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Space vector pulse width modulation for 3-phase matrix converter fed induction drive

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Abstract -- This paper describes the implementation of 3-phase matrix converter using Space Vector Pulse Width Modulation (SVPWM) to control three phase induction motor. The variable AC output voltage engendered using matrix converter with bidirectional power switches controlled by appropriate switching pulse. The conventional PWM converter produces common mode voltage across the load terminal, which causes the common mode current and hence leads to bearing failure in load drive. These problems can be overcome using SVPWM and hence minimizes the effect of the harmonics in the output voltage. The voltage stress on the power switch is reduced using SVPWM based 3-phase matrix converter. The simulation is done using MATLAB simulink and the SVPWM control is designed using DSP controller.

Keywords: Matrix converter, Space Vector Pulse Width Modulation (SVPWM), AC motor drive, DSP controller, Common Mode Voltage (CMV).

1. Introduction

In recent days power electronic converters are used in various applications such as industrial, medical, power system applications, energy transportation, and railway applications. Optimization of power electronic converter design and operation is important to improve power processing level to meet the demand and to enhance the quality of power [1]. Power electronic converters such as the rectifier, inverter, cyclo-converter and ac voltage controller are used to convert voltage from one level to another. Among them inverters are extensively used in numerous applications in which the essential voltage is AC always in nature [2], [3]. Even though most of the drives require DC source to operate in four quadrants, so rectifiers are used to generate DC voltage [4]. Basically for converting AC-AC, the conventional converters cyclo converter and ac voltage controller are used, but these converters are not able to provide control on frequency and voltage with reduced harmonics and controlled output AC current [5].

The matrix converter is used to convert AC-AC source with minimized ripple content [6]. It has merit over conventional rectifier - inverter power frequency combination, with reduced higher order harmonics and no lower order harmonics [7]. The matrix converter has main features like input AC source is fully controlled, bidirectional energy flow capability, input power factor can be controlled, exclusion of dc link filters and power devices can be used with zero switching due to that power loss is minimised [8], [9]. The main disadvantage of matrix converter is that it requires more power semiconductor devices compare to traditional rectifier-inverter pair [10].

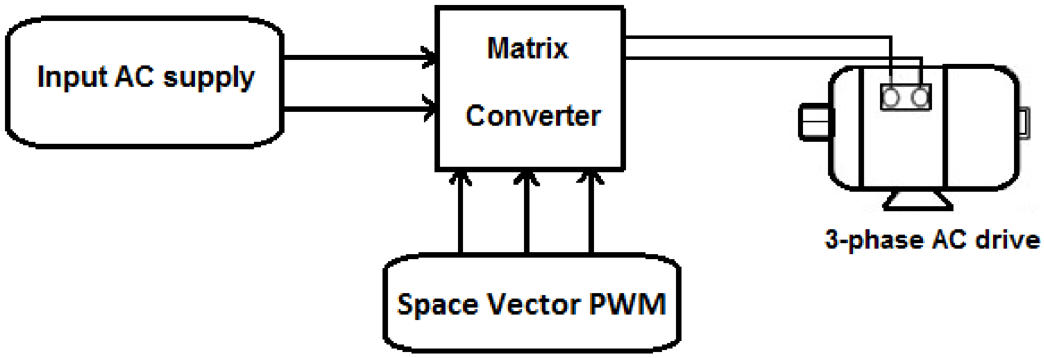

Fig.1. Block diagram of 3-phase matrix converter fed IM drive

Pulse width modulation (PWM) is generally used switching control to maintain voltage amplitude and frequency with fast dynamic response. Due to these conventional PWM methods, the circulating current in the converter system starts increase [11],[12]. Common Mode Voltage (CMV) of the converter also increases; it leads to failure of motor bearings and increases the electromagnetic interference problems. To eradicate these problems the additional filter are added, which minimise the power density and increase the initial cost of the system [13], [14]. For several applications, the multilevel converters are used to decrease the CMV issue, at same time the complexity increases in PWM switching pulse generation with these motive sinusoidal pulse width modulation and space vector modulation are employed to minimize the losses and also it is easy to implement. THD of converter decided by switching frequency of the power devices and maximum power transfer level depends on the characteristics of the controller [15].

Single/ three phase IM are widely used in home and industrial applications especially at low power ranges (below 2.5 kW). These type of motors are used in variable speed applications, so it requires variable voltage which can be obtained through matrix converter[16]. For this application, inverter used is symmetric voltage magnitude and frequency and needs of large dc link capacitors and rectifier circuit[17]. But matrix converter act as a direct ac-ac converter, which has sinusoidal input current and adjustable output voltage and frequency.

This proposed work elucidates the performance of 3-phase matrix converter using space vector pulse width modulation to control the operation of three phase induction motor. It minimizes the effect on the harmonic fluctuation in AC output voltage and stress on the power switch is reduced. The simulation and experimental results of the proposed system is verified using matlab/simulink and TMS320F3812 controller respectively. Section-2 explains the operation of 3-phase matrix converter, section-3 describes about SVPWM controller and section-4 & 5 explicates simulation and experimental results discussion.

2. Three phase matrix converter

a. Structure

The block diagram of 3-phase matrix converter fed IM drive is shown in fig.1.The matrix converter includes 9 bidirectional switches, which allows any output phase voltage is connected to any input phase voltage. The input 3 phase terminal voltage is connected with three phase bidirectional switch that reduction in harmonic fluctuation. DC link filters are capacitive filter and inductive filter are eradicated, due to that cost of system is decrease. 3-phase matrix converter is shown in fig.2.

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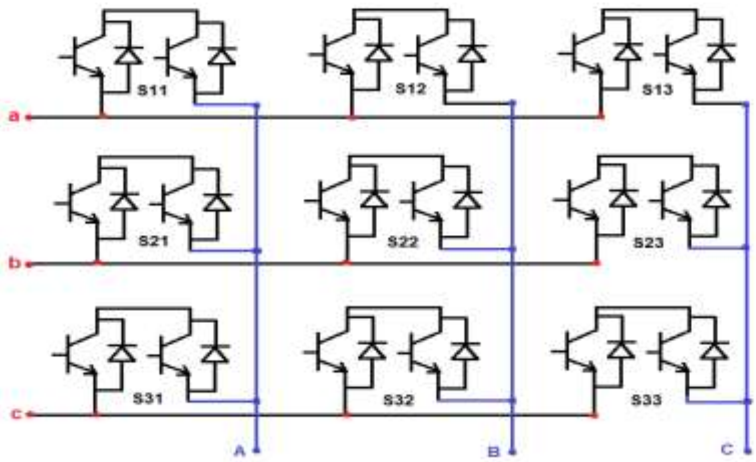

Fig.2. three-phase matrix converter

b. Operation of Matrix converter

The applied input instantaneous power will not be equal to output power. The difference between these input and output power should be absorbed or supplied by an energy storage devices like capacitor or inductor within the converter system. But matrix converter has single stage conversion unit with help of bidirectional switches instead of using multistage conversion and energy storage devices in the converter. Matrix converter with bidirectional switch is shown in fig.3. Due to the absence of energy storage devices, the instantaneous input power is equal to output power with ideal zero loss switches. The system consists of 9 bidirectional switches, which are connected as three groups. Each group contains of 3 switches and each bidirectional switch is connected to both input voltage and output voltage.

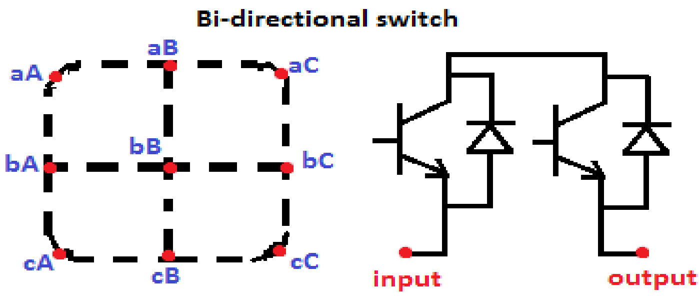

Fig.3. Matrix converter with bi-directional switch

Totally the operation of 3 phase matrix converter has 27 permitted switching modes, in that 18 active vector modes, 3 zero vector modes, 3 normal vector modes and 3 inverse vector modes. The fig.3 illustrates that, a, b, c are input voltages for bi-directional switches and A, B, C are output voltages of matrix converter. Here all input phase voltages are connected to output phase voltage. And these bidirectional switches are switched ON rotational basis, which avoids the switching of 2 switches in the same leg.

