MODELING AND SIMULATION OF VENTURINI MODULATION TECHNIQUE FOR THREE-TO-FIVE-PHASE MATRIX CONVERTER USING LABVIEW

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Abstract: Three phase to five phase matrix converter is an array of fifteen bidirectional switches arranged in a way to give five phase output supply for five phase variable speed electric drive applications. A five-phase system has industrial application oriented attractive salient features and fault-tolerant property suitable for safety critical applications. Space Vector and Carrier based modulation methods for five phase matrix converter are presented in many literatures. In this paper a modulation technique to a three phase to five phase matrix converter using Venturini enhanced approach is presented. Venturini modulation technique is less complex to implement than the Space Vector Modulation technique of comparable performance. If conventional controllers like microcontroller or digital signal controller is preferred for this application, it is needed to integrate and configure with FPGA to produce thirty gate pulses to drive the switches of five phase matrix converter. But LabVIEW provides visual modeling platform and software tools that can be directly integrated to FPGA for the real time implementation of modulation, commutation and control algorithms to produce thirty gate pulses to the fifteen bidirectional switches of matrix converter. The proposed algorithm is demonstrated using Matlab/Simulink and LabVIEW software packages.

Keywords: *Multiphase drives, Thee-to-five phase matrix converter, Modeling, Venturini modulation technique, LabVIEW.*

I. INTRODUCTION

The most important advantages of a matrix converter are the sinusoidal source-side current, controlled source-side power factor, lack of a bulky DC-link capacitor, and no limitation on output frequency range [1] – [8]. Detailed review of matrix converter topologies are presented in [10]. Multiphase motor drives have some inherent advantages over the traditional three-phase motor drives, such as increasing the frequency of torque pulsations, reducing the rotor harmonic current losses and improved system reliability.

Five phase drives are suitable for defense, hospitals, ship propulsions, traction drive and aircraft applications. The advantages and applications of five phase systems are presented in [9]. Space vector modulation method for a direct matrix converter with three-phase grid input and five-phase variable-voltage and variable-frequency output for five phase drive systems is presented in [12].The detailed analysis and implementation of a three-to-five-phase matrix converter feeding both inductive and five-phase induction motor loads based on an indirect space vector modulation scheme is given in [13]. Detailed analysis of three-phase input with five-phase output direct matrix converter topology with

Sinusoidal Carrier-Based PWM Technique, Direct Duty Ratio-Based PWM Technique and Space Vector PWM Technique are presented in [14].

Space vector modulation technique for Common-mode voltage control through vector selection in three-to-five phase matrix converter is presented in [15]. Carrier based modulation technique for three–to–five phase matrix converter is discussed in [16] – [19]. The analytical and simulation approach of model predictive control strategy to control active and reactive power simultaneously in addition to the source and load current using predictive approach for a three-phase input to five-phase output matrix converter is presented in [20].

MATLAB simulation of a 4 kW induction motor fed by a five-to-three phase matrix using Predictive Torque Control is presented in [21]. Direct Torque Control of Five phase permanent magnet synchronous motor fed with five phase matrix converter for harmonic elimination is presented in [22].

Analytical and simulation results of five-phase series-connected two-motor drive system is presented in [23]. A model predictive control based matrix converter for Wind Energy Conversion System consists of five-phase Permanent Magnet Synchronous Generator to generate five-phase voltage with variable amplitude and frequency is presented in [24].As per the review of modulation methods of matrix converter detailed in [25], Venturini modulation methods involves low complexity as compared to the space vector modulation of comparable performance. Space vector modulation for three-to-five phase matrix converter is presented in literatures.

In this paper modeling and simulation of Venturini modulation method for three-to-five phase matrix converter using LabVIEW software is presented. The thirty number of gate pulses needed to drive fifteen bidirectional switches of five-phase matrix converter and the four step commutation strategy using logic circuits can easily be implemented in real time in FPGA using LabVIEW software tools. LabVIEW FPGA tools produce fast prototyped solutions compared to conventional FPGA [26].

