The Nucleus **50**, No. 3 (2013) 253-260

The Nucleus
A Quarterly Scientific Journal of Pakistan
Atomic Energy Commission
NCLEAM, ISSN 0029-5698

MODELING AND SIMULATION OF MATRIX CONVERTER FOR WIND POWER GENERATION

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(Received June 11, 2013 and accepted in revised form September 10, 2013)

In this paper, a matrix converter structure is proposed which is suitable for wind power generation applications. The matrix converter (MC) is the most general converter type in the family of AC-AC converters. It is a single-stage converter which has an array of m×n bidirectional power switches to connect, directly, an m-phase voltage source to an n-phase load. It does not have any DC-link circuit and does not need any large energy storage elements. The key element in a matrix converter is the fully controlled four-quadrant bidirectional switch, which allows high-frequency operation. The proposed converter uses MOSFETs as bidirectional switches. The model has been implemented using MATLAB/SIMULINK. The results obtained are presented. The waveforms for input current and output voltage are sinusoidal with very low total harmonic distortion (THD). Low THD is an indication that the model is suitable for wind power generation applications. The simulation results confirm the reduction of conversion losses by 10% to 12% as compared to conventional two stage converters thereby increasing the overall conversion efficiency. The MOSFETs which have been used as switching devices have four to five times more switching frequency as compared to IGBTs thus improving the resulting wave shapes.

Keywords: Conventional converter, Matrix converter, MOSFET, Pulse width modulation, THD, MATLAB/SIMULINK, Wind Power

1. Introduction

The three phase matrix converter is an array of nine bidirectional switches arranged as a matrix. Each output line is linked to each input line via a bidirectional switch. These switches can be used to generate voltages with variable amplitude and frequency at the output side by switching input voltage with various modulation algorithms [4, 5].

The matrix converter (MC) has been extensively researched during recent years as a power electronic converter for use in wind turbine power generation systems in place of conventional ac-dc-ac converters [1]. There are different topologies of matrix converters. The mostly used topology is direct MC topology [2]. Some researchers have proposed indirect MC topology [1] but it suffers from the drawback of having limited input-output voltage ratio. On the other hand direct MC topology is well developed for more than a quarter century [3]. Some researchers have compared MC with conventional two stage ac-dc-ac converter and have shown that power to volume ratio of MC is much better than that of corresponding back to back power converter. Similarly the power to mass ratio of MC is five times higher than that of a conventional converter [5]. It can be concluded that the main advantages of MC are its compactness and reliability which ultimately make it suitable for use in wind energy conversion systems. Figure 1 shows a typical three-phase input to three-phase output matrix converter, with nine bidirectional switches. Recently, the most popularly used switching algorithm is space vector modulation algorithm that allows the control of input current and output voltage vectors independently. Space vector modulation algorithm has many advantages with respect to the traditional modulation techniques such as, it is able to obtain maximum voltage ratio without adding third harmonics, it can be easily implemented due to facilitated control algorithm, and it can be easily operated under unbalanced conditions [6, 7].

In this study, simulation of three-phase to three-phase matrix converter feeding a passive RL load has been performed. In the simulation, power circuit of matrix converter has been modeled using power electronics toolbox of MATLAB/SIMULINK. The switching duty cycle computation using space vector modulation algorithm is implemented. It provides independent control of output voltage amplitude and frequency with minimum switching losses. The current and voltage waveforms of input, output and harmonic spectra obtained by simulation are investigated.