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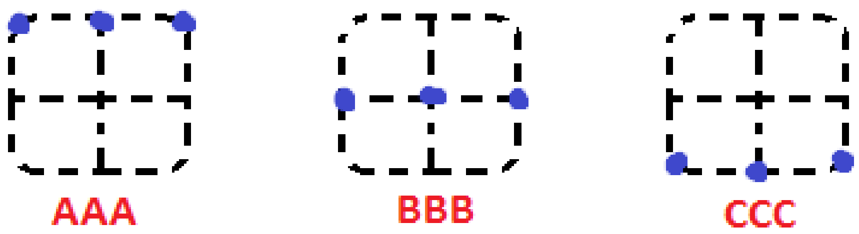

Fig.4. Matrix converter – zero vector modes

The fig.4 shows zero vector modes of 3 phase matrix converter and in that all output phases are connected in single input phase, which leads to the damage the system because 3 phase load is connected with 1 phase input. The normal active vector and opposite vector modes are applicable for forward and reverse operation of induction motor.

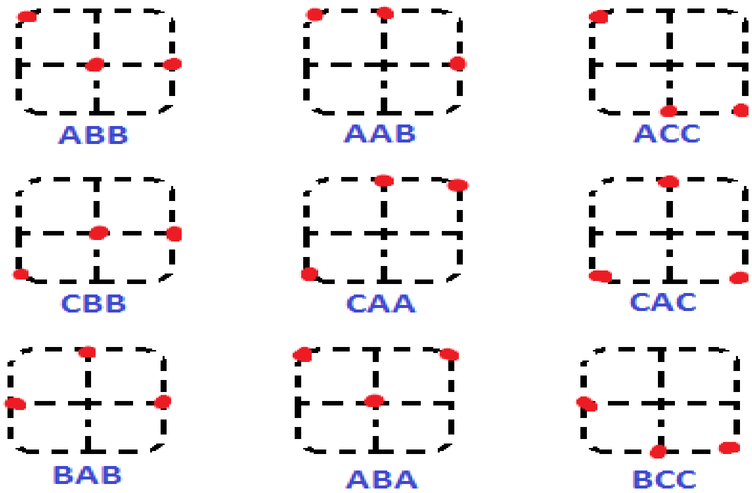

Fig.5. Matrix converter – active vector modes

The fig.5 shows active vector modes of matrix converter, this is used for direct conversion of operating states. The matrix converter can operate in any combination of active vectors to generate non-fluctuated ac output voltage.

3. Space Vector Pulse Width Modulation (SVPWM) control

SVPWM is a switching control method for the power electronic switches which recognizes the switching sequences by assignment of a switching vector in d-q space region [16]. It is enhanced at harmonic content level diminution and increasing output voltage amplitude as contrast to traditional SPWM (Sinusoidal Pulse Width Modulation), which is generally used. It reduces the common mode voltage which is the difference between vector sum of the voltage level potential at power converter system output and ground point [17], [18]. The voltage across the proposed matrix converter has minimum voltage fluctuation and reduced harmonic input current source. The voltage stress across the bi-directional switches and CMV level can be controlled using SVPWM.

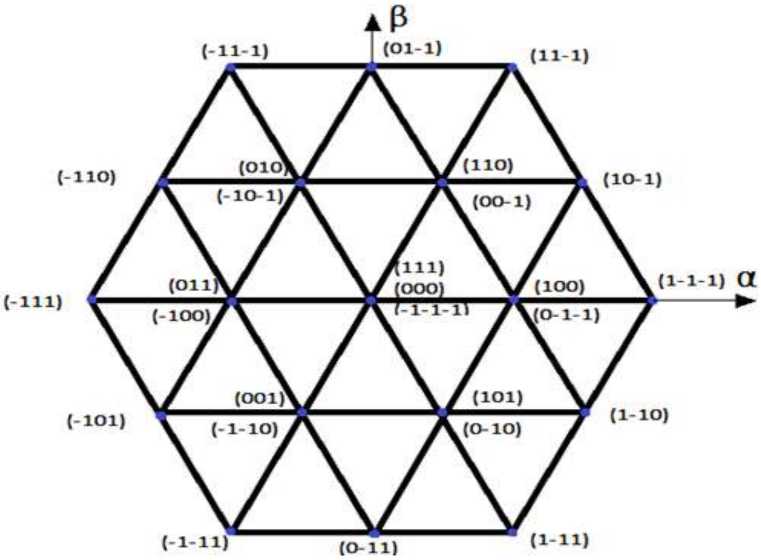

Fig.6a. Space vector representation for 3-phase power converters

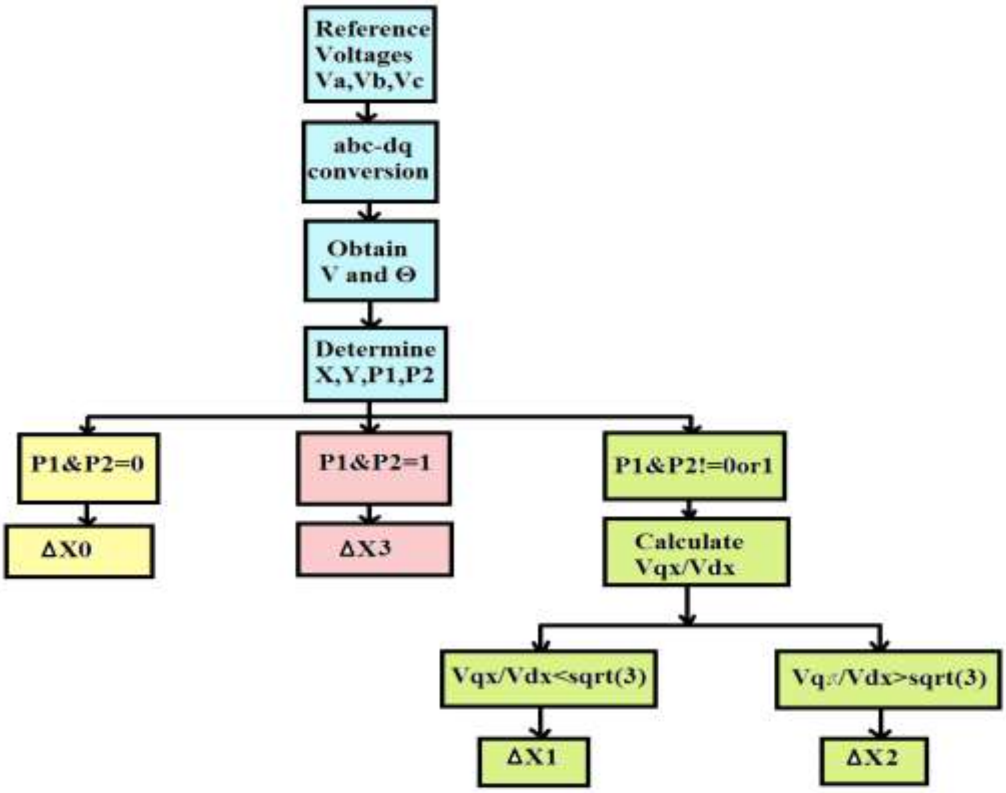

Fig.6b. Flowchart for switching pulse generation using SVPWM method

For determining the switching state vectors of the matrix converter, the space vector control is divided into six sectors and each sector has four triangles. Each intersection point refers to vertex, in that some of the vertices point has redundancy in switching states. Twenty seven switching states are possible for 3-phase matrix converter, which discussed in section 2. The following steps are used to generate the gating pulses for bi-directional switches of matrix converter. The flowchart is shown in fig.6b., in that X & Y

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parameters are used to find the sector identification, P1 & P2 are used to identify the triangle for reference vector calculation.

$$X = \text{integer } [\theta/60] + 1 \quad (1)$$

(Since the sector numbering starts from 1 to 6))

And the angle of the space vector in that sector can be determined by the remainder of the above division

$$Y = \text{remainder } [\theta/60] \quad (2)$$

For the determination of triangle, Let the coordinates of the space vector be (V_D, Vq) in the d-q axis plane. Now two constants P1 and P2 are defined as

$$P1 = \text{integer } (V_d + V_q/\sqrt{3}) \quad (3)$$

and $$P2 = \text{integer } (V_q /h) \quad (4)$$

Where h($\sqrt{3}/2$) is the height of the small triangle.

- ✓ Sector identification for reference vector – based on magnitude and angle calculation
- ✓ Triangle identification in the sector
- ✓ Switching vector calcuation
- ✓ Switching pulse generation for bi-directional switches placed in the matrix converter.

