Speed Control of Three Phase Induction Motor using Two Level Inverter with SVPWM Technique

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Abstract— This paper presents the theoretical and practical aspects of implementation of Space Vector Pulse Width Modulation (SVPWM) in controlling the speed of three induction motor. SVPWM is implemented by using 32 bit ARM Cortex Microcontroller Discovery Board (STM32F4072F407XX MCU). The algorithm to generate SVPWM has been implemented as Simulink model constructed in MATLAB and applied two level inverter module which is connected to three phase induction motor. Digital Storage Oscilloscope Tektronix is used to trace and analyze all output waveform.

Key words: SVPWM (Sine Pulse Width Modulation), Three Phases Two Level Inverter and Three Phase Induction Motor

I. INTRODUCTION

Three phase voltage source inverters are widely used in variable speed AC motor drive applications since they provide variable voltage and variable frequency output through Pulse Width Modulation (PWM) control. Continuous improvement in terms of cost and high switching frequency of power semiconductor devices and development of machine control algorithms leads to growing interest in more precise PWM techniques. PWM has been studied extensively during the past decades. Many different PWM methods have been developed to achieve the following aims: wide linear modulation range; less switching loss; less total harmonic distortion (THD) in the spectrum of switching waveform. The study of SVPWM technique reveals that space vector modulation technique utilizes DC bus voltage more efficiently and generates less harmonic distortion when compared to sinusoidal PWM technique.

II. BASIC OF SVPWM METHOD

The space vector PWM (SVM) method is an advanced, computation-intensive PWM method and is possibly the best method among the all PWM techniques for variable-frequency drive application Space vector modulation (SVM) is an algorithm for the control of pulse width modulation (PWM). SVPWM is considered a better technique of Pulse Width Modulation implementation, as it has the following advantages like,

1) Better fundamental output voltage.
2) Useful in improving harmonic performance and reducing THD.
3) Extreme simplicity and its easy and direct hardware implementation in a Digital Signal Controller (DSC).
4) SVPWM can be efficiently executed in a few microseconds, achieving similar results compared with other PWM methods.

It is used for the creation of alternating current (AC) waveforms. To implement space vector modulation a reference signal V_{ref} is sampled with frequency $f_s(T_s = 1/f_s)$. The reference signal may be generated from three separate phase references using the transform. The reference vector is then synthesized using combination of the two adjacent active switching vectors and one or both of the zero vectors. Various strategies of selecting the order of the vectors and which zero vector(s) to use exist. Strategy selection will affect the harmonic content and the switching losses. The circuit model of a typical three-phase voltage source PWM inverter is shown figure.1 in S1 to S6 are the six power switches that shape the output, which are controlled by the switching variables. When an upper transistor is switched on, i.e., when a, b or c is 1, the corresponding lower transistor is switched off is 0. Therefore, the on and off states of the upper transistors S1, S3 and S5 can be used to determine the output voltage.

III. ANALYSIS & MODELING OF SPACE-VECTOR PULSE WIDTH MODULATION TECHNIQUE

A three-phase two-level inverter shown in figure.2 provides eight possible switching states, made up of six active and two zero switching states. Active vectors divide plane for six sectors, where a reference vector V_{ref} in figure.3 is obtained by switching on (for proper time) two adjacent vectors. It can be seen that vector V_{ref} is possible to implement by the different switching on/off sequence of V_1 and V_2.

The fundamental difference between SVPWM and SPWM is the existence of two additional zero voltage states V0 (000), and V7 (111). In addition to the six possible voltage vectors associated with the VSI, there are two zero voltage states associated with having all three of the positive pole switches on or all three of the negative pole switches on. This fact allows more output voltage since the third harmonic component exists. Thus, SVPWM is often considered as an eight state operation. Locus comparison of maximum linear control voltage in sine PWM and SVPWM is shown in figure 4. The SVPWM generates less harmonic distortion in the output voltages or currents in comparison with SPWM; also the voltage utilization achieved by SVPWM is $2/\sqrt{3}$ times of SPWM.