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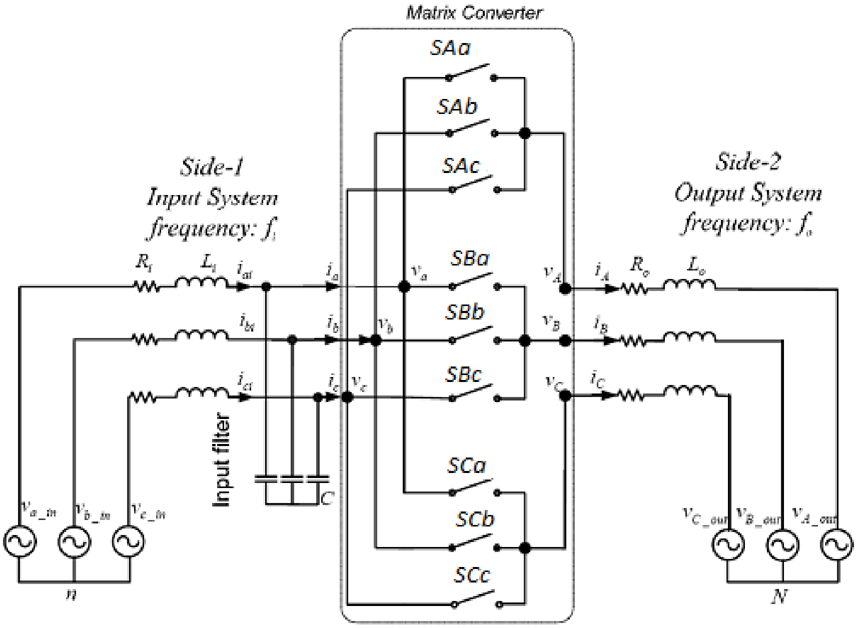

Figure 1. Three phase matrix converter structure.

2. Matrix Converter Structure

The structure of a three phase matrix converter (MC) is shown in Figure 1. The MC connects the three-phase ac voltages on input side to the three-phase voltages on output side by a 3×3 matrix (or array) of bi-directional switches. In total, MC needs 9 bi-directional switches, one switch between each input phase and each output phase. A second-order L-C filter is used at the input terminals to filter out the high frequency harmonics of the input currents [10-13].

The MC, as an AC - AC converter, satisfies the requirement of providing a sinusoidal voltage on the load side and a sinusoidal current on the source side. Meanwhile, it is possible to adjust the input displacement angle and control the output voltage magnitude and phase angle by properly operating the switches. Since there is no dc-link as compared with a two-stage conventional AC - DC - AC converter, MC can be recognized as a full-silicon structure in a compact design. Also, the structure is inherently capable of a four-quadrant operation, with the output voltage and input current having sinusoidal shape with low distortion.

The proposed Matrix Converter (MC) model consists of nine bidirectional switches. MOSFETs are used as switches. Two MOSFETs are connected back to back to form a bidirectional switch. Thus, there are total eighteen MOSFETs connected in pairs, with each pair acting as a bidirectional switch. There are three bidirectional switches corresponding to each phase. The proposed MC structure is shown in Figure 2.

3. Modulation Strategy for the Matrix Converter

In the MC, the switching method should be chosen in such a way that the output voltages have sinusoidal waveforms at the desired frequency, magnitude and phase angle. Also, the input currents should be sinusoidal at the desired power factor displacement. In order to achieve this target, a proper choice of the switching pattern should be applied to the switches of the MC in a switching period. A proper switching pattern is obtained by choosing a suitable modulation method. The modulation problem, in general, starts with choosing a switching function, as is given in equation1, for the switches of the MC [5, 9, 16];

$$S_{ij}\ t = \begin{cases} 1 & S_{ij} = closed \\ 0 & S_{ij} = open \end{cases} \qquad (1)$$