4. Simulation results and discussion

The simulation of the projected system is designed in Matlab/simulink16a. Three phase matrix converter are connected with load of three phase 3HP induction motor with an input voltage of 230V. Fixed three phase voltage is converted into variable voltage and variable frequency through matrix converter with help of bi-directional switches. Bi-directional switches in the system is controlled by proper switching pulse generation using SVPWM method, which is shown in fig.7.

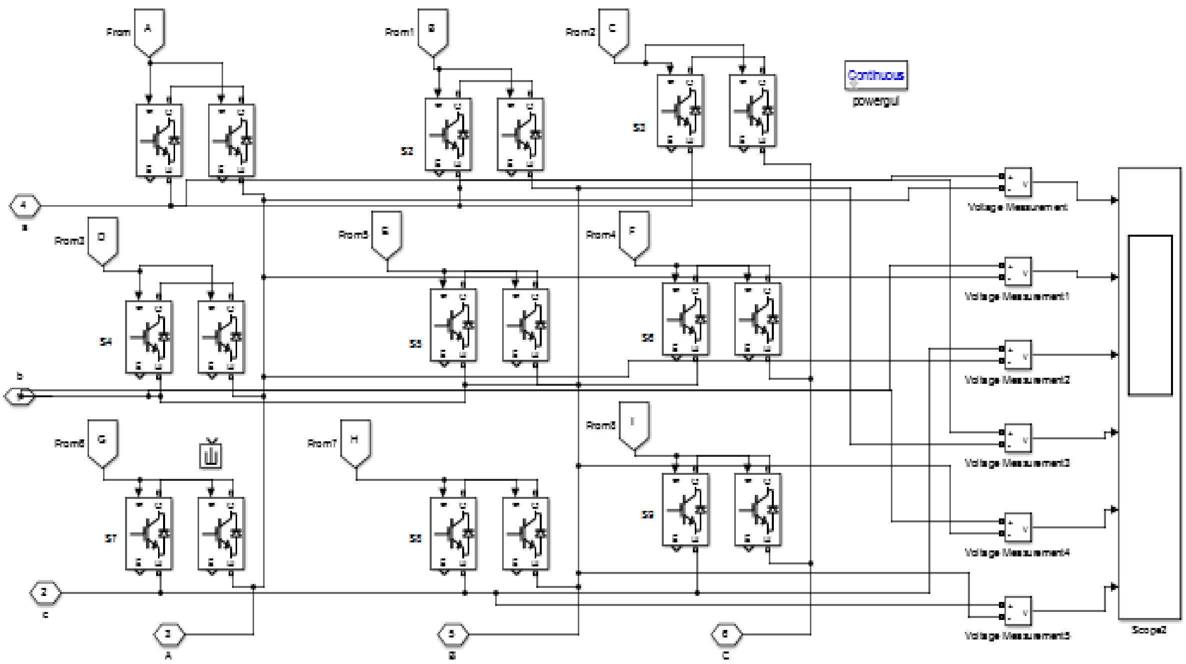

Fig.7. Simulation diagram of matrix converter

The 3-phase output voltage of matrix converter with 219V is obtained from fixed three phase input voltage of 230V which are shown in fig.8 and fig.9. And three output current of 13.7A, obtained is given in fig.10. Harmonic content & voltage stress of proposed system is minimised. Harmonic spectrum for variable 3-phase output voltage of 0.31% and for 3-phase output current of 0.34% is shown in fig.11 & fig.12 respectively.

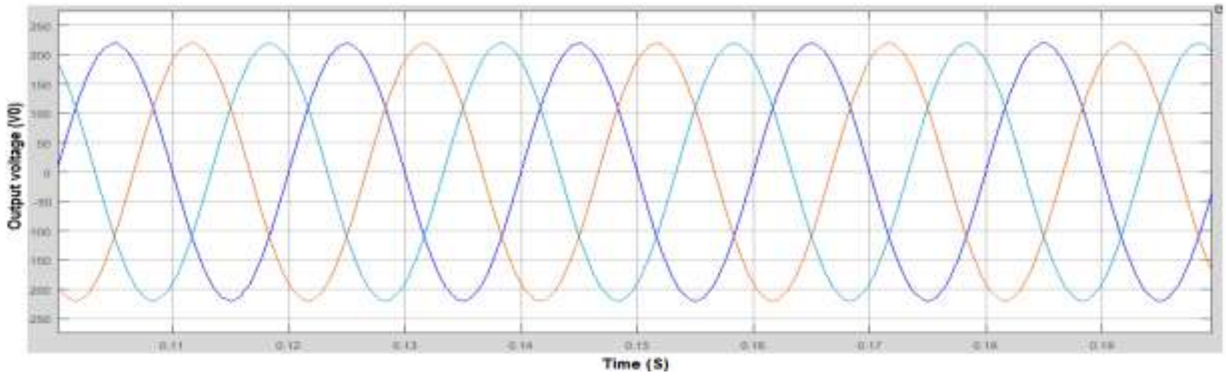

Fig.8. 3 phase variable output voltage of matrix converter

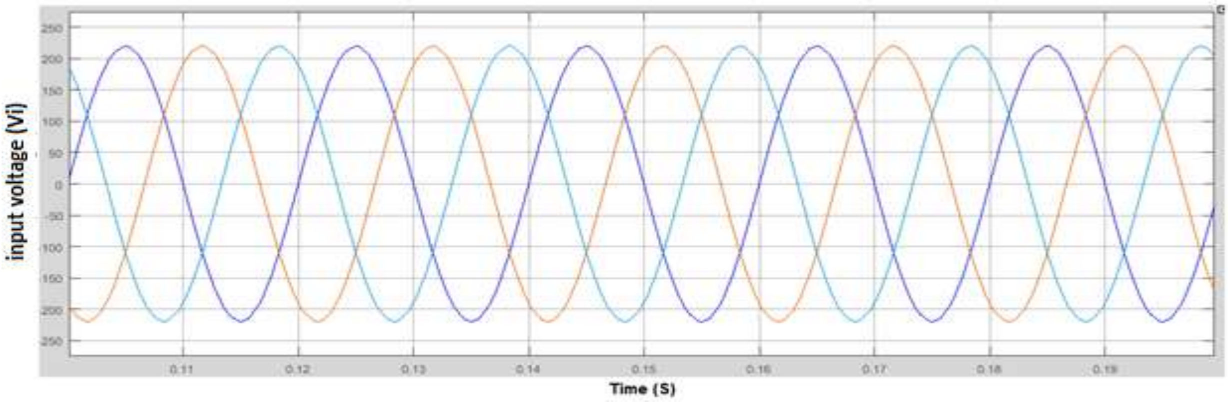

Fig.9. 3 phase input voltage of matrix converter

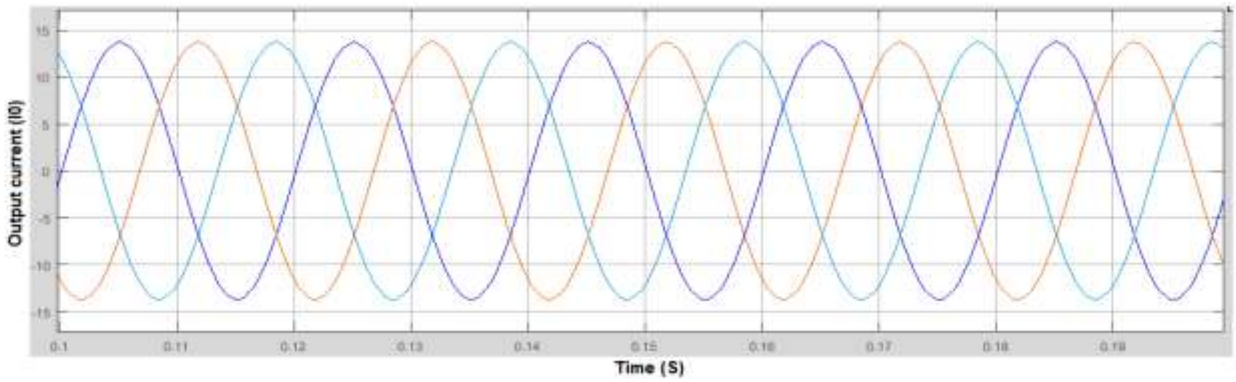

Fig.10. 3 phase output current of matrix converter

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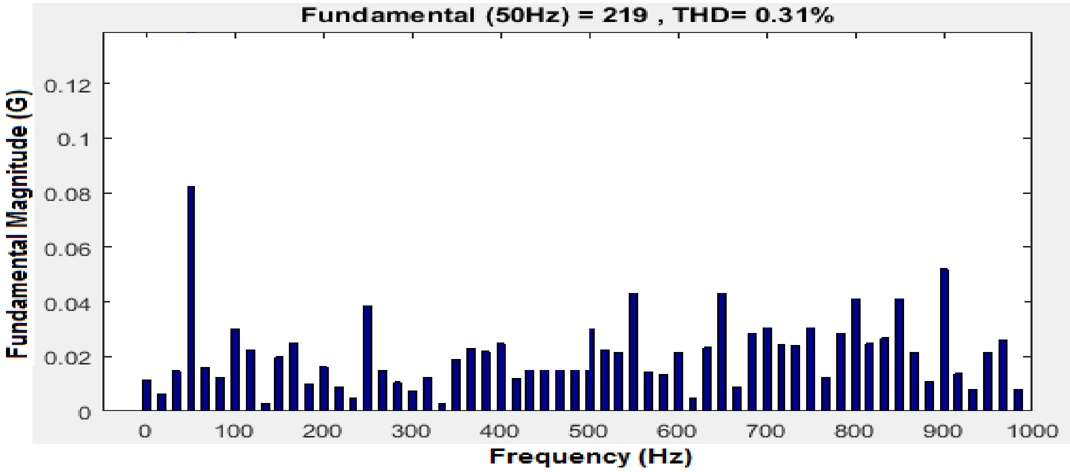