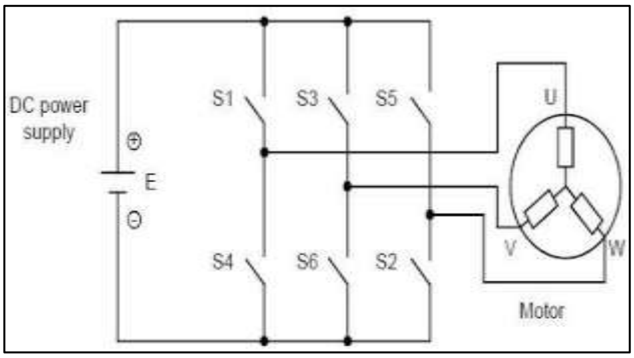

Fig. 1: Three Phase Voltage Source Inverter Bridge Circuit

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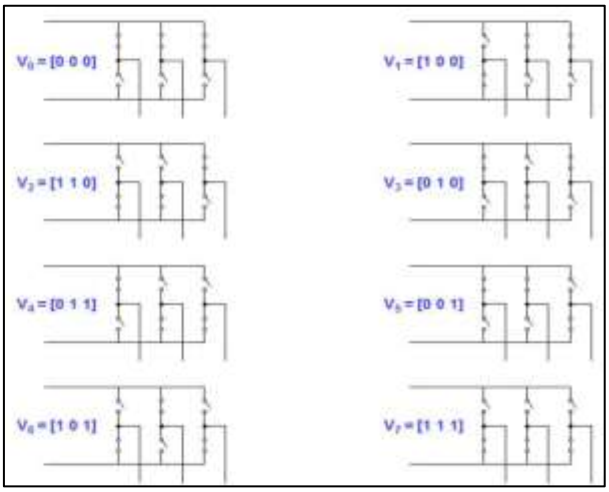

Fig. 2: Eight Inverter Voltage Vectors (V0 to V7)

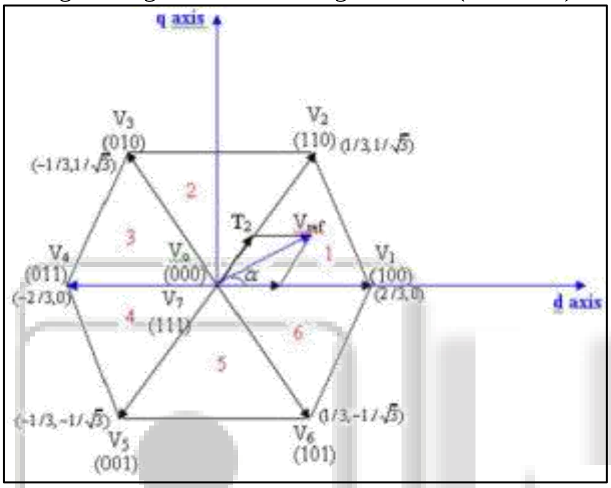

Fig. 3: The Eight Vectors in the Stationary Frame

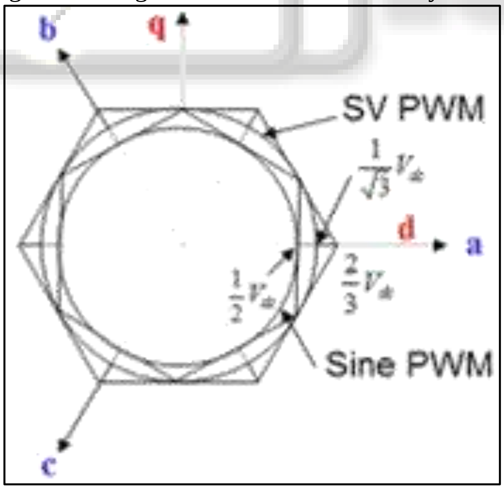

Fig. 4: Locus Comparison of Maximum Linear Control Voltage in Sinusoidal PWM and SVPWM

To realize the SVPWM, first determine, V_d, V_q and α, secondly determine the time duration, T_1, T_2, T_0 thirdly determine the switching time of each switch (S1 to S6).

1) Step 1: determination of the sector at which the vector is placed, this achieved by determination of the V_d, V_q and α According to the coordinate transformation in figure 5.

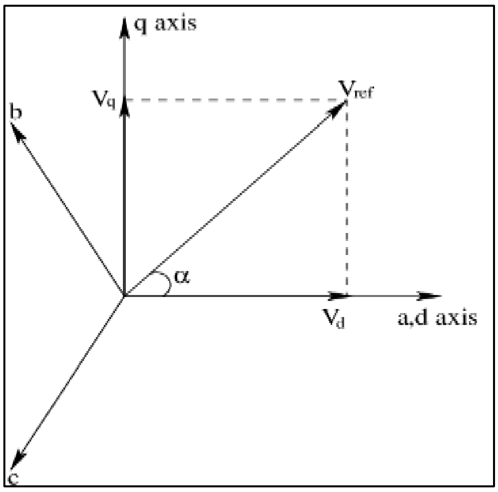

Fig. 5: Voltage Space Vector and its Components in (d, q) Coordinate

$$V_d = V_{an} - V_{bn}\cos 60 - V_{cn}\cos 60 \quad \text{.............(1)}$$

$$= V_{an} - \tfrac{1}{2}V_{bn} - \tfrac{1}{2}V_{cn} \quad \text{........................ (2)}$$

