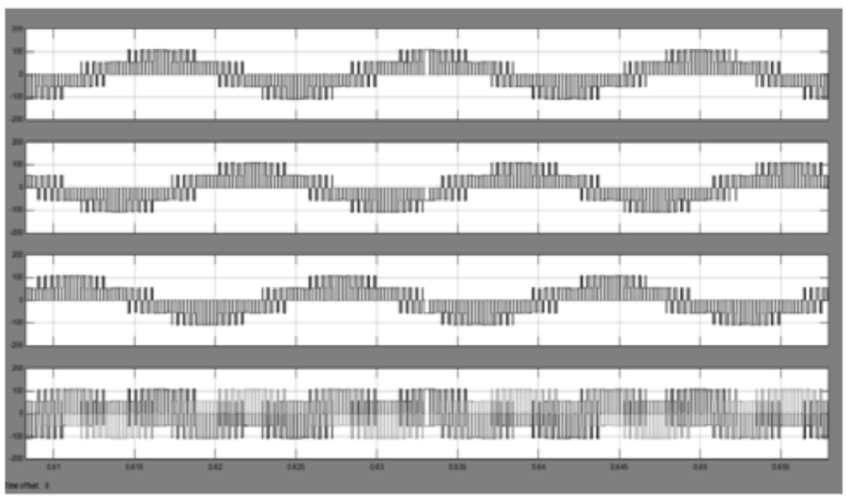


Figure 15: Three Phase Output Voltage across star connected “RL” Load

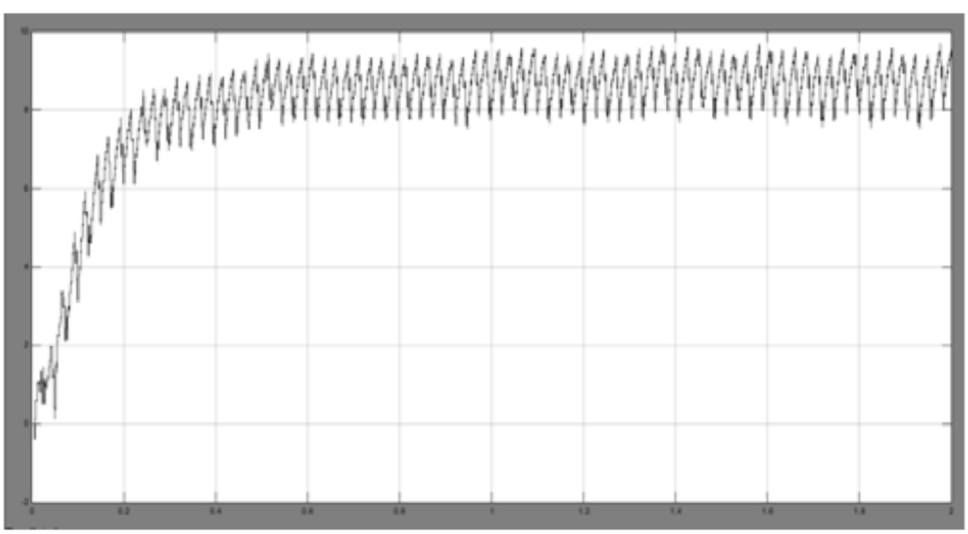


Figure 16: Voltage across the Z-Source Network Capacitor

Figure 9 represents the torque characteristics where the electromagnetic and mechanical torque is obtained at 22.75 and 22.8 Nm respectively. Thus the motor speed is obtained at 126.25 RPM. The Figure 10 represents the output voltage and current waveforms of the wind power generation system. The peak output power across the wind generation system is obtained at 153 watts, where the peak voltage and current is obtained at 51 volts and 3 Amperes respectively. The Figure 11 represents the input pulses to the rectifier switches of ultra-sparse matrix converter using Sinusoidal Pulse Width Modulation Technique.

Figure 12 represents the DC output voltage across the DC Link Capacitor, obtained at 165 Volts. Figure 13 represents the DC link Current waveform, with a peak current of 1.8 Amperes. The inrush current across the DC link voltage is limited to 1.8A is an advantage of the proposed system compared to the conventional system with 10 A inrush current [1]. The DC voltage is again fed to the Inverter for the generation of three phase AC waveform. The Inverter side switches are controlled by the Space vector Pulse Width Modulation technique that consists of transformation of the three phase rotating reference quantities into stationary reference quantities. The Figure 17 represents the circuit configuration of the Space vector Pulse Width Modulation technique for generation of pulses to the six inverter switches.