Fig.11. THD analysis for 3-phase matrix converter variable output voltage

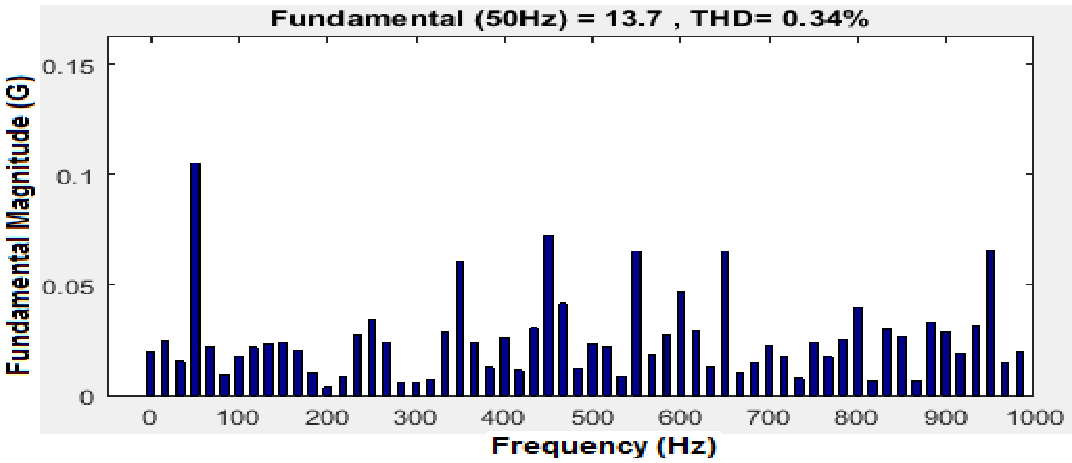

Fig.12. THD analysis for 3-phase matrix converter output current

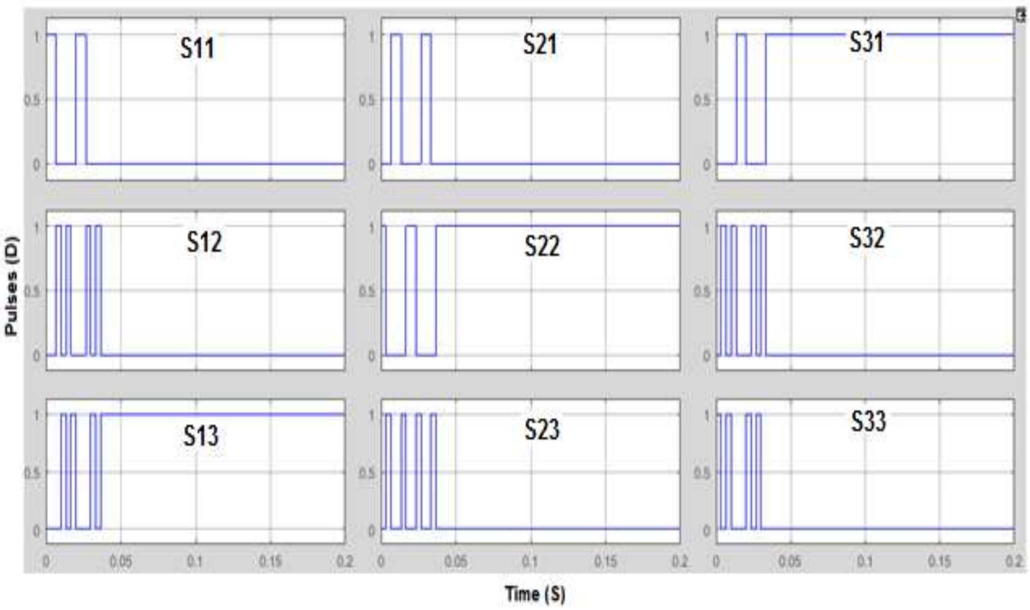

Fig.13. Switching pulse generation for matrix converter using SVPWM

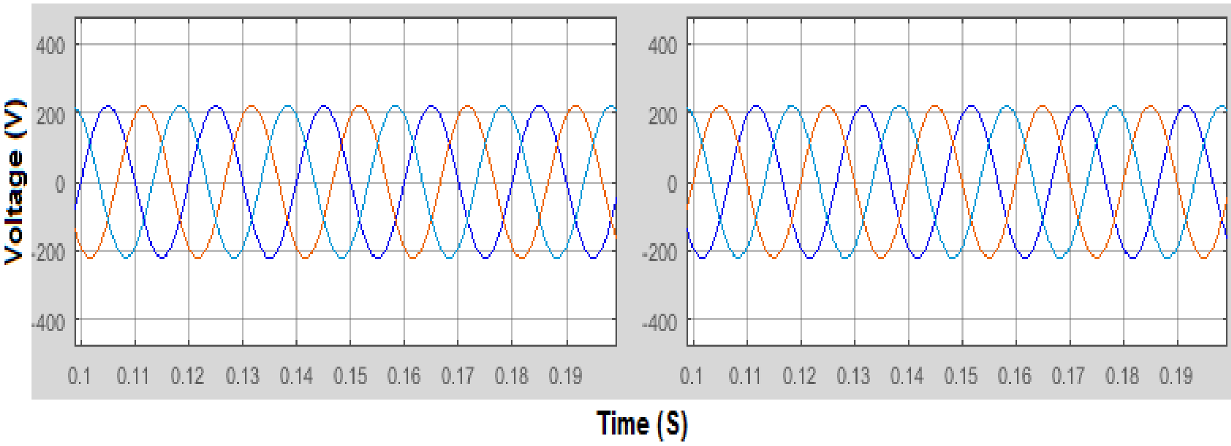

Fig.14. Comparison between input voltage & output voltage

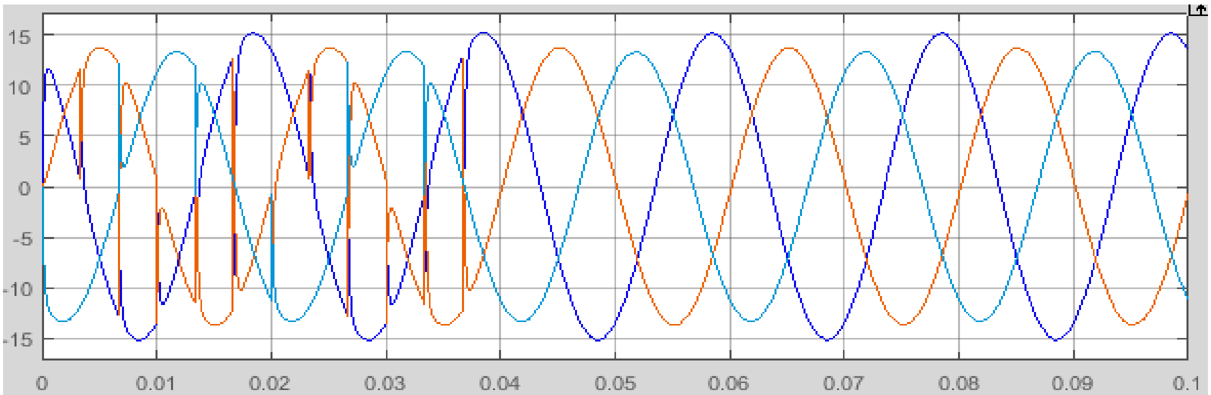

Fig.15. input current of matrix converter with 3-phase IM drive

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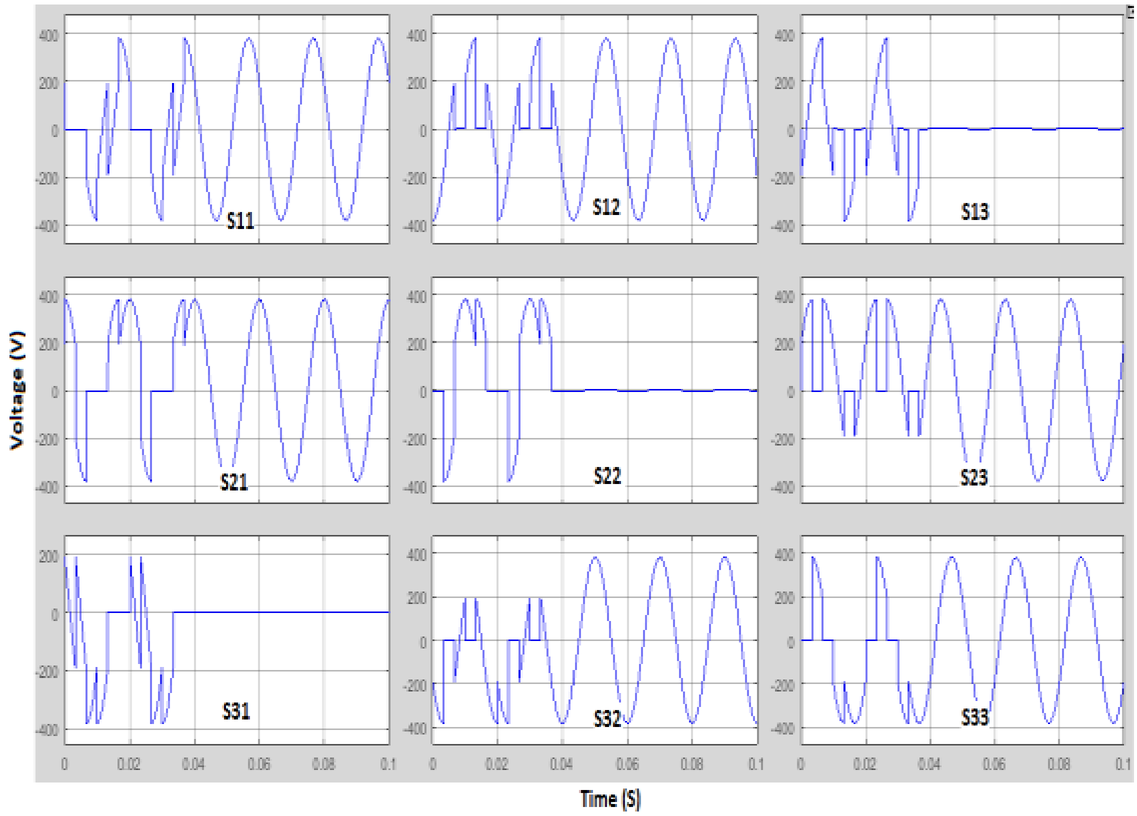
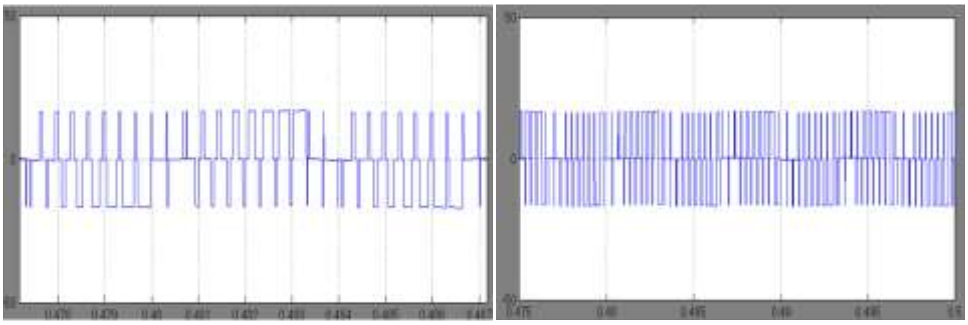


Fig.16. Voltage stress across bi-directional switches (S11, S12, S13, S21, S22, S23, S31, S32, S33)



(a) (b)

Fig.17. Common mode voltage reduction (a) a-phase (b) b-phase

The fig.13 shows the switching pulse generation for bi-directional switches (S11 to S33) positioned in the matrix converter using SVPWM, which is shown in fig.13. And fig.14 shows the comparison between applied 3-phase input voltage and 3-phase output voltage. In fig.15 shows input current of matrix converter with 3-phase IM drive, which contains more