$$V_q = 0 + V_{bn}\cos 30 - V_{cn}\cos 30 \quad \text{...............(3)}$$

$$= V_{an} + \tfrac{\sqrt{3}}{2}V_{bn} - \tfrac{\sqrt{3}}{2}V_{cn} \quad \text{......................(4)}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} \quad \text{.....................(5)}$$

$$\left|\overrightarrow{V_{ref}}\right| = \sqrt{V_d{}^2 + V_q{}^2} \quad \text{........... ....(6)}$$

$$\alpha = \tan^{-1}\left(\frac{V_q}{V_d}\right) = \omega_s t = 2\pi f_s t \quad \text{.....................(7)}$$

$$\left(\text{Where } f_s = \frac{1}{T_s}\right)$$

According to the value of α we can find the sector number, such as $0 \le \alpha \le \frac{\pi}{3}$ gives sector 1.

2) Step 2: is to determine the time duration T_1, T_2, T_0, and this is shown as in fig 6, the reference vector expressed by a combination of two adjacent vectors, and the switching time duration at Sector 1 can be expressed as:

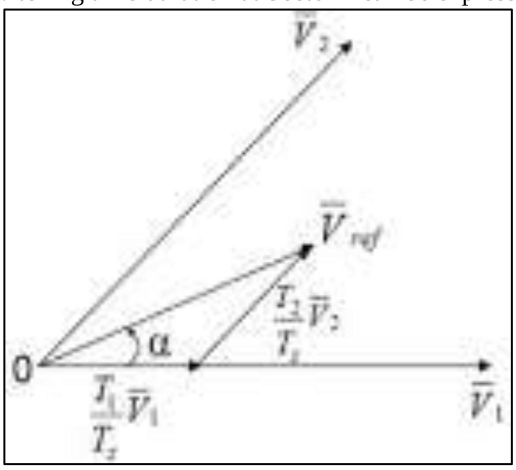

Fig. 6: Reference Vector as a Combination of Adjacent Vectors at Sector 1

Switching time duration at any Sector

$$T_m = T_s * m * \frac{\sqrt{3}}{2} * \left(\sin\left(\frac{n}{3}\pi - \alpha\right)\right) \quad \text{......... ..(8)}$$

$$T_{m+1} = T_s * m * \frac{\sqrt{3}}{2} * \left(\sin\left(\alpha - \frac{n-1}{3}\pi\right)\right) \quad \text{... (9)}$$

$$T_0 = T_s - T_m - T_{m+1} \quad \text{............................. .(10)}$$

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(Where n=1 to 6 (that is sector 1 to 6)
$0 \leq \alpha \leq 60$)

3) Step 3: is used to determine the switching time of each switch by determine the modulating functions which compared with a triangle wave to give the predetermined patterns for the upper three switches, this is achieved by the table 1.

Sector	Upper switches (S_1, S_3, S_5)	Lower switches (S_4, S_6, S_2)
1	$S_1=T_1+T_2+\frac{T_0}{2}$ $S_3=T_2+\frac{T_0}{2}$ $S_5=\frac{T_0}{2}$	$S_4=\frac{T_0}{2}$ $S_6=T_1+\frac{T_0}{2}$ $S_2=T_1+T_2+\frac{T_0}{2}$
2	$S_1=T_1+\frac{T_0}{2}$ $S_3=T_1+T_2+\frac{T_0}{2}$ $S_5=\frac{T_0}{2}$	$S_4=T_2+\frac{T_0}{2}$ $S_6=\frac{T_0}{2}$ $S_2=T_1+T_2+\frac{T_0}{2}$
3	$S_1=\frac{T_0}{2}$ $S_3=T_1+T_2+\frac{T_0}{2}$ $S_5=T_2+\frac{T_0}{2}$	$S_4=T_1+T_2+\frac{T_0}{2}$ $S_6=\frac{T_0}{2}$ $S_2=T_1+\frac{T_0}{2}$
4	$S_1=\frac{T_0}{2}$ $S_3=T_1+\frac{T_0}{2}$ $S_5=T_1+T_2+\frac{T_0}{2}$	$S_4=T_1+T_2+\frac{T_0}{2}$ $S_6=T_2+\frac{T_0}{2}$ $S_2=\frac{T_0}{2}$
5	$S_1=T_2+\frac{T_0}{2}$ $S_3=\frac{T_0}{2}$ $S_5=T_1+T_2+\frac{T_0}{2}$	$S_4=T_1+\frac{T_0}{2}$ $S_6=T_1+T_2+\frac{T_0}{2}$ $S_2=\frac{T_0}{2}$
6	$S_1=T_1+T_2+\frac{T_0}{2}$ $S_3=\frac{T_0}{2}$ $S_5=T_1+\frac{T_0}{2}$	$S_4=\frac{T_0}{2}$ $S_6=T_1+T_2+\frac{T_0}{2}$ $S_2=T_2+\frac{T_0}{2}$