In equation 1;

i = A, B, C,   &   j = a, b, c,

The following constraint applies to the switching functions:

$$S_{ia} + S_{ib} + S_{ic} = 1 \qquad (2)$$

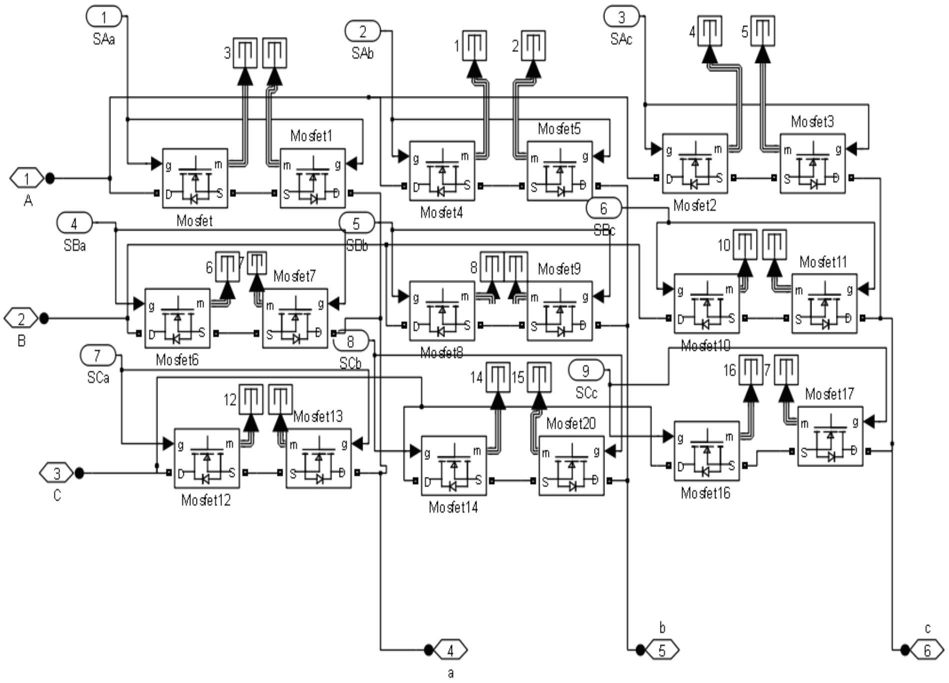

Figure 2. SIMULINK block diagram of proposed matrix converter.

This constraint comes from the fact that MC is supplied from a voltage source and generally feeds an inductive load. Connecting more than one input phase to one output phase causes a short circuit between two input sources [19]. Also, disconnecting all input phases from an output phase results in an open circuit in the load. This gives rise to two unwanted situations in MC, which is shown in Figure 3 (a) and 3 (b).

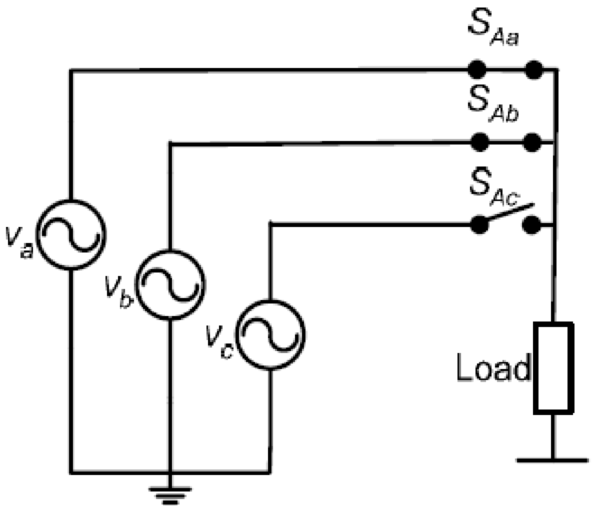

Figure 3a. Short circuit of two input phases.

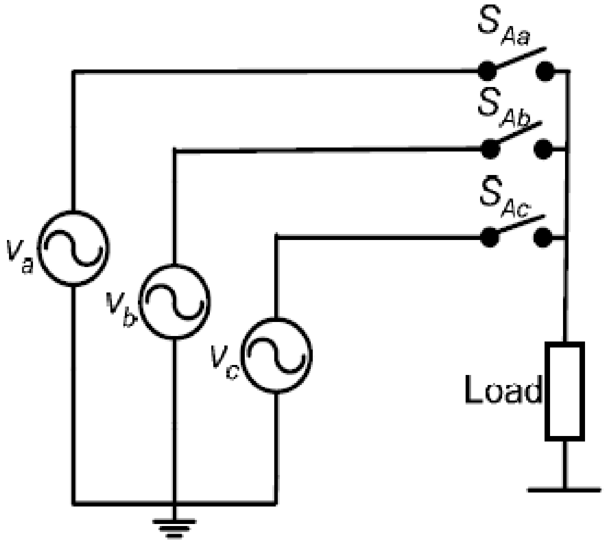

Figure 3b. Open circuit of inductive load.