fluctuation. The life of power converter depends on voltage stress on the power switches, fig.16 shows voltage stress across all the switches placed in proposed converter. Basically any PWM technique output of all phases are in the form pulses, so CMV consists of high switching frequency voltage pulses of assured magnitude which occur between the phase and the ground point. Fig.17 shows the CMV reduction for a & b phase, which reduces the CMV compared to the other conventional PWM schemes.

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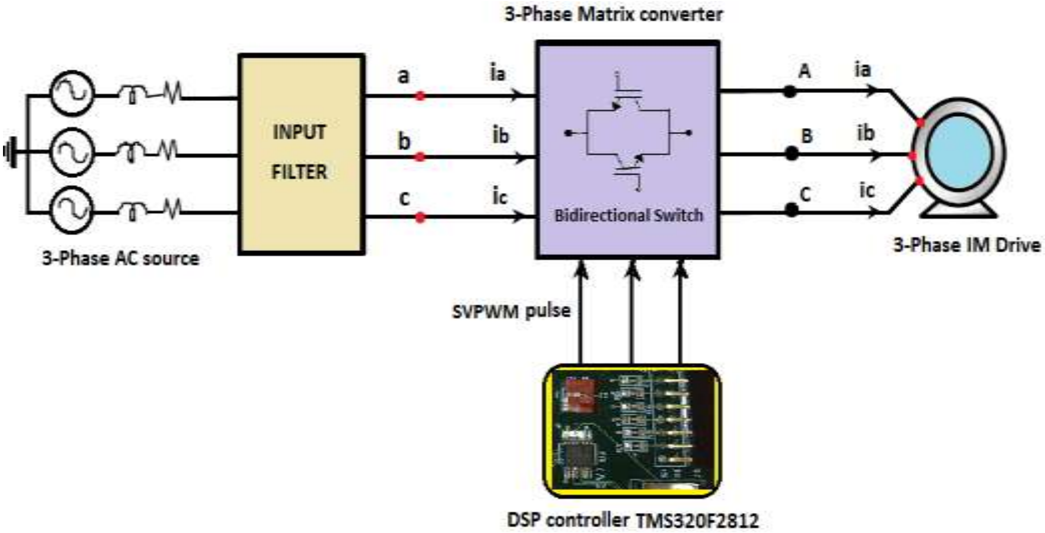
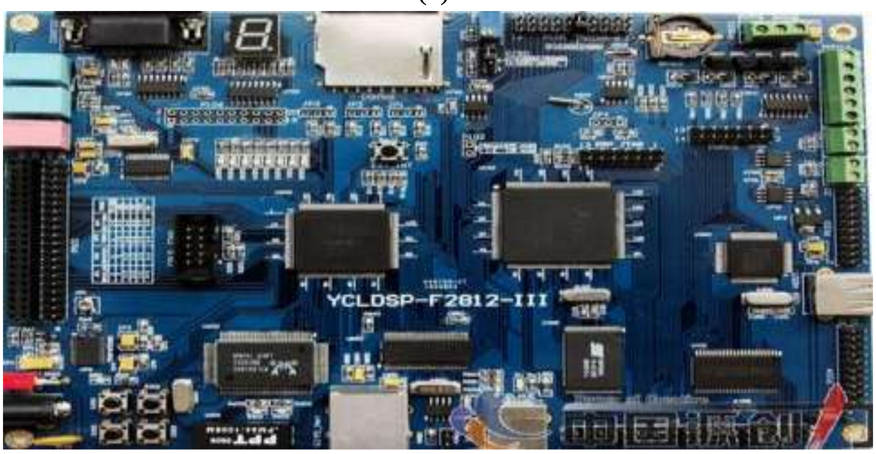
5. Experimental results

To verify the simulation results of proposed scheme, hardware setup of 3-phase matrix converter is design and tested. Fixed three phase input voltage is converted to variable voltage and frequency using matrix converter. To remove the current harmonics, the input filter is used in front end of the matrix converter. The output of matrix converter is connected with 3-phase IM drive with rating of 3HP, 415 V, 50Hz & 1500 RPM, which is controlled through DSP controller- TMS320F2812 with SVPWM switching technique.