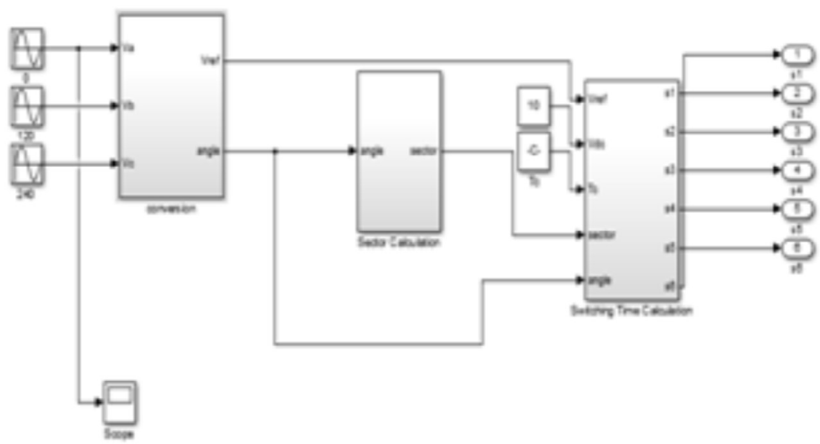


Figure 17: Simulink model of Space Vector Pulse Width Modulation Scheme

The inverter output voltage and current waveforms are represented by the Figure 14. The output voltage and current are obtained at 166 Volts and 1.8 Amperes respectively. The controller and the Z-Source Network plays a major role in boosting the voltage from 51 volts to 166 volts from the Figure 10 and Figure 14 respectively. Figure 16 shows the output voltage across the Z-Source Network Capacitor obtained at 9.5 Volts. The Z-Source Configuration plays major role in increasing the net output voltage of the converter System. The Figure 15 shows

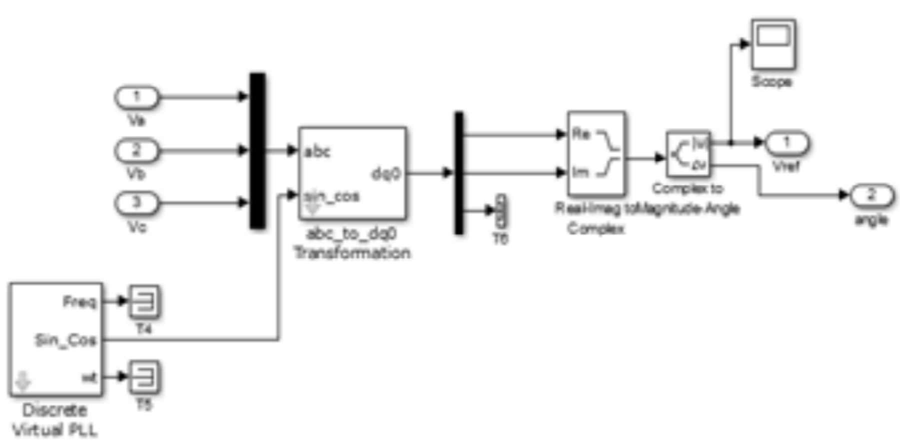


Figure 18: Transformation of the three Phase quantities into two phase quadrature quantities

the three phase output voltage across the Star-Connected Delta connected "RL" Load. The output voltage across each phase is obtained at 110 Volts and is phase displaced by an angle of 120° with each other. The Figure 18 represents the transformation of the three phase "abc" quantities into two phase "dq" quadrature quantities. Furthermore the efficiency of the Matrix Converter System can be improved by implementing the Fuzzy Logic Controller in the Proposed System [13].

7. CONCLUSION

The Series Z-Source based Ultra-Sparse Matrix Converter is implemented for the Wind Energy Conversion System. The inrush current across the DC link Capacitor is limited compared to the existing topologies by using the effective shoot through capability of Series Z-Source Network Configuration. The Proposed type of Converter using Space vector Pulse Width modulation is implemented to improve the AC Output Voltage with respect to the input voltage. The proposed system can be used for the AC Drives in industrial applications as well as for interfacing with Hybrid Power Applications.

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