Considering the two states for each switching function based on equation (1), there are 512 states for a total of 9 switches in the MC. By applying the constraint as is given in equation (2) to the switching algorithms of the MC, only 27 allowable combinations can exist [20]. The connections between MC input and output phases can be divided in three different groups according to their properties, as presented in Table 1.

Table 1. Classification of switch state combinations.

Categories	No. of combinations	State property
Group I	Six combinations	Each output phase is connected to a different input phase.
Group II	3×6 combinations	Two output phases are connected to the same input phase.
Group III	Three combinations	Three output phases are connected to the same input phase.

4. Space Vector Pulse-width Modulation (SVPWM) Technique

SVPWM can be applied to output voltage and input current control. The voltage space vector of the target matrix converter output voltages is defined in terms of the line-to-line voltages [4, 5, 18]. The output voltage and input current are given by equations (3) and (4).

$$V_o(t) = \frac{2}{3}\left(V_{ab} + aV_{bc} + a^2V_{ca}\right) \quad (3)$$

$$I_i(t) = \frac{2}{3}\left(I_a + aI_b + a^2I_c\right) \quad (4)$$

where $a = e^{\frac{j2\Pi}{3}}$

In the complex plane, $V_o(t)$ is a vector of constant length rotating at angular frequency ω_o. In the SVM, it is synthesized by time averaging from a selection of adjacent vectors in the set of converter output vectors in each sampling period.

In the SVM, the Group I vectors are not used. The group II consists of eighteen space vectors are constant in direction but the magnitude depends on the input voltages and the output currents for the voltage and currents space vectors respectively. On the contrary, the magnitude of the six rotating vectors remains constant and corresponds to the maximum value of the input line-to neutral voltage vector and the output line current vector, while its direction depends on the angles of the line-to-neutral input voltage vector α and the input line current vector β.

The desired output is synthesized from the Group II active vectors and the Group III zeros vectors. The Switching times for the space vectors for the sector are given by equations (5), (6) and (7).

$$t_1 = \left(\frac{|V_o|}{V_{env}}\right) T_{seq} \sin(\theta) \quad (5)$$

$$t_6 = \left(\frac{|V_o|}{V_{env}}\right) T_{seq} \sin(60 - \theta) \quad (6)$$

$$t_o = T_{seq} - (t_1 + t_6) \quad (7)$$

Where t_0 is the time spent in the zero vector (at the origin). There is no unique way for distributing the times (t_1, t_6, t_0) within the switching sequence. The example for switching times is shown in Figure 4.

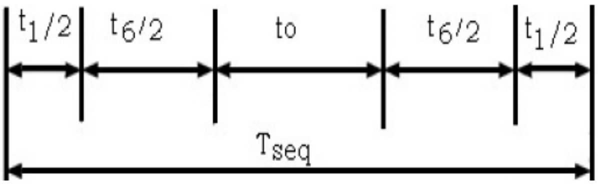

Figure 4. Switching times.

For good harmonic performance at the input and output ports, it is necessary to apply the SVM to input current control and output voltage control. This generally requires four active vectors in each switching sequence, but the concept is the same. Under balanced input and output conditions, the SPVM technique yields similar results to the other methods. However the increased flexibility in choice of switching vectors for both input current and output voltage control can yield useful advantages under unbalanced conditions.