II. MODELING OF VENTURINI MODULATION ALGORITHM

2.1Three-to-three-phase direct matrix converter

Basic configuration of Direct Matrix Converter without dc link energy storage elements and a conversion technique named as Venturini Algorithm to produce a variable frequency sine wave output from the fixed frequency sine wave input was proposed by Venturini [2], with a limitation on voltage transfer ratio of 0.5 and a restriction in the input power factor control. An enhanced modulation method for direct Matrix Converter which can produce optimum voltage transfer ratio of 0.866 was presented by Alesina and Venturini [3].

In enhanced modulation method the voltage transfer ratio is raised to 0.866 by injecting third-harmonic of the input frequency to the input-phase voltages and by subtracting the third harmonic of the output frequency from the desired output phase voltages. Fig.1 shows the Matlab simulation result obtained for the envelope of input and output voltage with 86.6 % voltage transfer ratio for three-to-three phase direct matrix converter.

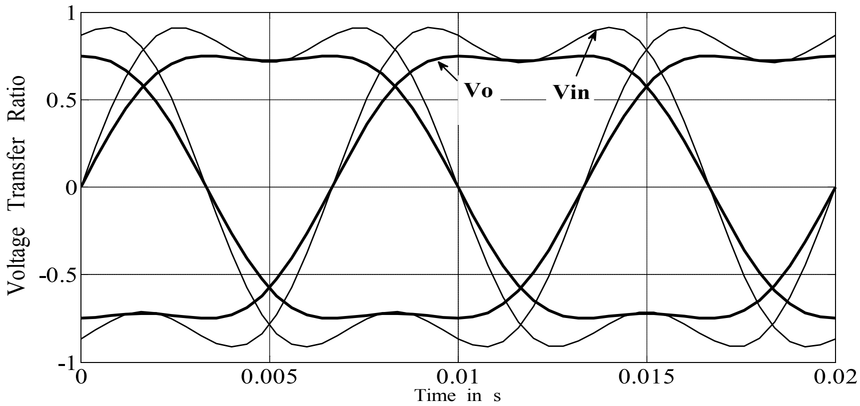


Figure.1. Envelope of Input and output voltages for 86.6 % voltage transfer ratio in three-to-three phase direct matrix converter

2.2 Three-to-five-phase direct matrix converter

The general power circuit topology of a three-to-five-phase direct matrix converter is illustrated in Figure2.There are five legs, where each leg has three bidirectional power switches with antiparallel connected insulated-gate bipolar transistors (IGBTs)and diodes. The input source is identical to a three-to-three-phase matrix converter developed in [10–12].A small LC filter is connected at the source side to eliminate ripple, and the output is five phases with72° phase displacement between each phases. The switching function is defined as Sij ={1 for a closed switch, 0 for an open switch}, i ={a, b, c}(input), j={A, B, C, D, E} (output). The switching constraint is Saj +Sbj +Scj =1. In the case of a multiphase voltage source inverter, nth harmonic injection concept can be used for the enhancement of the modulation index. By injecting the nth harmonic component of magnitude Mn = − (M1 sin(π⁄2m))⁄m, where m is the number of phases, the output voltage can be increased by 1⁄cos(π⁄2m). The same approach can be employed to enhance the output voltage magnitude of the matrix converter. The output voltage becomes 75% of the input voltage by only injecting the third harmonic.