(a)



(b)

Fig.18. (a) Block diagram of hardware implementation (b) DSP-2812 controller

Generally the purpose DSP controller is filtering, PWM generation, calculation of analog signals characteristic, real time implementation of complex algorithms & drives control. It contains 128K external memory, 32 bits accumulator, 16-bit timer and harvard architecture. Mostly to control IM drives, DSP controller is used. Because dsp controller can provide high speed, high resolution, sensorless control to reduce cost of system and precise control to provide better consumption, decreases number of look up tables and to generate high resolution switching pulses. The block diagram of hardware implementation and dsp controller-2812 is shown in fig.18a & 18b respectively.

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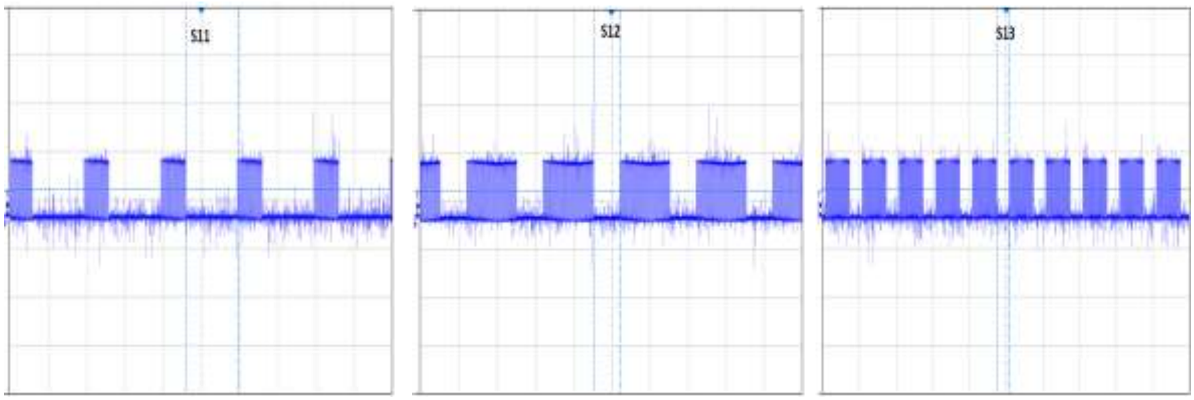
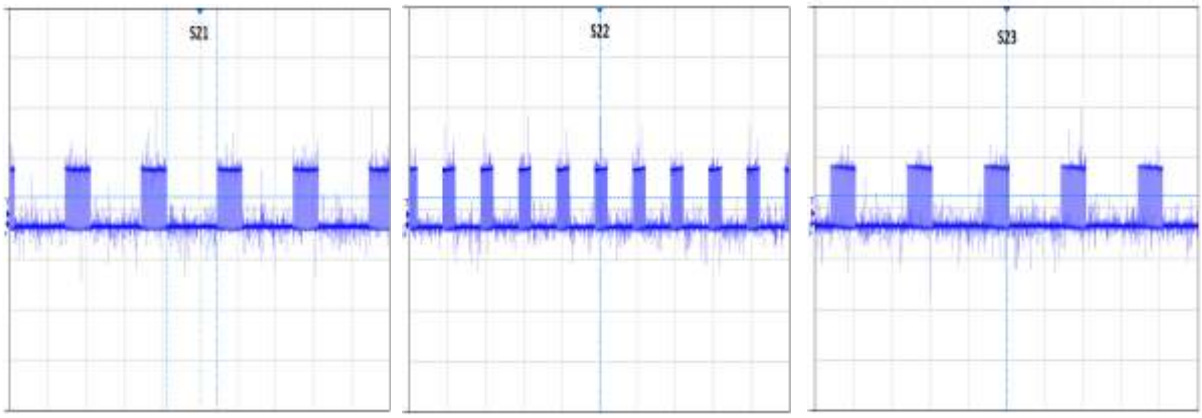
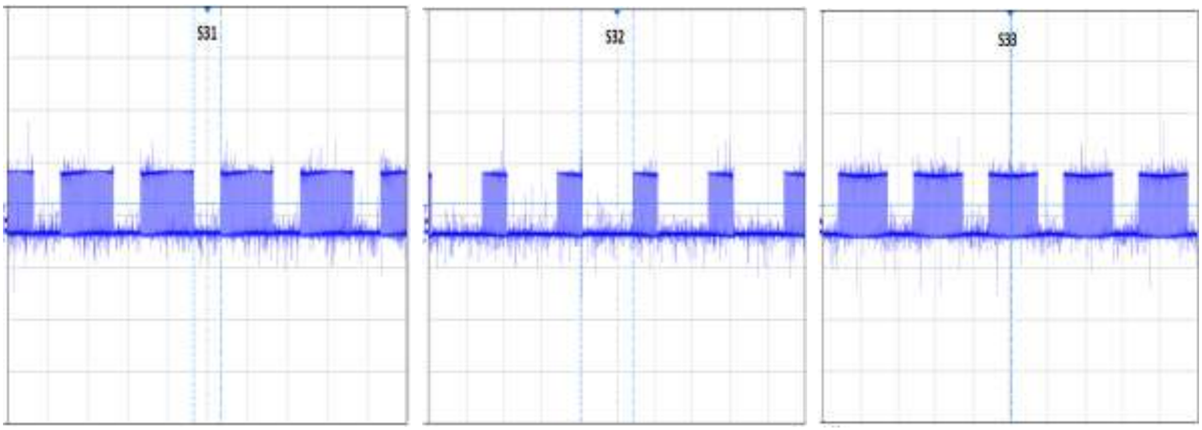
The fig.19 shows the gating pulses for matrix converter switches (S11-S33) and fig.20 shows the zoomed view of gating pulse for switch S21. Matrix converter is connected with 3-phase IM drive, which generates the output voltage of 207V, for all three phases are shown in fig.21 and output current of 10.2A in all 3-phases are shown in fig.22.



(a)



(b)



(c)

Fig.19. Gating pulses for 3-phase matrix converter (a) S11, S12, S13 (b) S21, S22, S23 (c) S31, S32, S32

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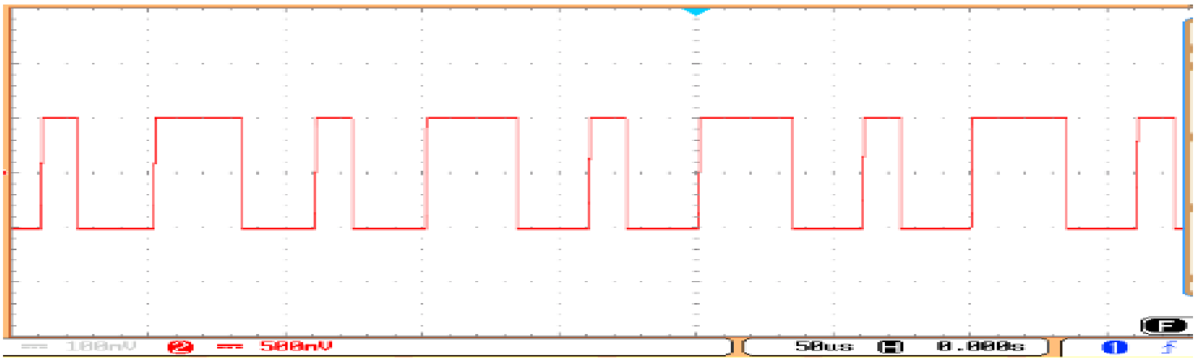
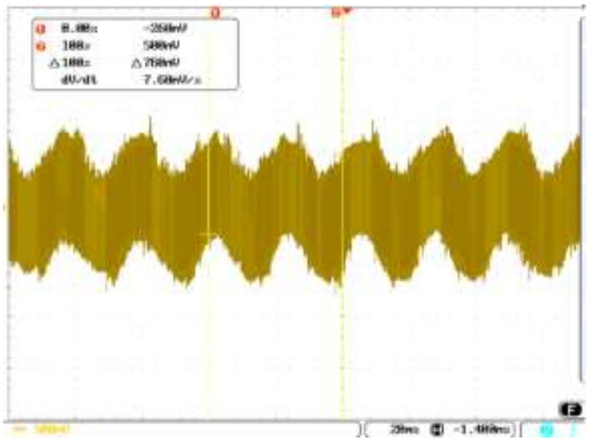
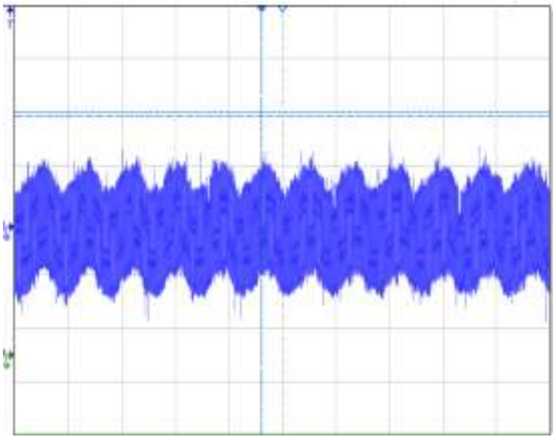