5. Simulation of Matrix Converter

The Matrix Converter (MC) is simulated using MATLAB / SIMULINK environment. SIMULINK block diagram of MC is shown in Figure 5. The important blocks in this model are input filter block, MC structure block, duty cycle calculation block, switching times calculation block and pulse generation block. The input to duty cycle block is the sector location and the output is the duty cycles. These are used for calculating the switching times. The input to the pulse generation block is switching times and also voltage and current sector. The outputs of pulse generation block are pulses which are directly connected to the switches of the matrix converter.

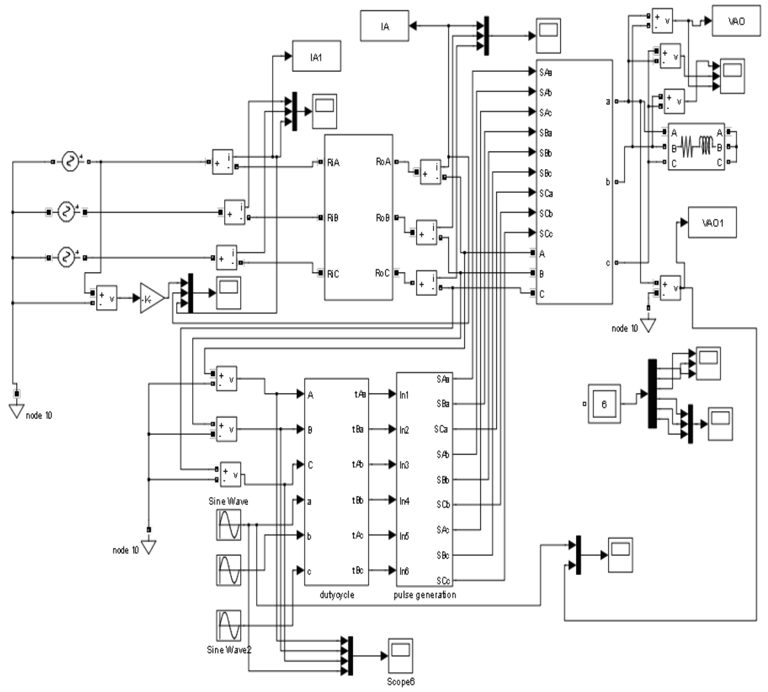

Figure 5. MC SIMULINK block diagram.

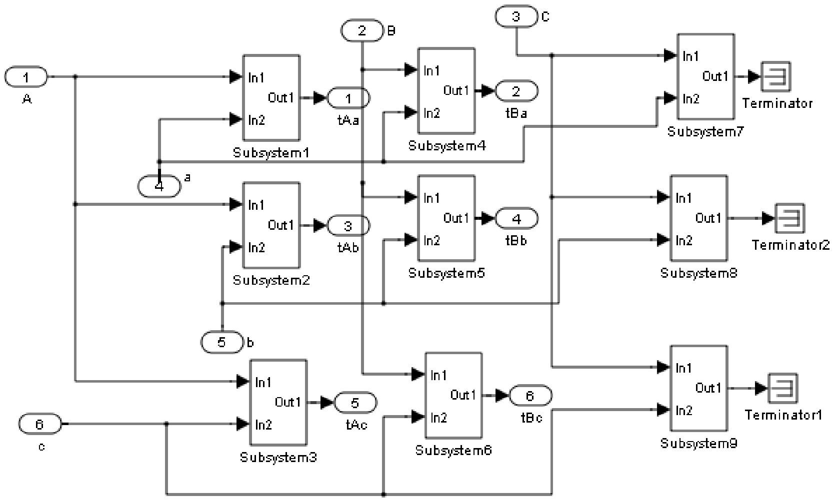

Figure 6. SIMULINK block diagram of duty cycle block.

The SIMULINK block diagram of MC structure is shown in Figure 2. The MC structure uses MOSFET switches. The duty cycle block calculates the following switching times tAa, tBa, tAb, tBb, tAc, tBc. The duty cycle SIMULINK block diagram is shown in Figure 6, while Figure 7 shows the sub-system block diagram.