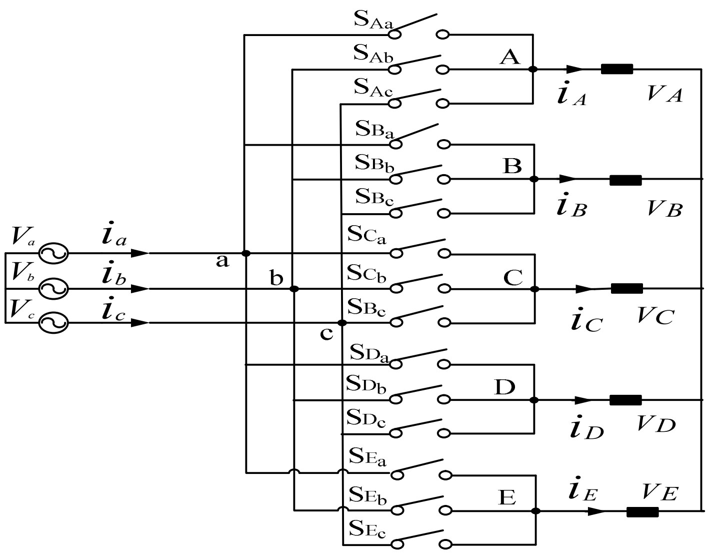


Figure.2 Topology of three-to-five-phase direct matrix converter

This increase is the same as that achieved in the three-to-three-phase matrix converter. In the case of three-to-five-phase matrix converter, the third harmonic of output cannot be injected, hence the fifth harmonic of the output frequency is injected. The maximum output voltage magnitude thus achieves 78.86% of the input voltage magnitude by injecting third harmonics at the input side and fifth harmonics at the output side in the linear modulation region. Fig.3 shows the Matlab simulation result obtained for the envelope of input and output voltage with two step harmonic injection described in equations (1) and (2) for three-to-five phase direct matrix converter. In Venturini enhanced modulation method for direct Matrix Converter [27], for a given set of three-phase input voltages, a desired set of output voltages can be synthesized by sequential piecewise sampling of the input waveforms. The duration of each sample is derived mathematically to ensure that the average value of the actual output waveform within each sampling cycle tracks the required output waveforms. The input and output voltage vectors are defined by the relationship between them and they are written as given in equation (3).

$$V_a(t) = V_m\left(\sin\omega_i t + \frac{2\sqrt{3}}{12}\sin 3\omega_i t\right) \quad (1)$$

$$V_A(t) = 0.7886V_m\left(\sin\omega_o t - \frac{2\sqrt{3}}{48.5}\sin 5\omega_o t\right) \quad (2)$$

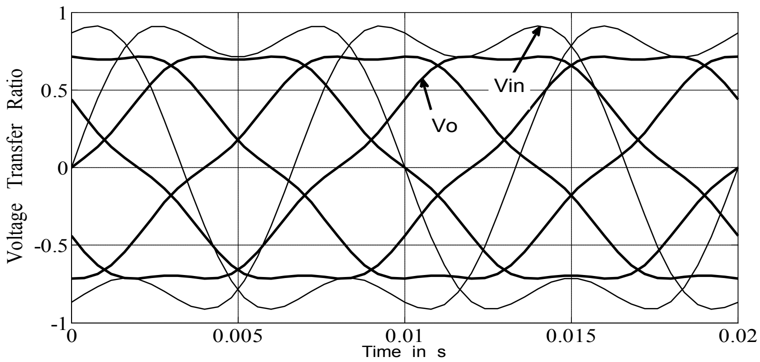


Figure.3. Envelope of Input and output voltages for 78.86 % voltage transfer ratio in three-to-five phase direct matrix converter

$$\vec{V}_{in} = \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} = \begin{bmatrix} V_m\cos\omega_i t \\ V_m\cos\left(\omega_i t - \frac{2\pi}{3}\right) \\ V_m\cos\left(\omega_i t - \frac{4\pi}{3}\right) \end{bmatrix}, \quad \vec{V}_{out} = \begin{bmatrix} V_A(t) \\ V_A(t) \\ V_B(t) \\ V_C(t) \\ V_D(t) \\ V_E(t) \end{bmatrix} = \begin{bmatrix} V_m\cos\omega_o t \\ V_m\cos\left(\omega_o t - \frac{2\pi}{5}\right) \\ V_m\cos\left(\omega_o t - \frac{4\pi}{5}\right) \\ V_m\cos\left(\omega_o t - \frac{6\pi}{5}\right) \\ V_m\cos\left(\omega_o t - \frac{8\pi}{5}\right) \end{bmatrix} \quad (3)$$