Fig.20. Gating pulse of switch S21



(a)



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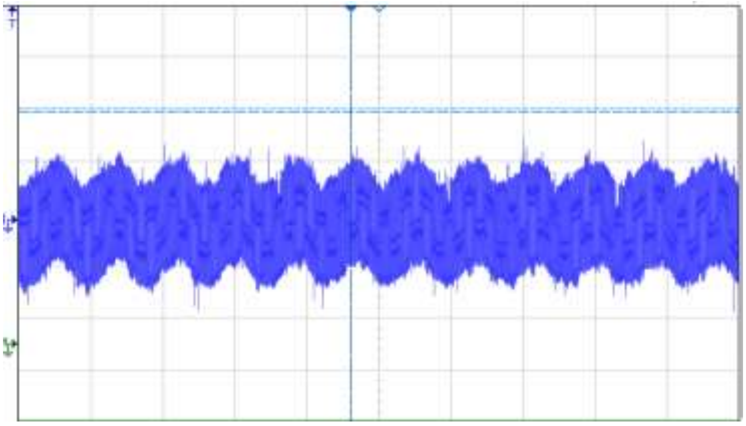

(c)

Fig.21.Output voltage of matrix converter with 3-phase IM drive (a) Va (b) Vb (c) Vc

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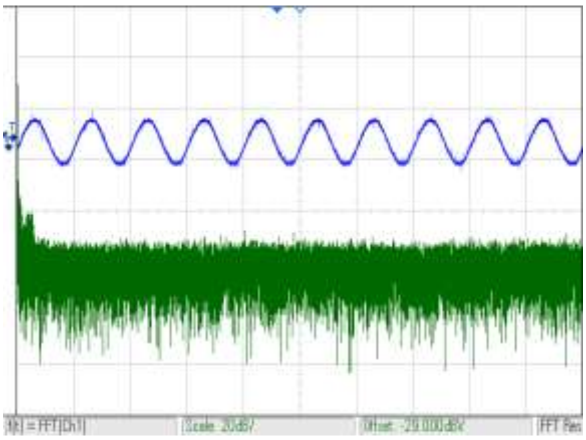
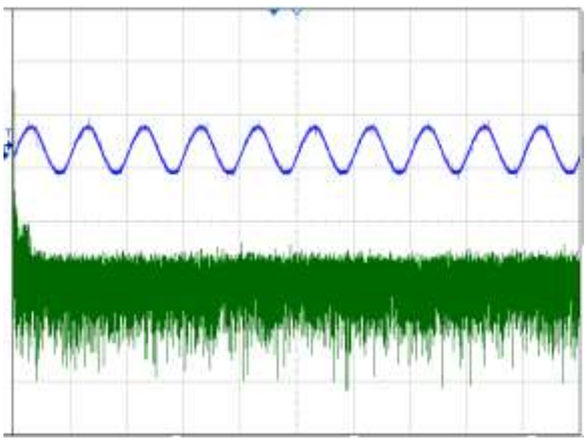
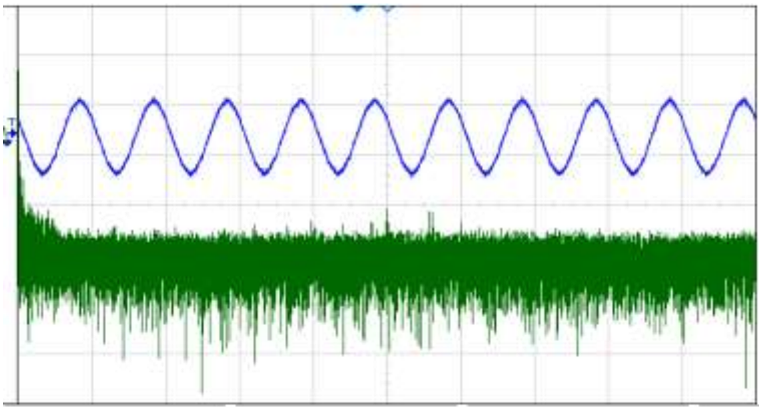


(a)

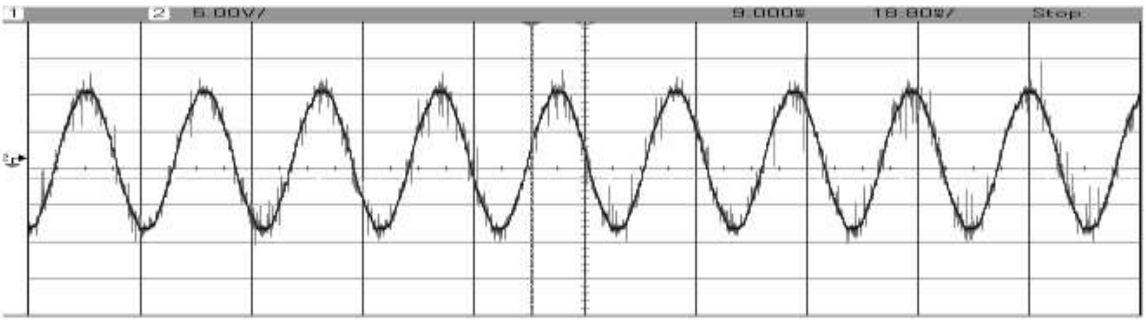


(b)

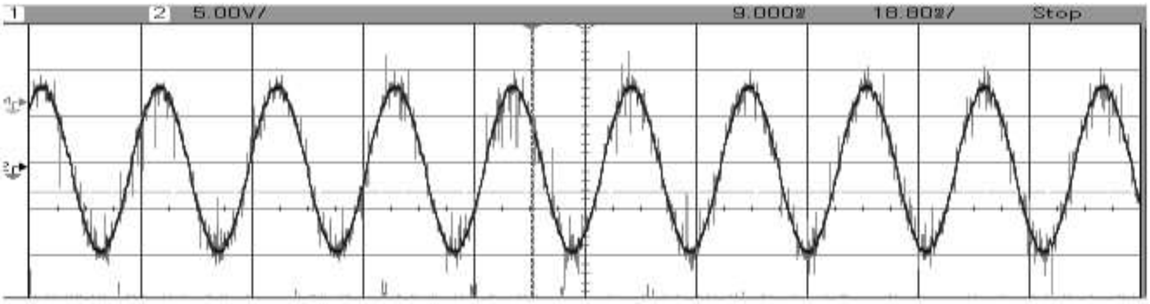


(c)

Fig.22. Output current of 3-phase matrix converter with FFT analysis (a) Ia (b) Ib (c) Ic



(a)



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(b)

Fig.23. Voltage stress across the switch in the of matrix converter (a) S11 (c) S23