The pulse generation block generates control pulses which in turn control the switches of MC. The switching times calculated by switching times calculation block are used as input to this block. Figure 8 shows SIMULINK block diagram of sub-systems of pulse generation block.

The switching process of the semiconductor devices leads to high-frequency harmonics in the network currents. These current harmonics cause additional losses on the utility system and may excite electrical resonance, generating large over-voltages. Thus a second order low pass filter is used in order to minimize the harmonic content of the currents injected into the network.

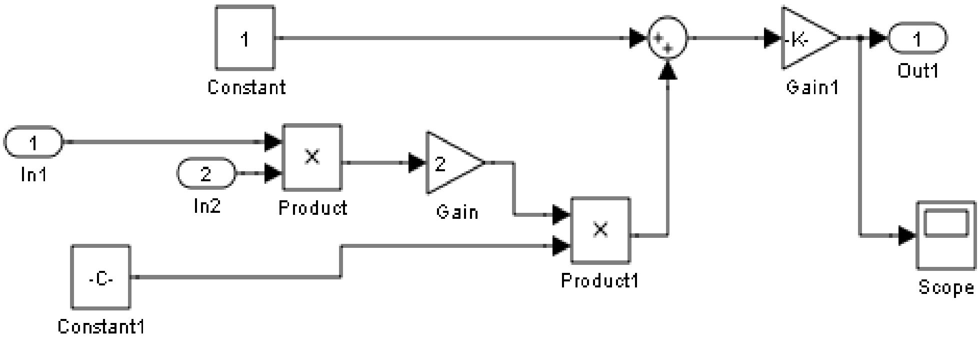

Figure 7. SIMULINK block diagram of sub-system of duty cycle block.

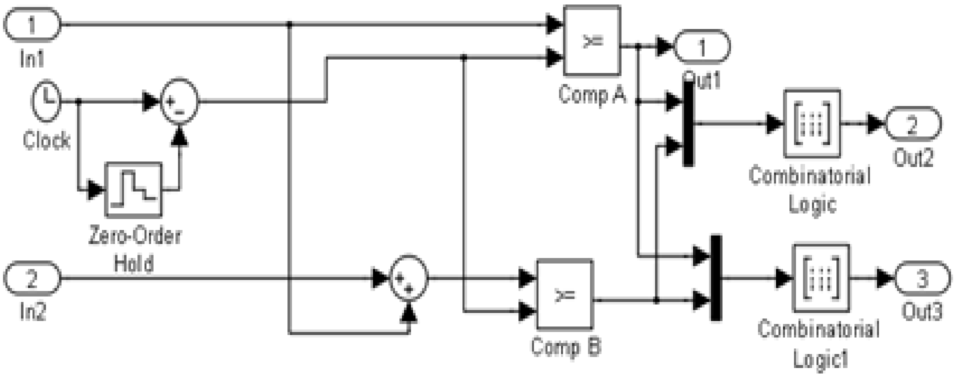

Figure 8. SIMULINK Block Diagram of sub-system of pulse generation block.

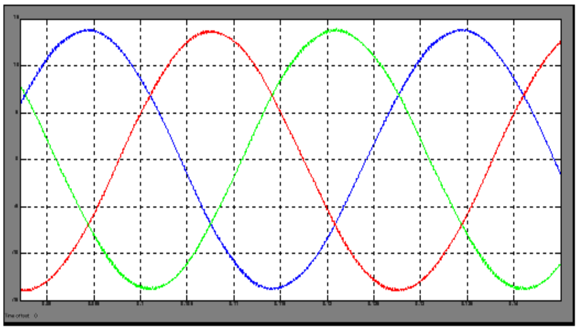

Figure 9. MC input currents.