$$\vec{V}_{out} = M\,\vec{V}_{in} \quad (4)$$

$$\begin{bmatrix} V_A(t) \\ V_B(t) \\ V_C(t) \\ V_D(t) \\ V_E(t) \end{bmatrix} = \begin{bmatrix} m_{11}(t) & m_{12}(t) & m_{13}(t) \\ m_{21}(t) & m_{22}(t) & m_{23}(t) \\ m_{31}(t) & m_{32}(t) & m_{33}(t) \\ m_{41}(t) & m_{42}(t) & m_{43}(t) \\ m_{51}(t) & m_{52}(t) & m_{53}(t) \end{bmatrix} \begin{bmatrix} V_a(t) \\ V_b(t) \\ V_c(t) \end{bmatrix} \tag{5}$$

where,

$$M = \begin{bmatrix} m_{11}(t) & m_{12}(t) & m_{13}(t) \\ m_{21}(t) & m_{22}(t) & m_{23}(t) \\ m_{31}(t) & m_{32}(t) & m_{33}(t) \\ m_{41}(t) & m_{42}(t) & m_{43}(t) \\ m_{51}(t) & m_{52}(t) & m_{53}(t) \end{bmatrix} \tag{6}$$

$\overrightarrow{M}$ is the instantaneous transfer function matrix.By a mathematical approach, the switching functions required to obtain the target output voltages is given in equation (7).

$$m_{ij}(t) = \frac{1}{3} + \frac{2}{3} q \cos\left(\omega_i t - 2(j-1)\frac{\pi}{3}\right)\left\{\cos\left(\omega_0 t - 2(i-1)\frac{\pi}{5}\right) - \frac{2\sqrt{3}}{48.5}\cos\left(5\omega_0 t\right) + \frac{2\sqrt{3}}{12}\cos\left(3\omega_i t\right)\right\}$$
$$- \frac{2q}{3\sqrt{3}}\left\{\cos\left(4\omega_i t - 2(j-1)\frac{\pi}{3}\right) - \cos\left(2\omega_i t - 2(1-j)\frac{\pi}{3}\right)\right\} \tag{7}$$

III. RESULTS AND DISCUSSION

Mathematical modeling of five phase matrix converter with R-L load and Venturini modulation algorithm for five phase matrix converter are performed in Matlab/Simulink and LabVIEW. The validity of the proposed algorithm using Venturini enhanced approach for five phase matrix converter is verified through modeling and simulation result analysis. The maximum value of input voltage is 1 pu and input frequency is 50 Hz in LabVIEW simulation. In LabVIEW the time format is in floating point representation. The simulation results obtained for line to line output voltages of all the five phases with different output frequencies and two line voltages for clearness using LabVIEW are shown in figures (4) – (9).

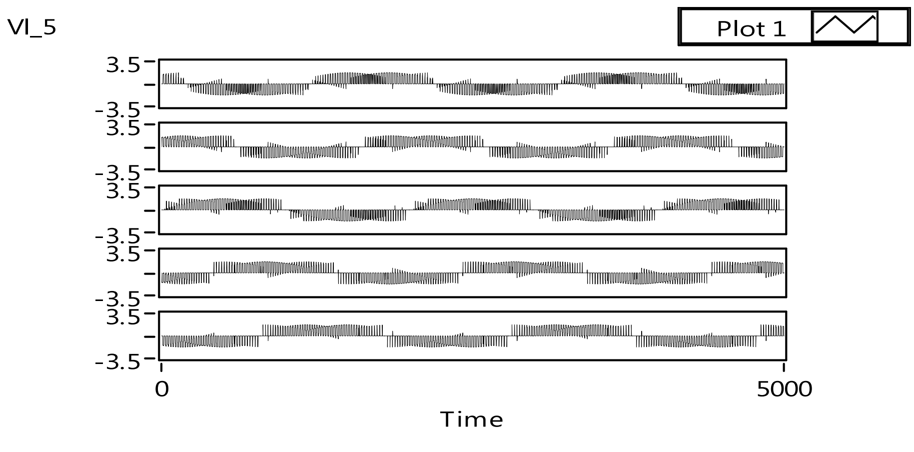
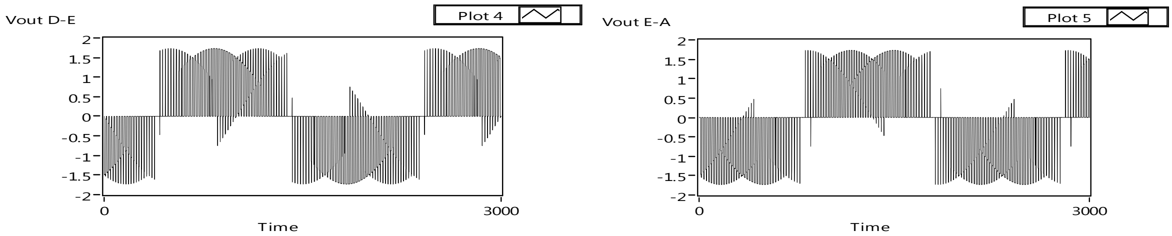