If the desired signal is outside the reachable space of the switching plane then the times $T_m + T_{m+1}$ is longer than T_s, it means the voltage saturation of the inverter. At this time, an over modulation should be performed to produce the maximum available voltage keeping its output with in hexagon limit. In this case the conduction times of the voltage vectors are represented as follows,

$$T'_m = \frac{T_s}{T_m+T_{m+1}} * T_m \quad \text{(11)}$$

$$T'_{m+1} = \frac{T_s}{T_m+T_{m+1}} * T_{m+1} \quad \text{(12)}$$

$$T_0 = 0 \quad \text{(13)}$$

IV. SPWM MATLAB SIMULATION

Fig.7 shows MATLAB simulation of SPWM technique. DC Link voltage supply of Vdc=600 Volt, resistive load of 50 ohm and MI=1, for fundamental frequency sine wave of 50 Hz, carrier frequency is 7 kHz. For determination V_d, Vq and α Fig.8 shows MATAB Blocks arrangement using equations 1 to 7.

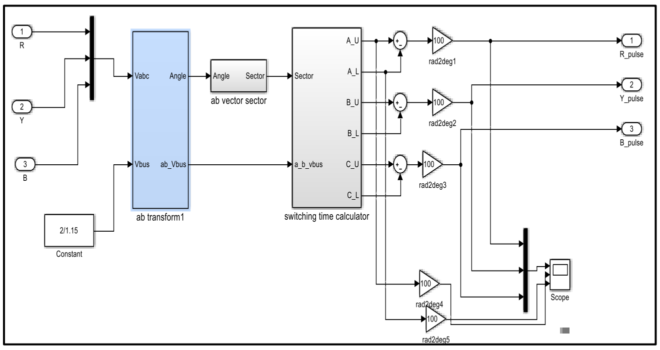

Fig. 7: MATLAB Simulation of SVPWM

Amplitude=1, sample time=0.000001

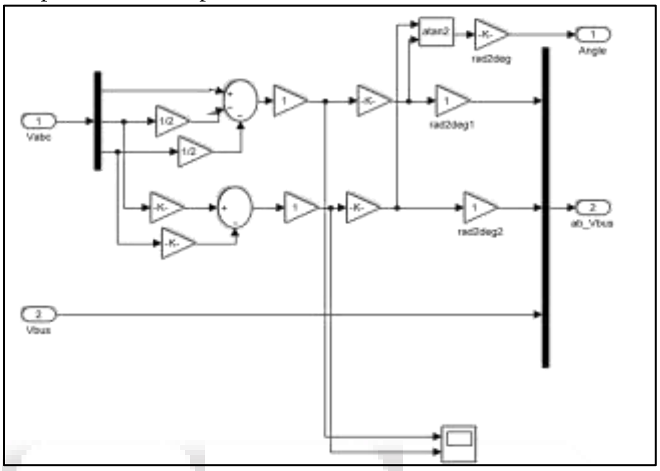

Fig. 8: Determination of V_d, V_q and α in MATLAB

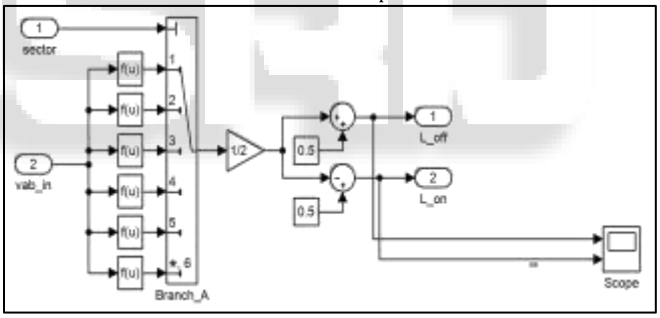

Fig. 9: Determination of Switching Patterns

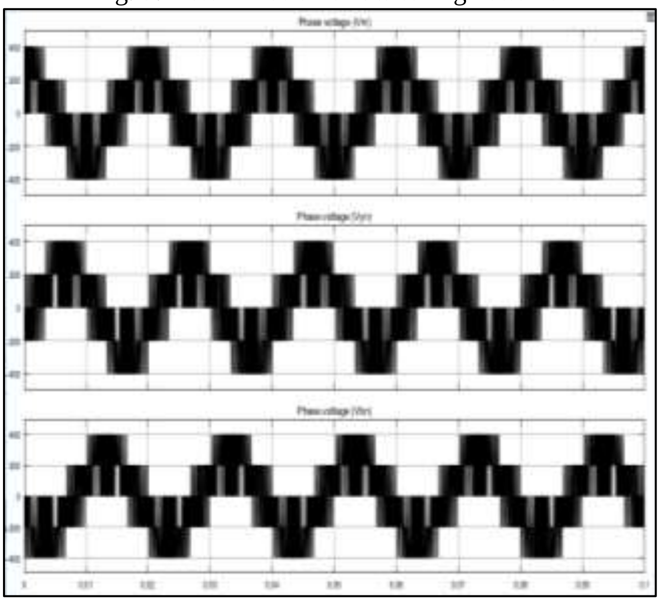

Fig. 10: Phase Voltages of SVPWM

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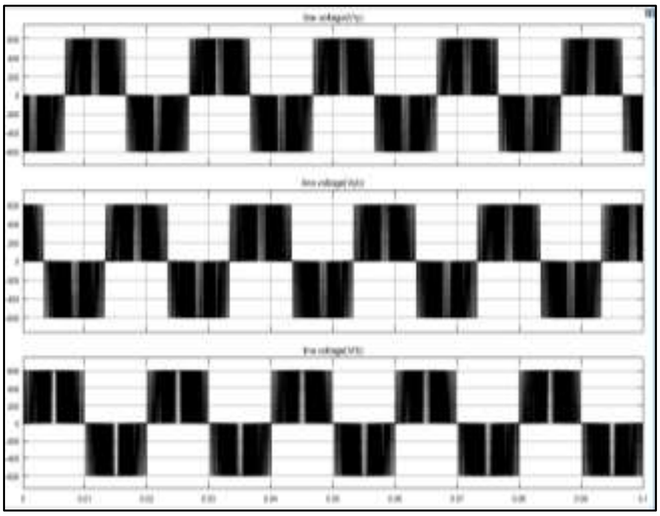

Fig. 11: Line Voltages of SPWM

V. PRACTICAL SET UP FOR VALIDATION OF SPWM USING 32-BIT ARM CORTEX MICROCONTROLLER