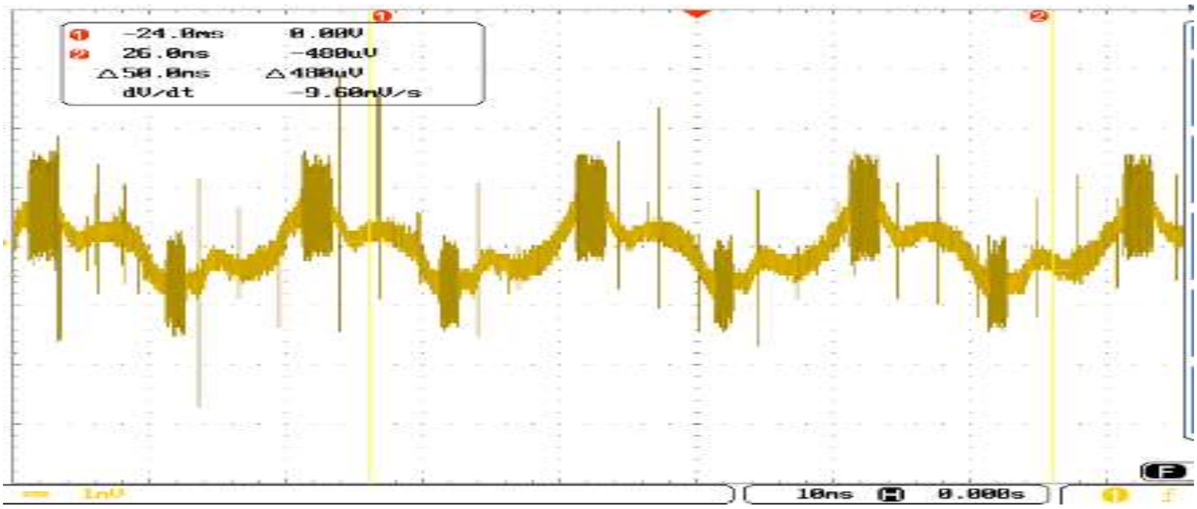

Fig.24. Input current of matrix converter with 3-phase IM drive

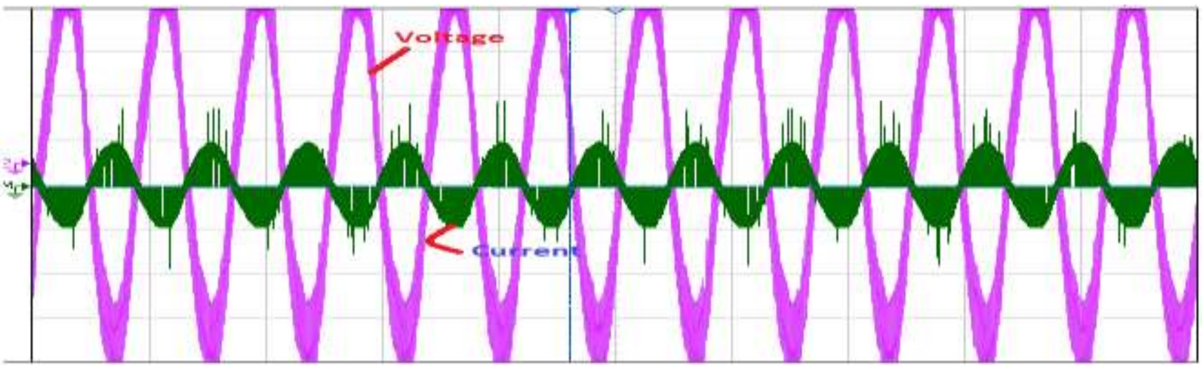

Fig.25. Output voltage & current waveform of 3-phase Matrix converter

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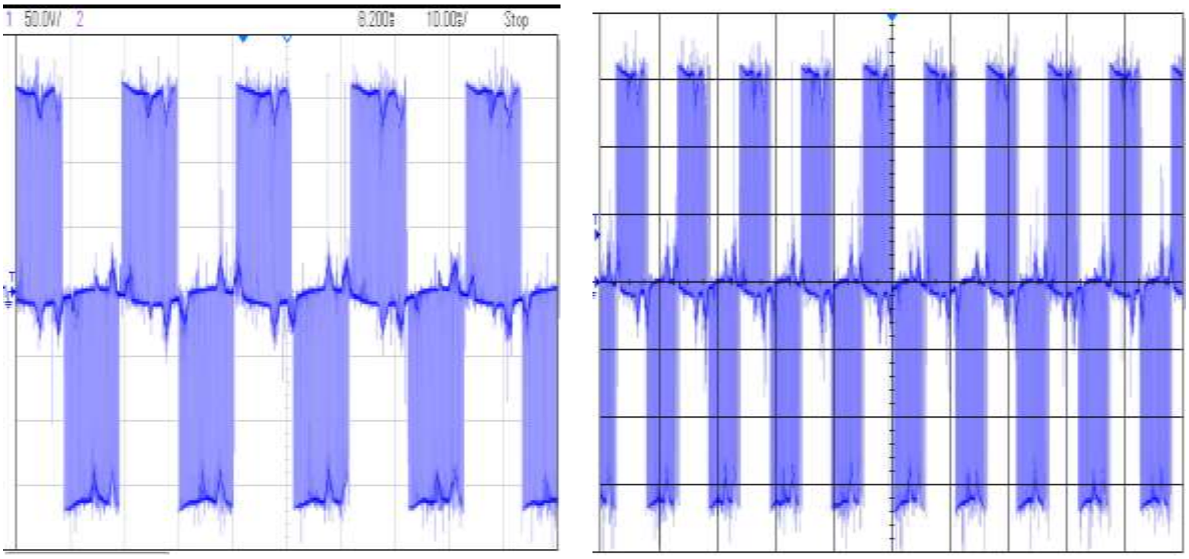

(a) (b)

Fig.26. Common mode voltage (a) a-phase (b) b-phase

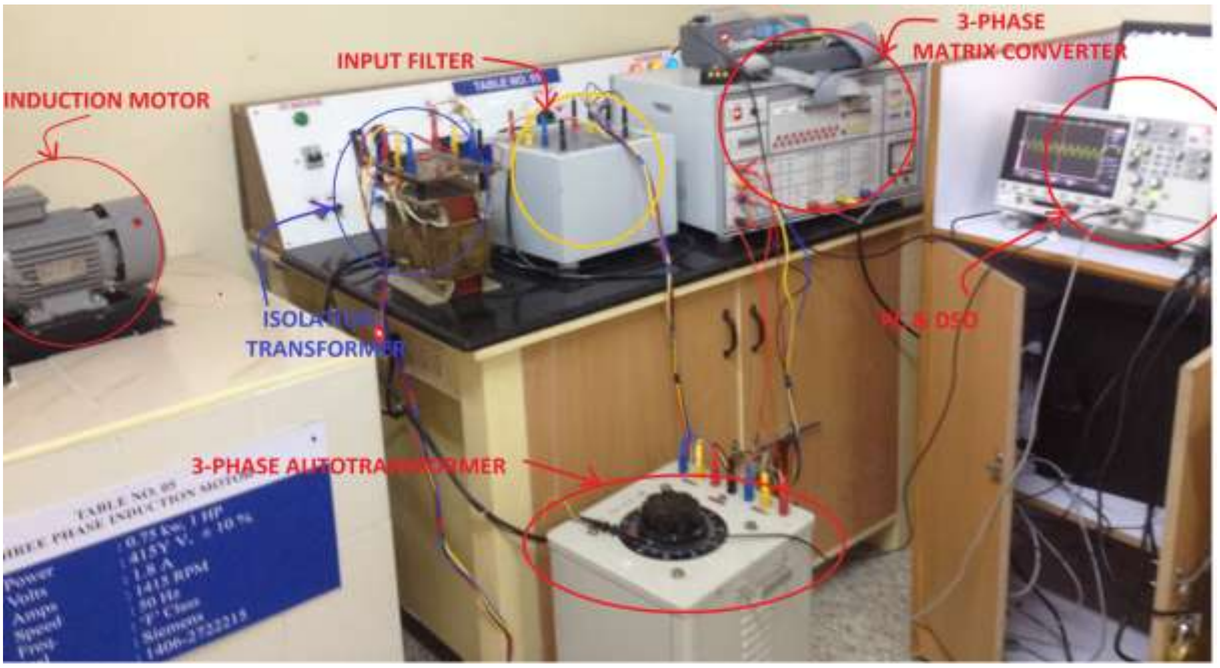

Fig.27. Experimental setup for 3-phase matrix converter with IM drive

Voltage stress across bi-directional switch of S11 & S23 for matrix converter system is shown in fig.23. Generally input current harmonics of power converter will increases due to changes in the non-linear load. Input current of matrix converter with 3-phase IM drive is shown in fig.24. Fig.25 shows the output voltage & current of 3-phase Matrix converter. Fig.26 shows the CMV reduction for a & b phase, which is similar to simulation result of V/11 reduction. And the experimental setup for 3-phase matrix converter system with IM drive has shown in fig.27.

Conclusion

This work describes the SVPWM implementation for 3-phase matrix converter to power the three phase induction motor drive. Matrix converters are designed to produce variable voltage and variable frequency with help of filtered input voltage and due to that current harmonics also minimised in the proposed system. The voltage across the bi-directional switches and common mode voltage is reduced by the use of SPWM switching pulse. Due to the reduction of CMV, bearing failure of IM drive can be minimized. The proposed scheme is simulated and executed using matlab/simulink and dsp controller respectively. The following are deliberated from this proposed work,

- ✓ Obtained variable output voltage and current with reduced harmonic level of 0.31% & 0.34% respectively.
- ✓ IM bearing failure evade with minimising common mode voltage and current.
- ✓ Voltage stress across bi-directional switch is controlled with help of SVPWM technique.

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