Figure.4. Line to line voltages with input and output frequencies of 50 Hz



(a) (b)

Figure.5. Line to line voltages with input and output frequencies of 50 Hz (a) V_{de} (b) V_{ea}

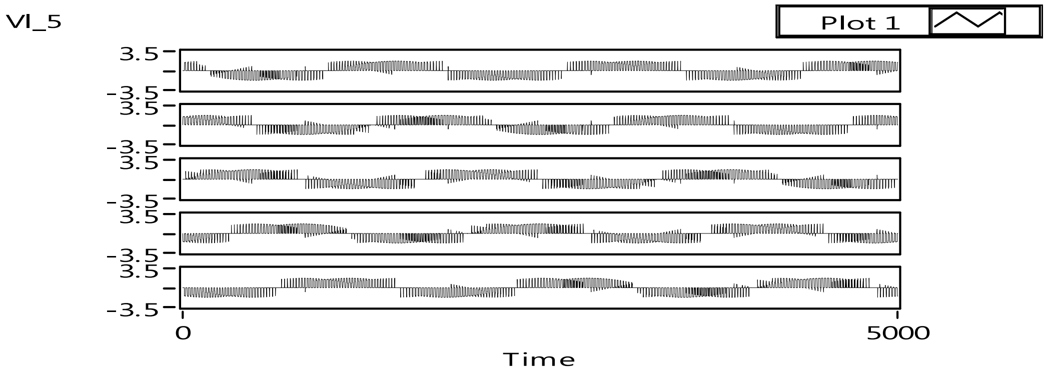
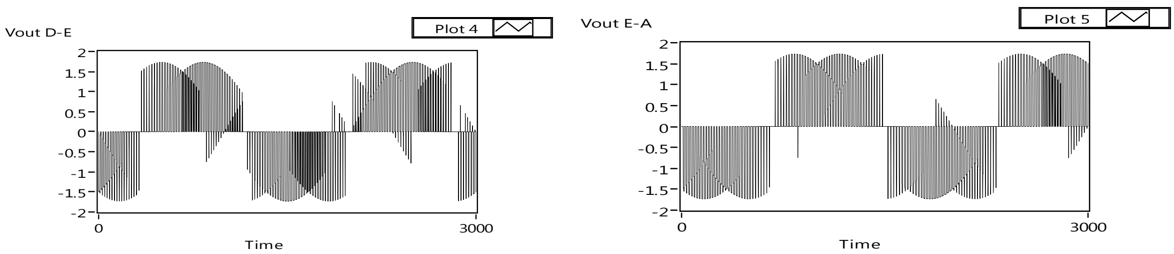


Figure.6. Line to line voltages with input and output frequencies of 50 Hz and 60 Hz



(a) (b)

Figure.7. Line to line voltages with input and output frequencies of 50 and 60 Hz (a) V_{de} (b) V_{ea}