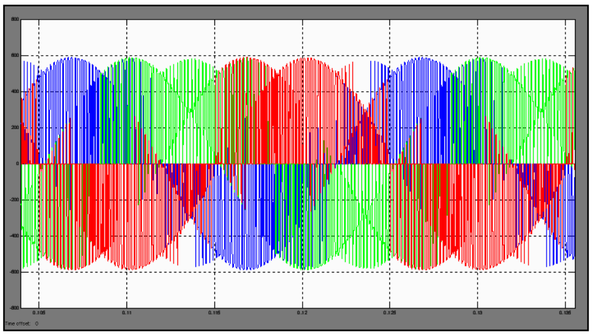

Figure 10. MC output voltages.

6. Simulation Results

The developed model is simulated using MATLAB / SIMULINK. The results obtained are shown in the following figures. Figure 9 shows the MC input current; Figure 10 shows the MC output voltages. The output voltages (Ub1, Ub2, Ub3) and output currents (Ib1, Ib2, Ib3) of three phase RL branch are shown in Figure 11.

7. Conclusions

In this paper, the model of a three phase matrix converter has been developed and simulated. The model has been implemented using MATLAB/SIMULINK. Since MC is a direct power conversion topology so conversion losses are reduced. The results confirm the reduction of conversion losses by 10% to 12% as compared to conventional two stage converters, hence increasing the overall conversion efficiency. Also the use of MOSFETs as switching devices increases the switching frequency by four to five times thereby improving the resulting wave shapes. It has been concluded that the developed Matrix Converter improves the performance of wind energy conversion system. The simulated

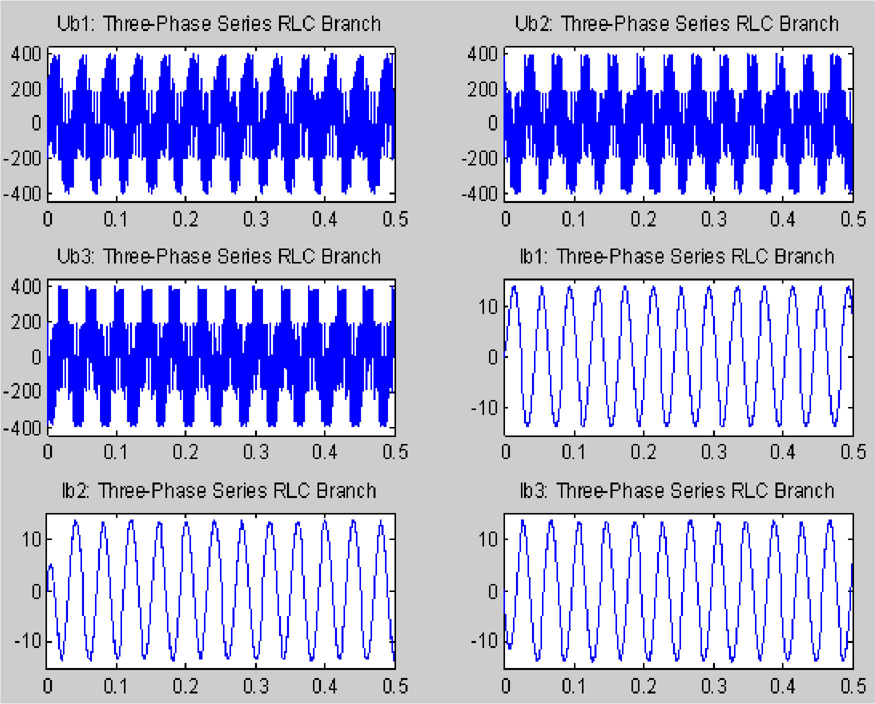

Figure 11. Output Voltages & Currents of Three Phase RLC Branch.

results show pure sinusoidal input current & output voltages, which authenticates that the developed model is most suitable for wind power generation applications. The SIMULINK models developed for MC are;1) MC structure block 2) Duty cycle block and 3) Pulse generation block. These models have been simulated and it has been verified that they met the desired results.

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