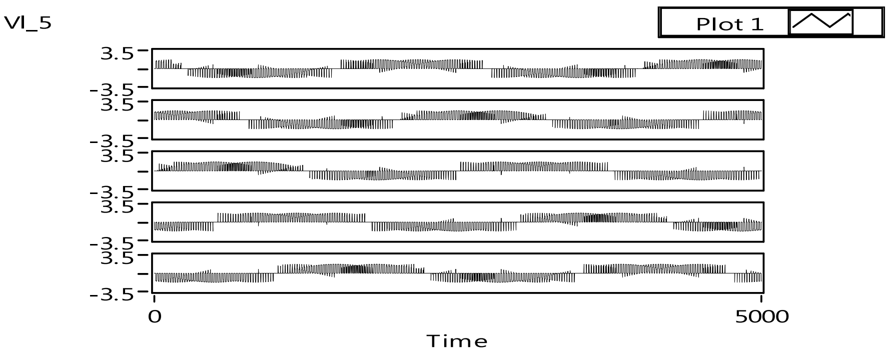
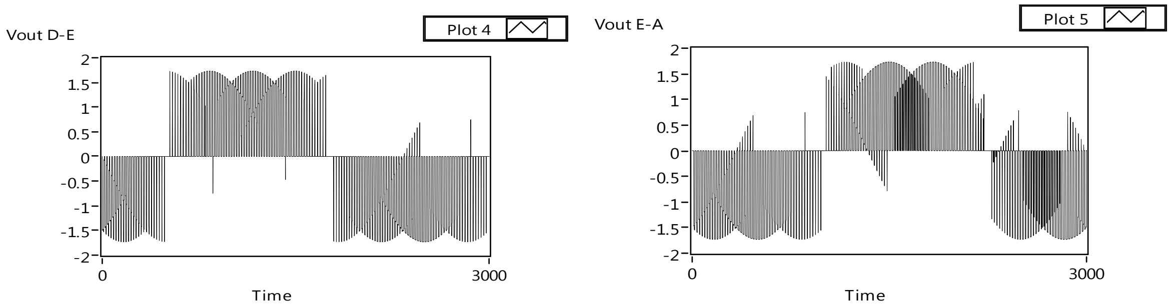


Figure.8. Line to line voltages with input and output frequencies of 50 Hz and 40 Hz



(a) ***(b)***

Figure.9. Line to line voltages with input and output frequencies of 50 and 40 Hz (a) V_{de} (b) V_{ea}

Maximum value of input voltage used is 325 V in Matlab for an R-L load of R = 10 Ω and L = 20 mH with input frequency of 50 Hz. The simulation results obtained for line to line output voltages of all the five phases using Matlab/Simulink is shown in figures (10) – (12). The phase current waveforms for three and five phase matrix converter fed R-L load are shown in figures (13) – (15).

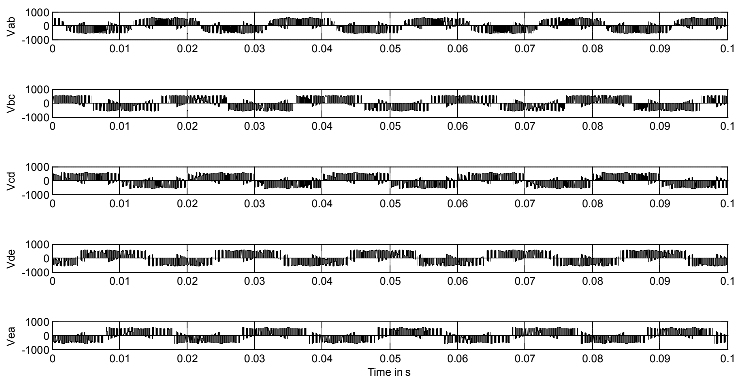


Figure.10. Line to line voltages with an output frequency of 50 Hz

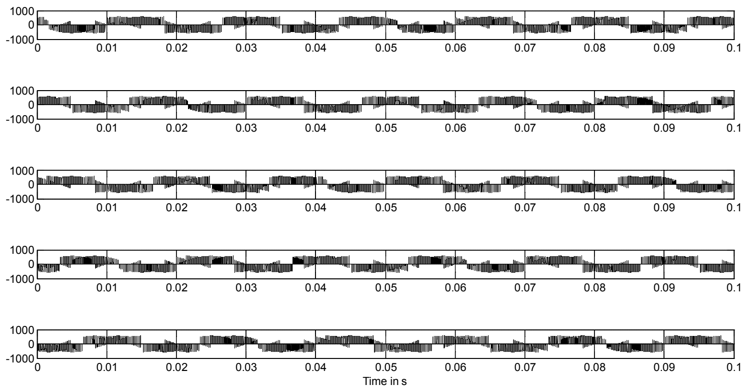


Figure.11. Line to line voltages with an output frequency of 60 Hz

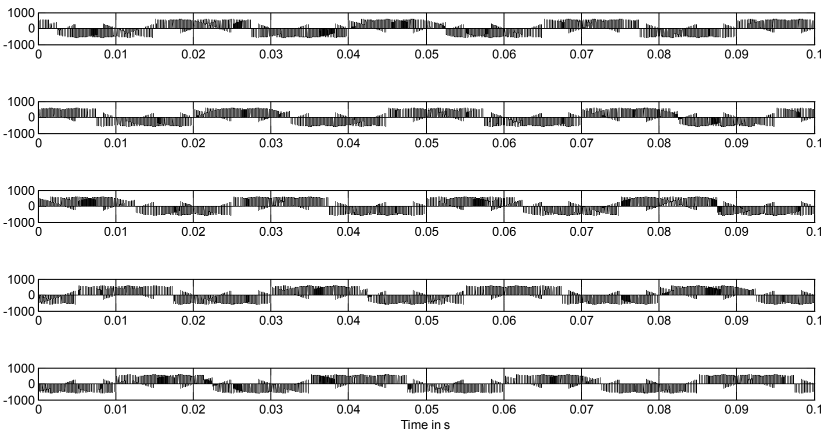


Figure.12. Line to line voltages with an output frequency of 40 Hz

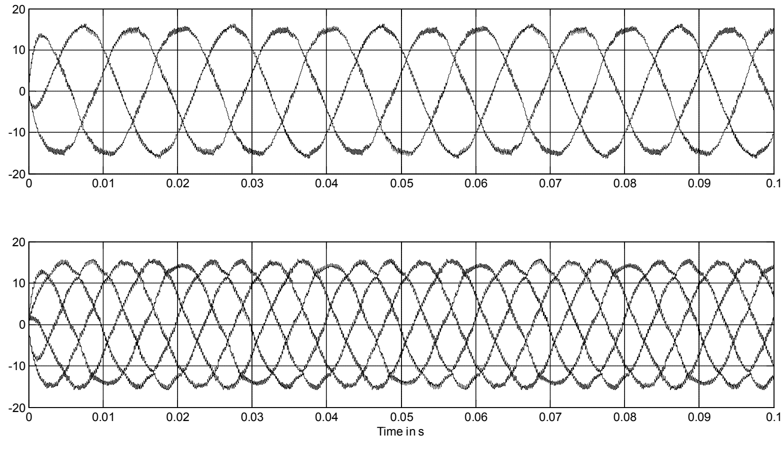


Figure.13. Phase current waveforms of 3 and 5 phase matrix converter for 50 Hz

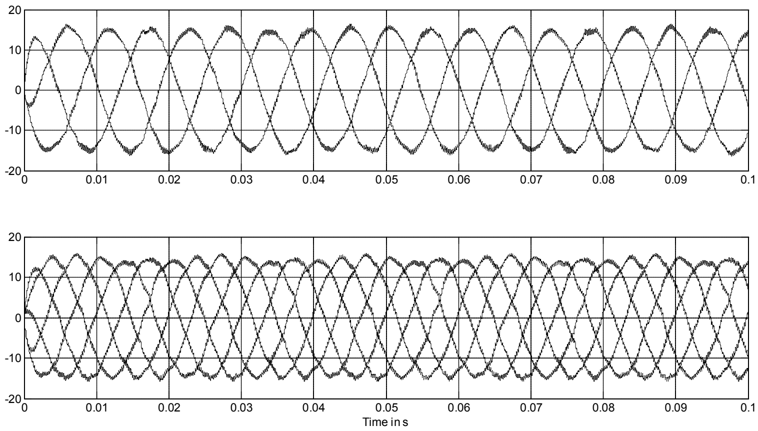


Figure.14. Phase current waveforms of 3 and 5 phase matrix converter for 60 Hz

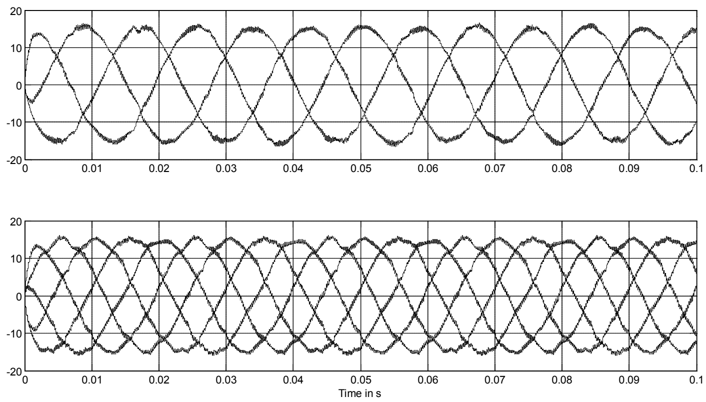


Figure.15. Phase current waveforms of 3 and 5 phase matrix converter for 40 Hz

The Fourier analyser block of Matlab/Simulink is used to verify the voltage transfer ratio of three-to-three phase and three-to-five phase matrix converter using the proposed algorithm. The maximum value of input phase voltage is 325 V. An output voltage magnitude of 281 V and 256 V obtained for three-to-three phase matrix converter and three-to-five phase matrix converter respectively are shown in figure 16. Hence the maximum input to output voltage transfer ratio of 86.6% for three-to-three phase and 78.86% for three-to-five phase matrix converter using the proposed algorithm is validated.

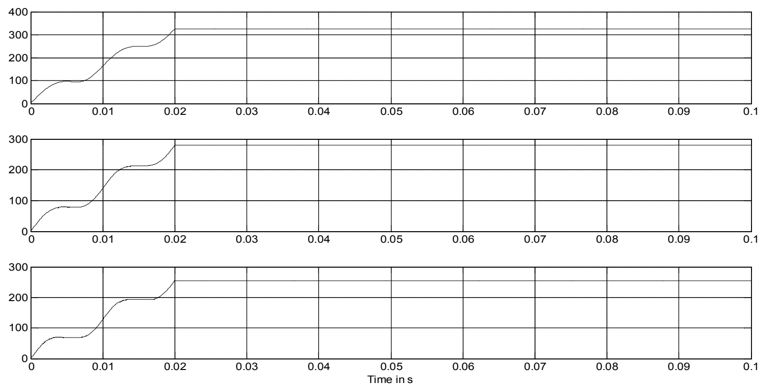


Figure.16. Input, three phase output and five phase output voltage magnitudes

CONCLUSION

In this paper mathematical modeling of Venturini modulation technique which is less complex to implement than the Space Vector Modulation technique of comparable performance is realized using Matlab and LabVIEW programs for three-to-three phase and three-to-five phase matrix converter. The maximum voltage transfer ratio of 86.6% for three-to-three phase matrix converter and 78.86% for three-to-five phase matrix converter are validated through the results. The sinusoidal output currents for three and five phase matrix converters fed R-L load are also verified through the results. This model can further be used for controller design of variable speed multiphase drive applications in LabVIEW- FPGA environment with voltage and current measurement based commutation techniques.

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