In this practical set up, three phase ac 2 HP, 220 Volt three phase inductions motor is used. Synchronous speed of motor is 1500 rpm. Single Phase Bridge AC rectifier with 450 Volt, 450 microfarad capacitor, 35 amps is used to generate 324 V DC supply for three phase inverter module. Three phase sine wave signals displaced by 120 degree are compared with the higher carrier frequency of 7 kHz of triangular signal using Boolean logic comparator for generating the pulses.32-bit ARM Cortex microcontroller (STM32F4072F407XX MCU) is interfaced with MATLAB to generate codes of program. Six pulses generated by microcontroller are given to three phase inverter module which is connected with the three phase induction motor.

Table.1 and Table.2 shows practical readings of V_{dc} DC link voltage, speed, V_L Line voltage and I_L current of three phase induction motor for no load and load condition of three phase induction motor with variation of MI. For the same MI, speed of motor is reduced form no load to full load condition.

SPEED (RPM)	VOLTAGE V_L(volt)	CURRENT I_L (amps)	DC LINK VOLTAGE V_{DC} (volt)	MODULATION INDEX
1496	234	1.4	324	0.97
1494	219	1.2	324	0.9
1492	198	1.08	324	0.8
1480	180	0.95	324	0.7
1478	129	0.62	324	0.5
1470	105	0.50	324	0.4
1458	78	0.38	324	0.3

Table 1: Practical Readings for SVPWM (on no Load Condition)

SPEED IN RPM	VOLTAGE V_L(volt)	CURRENT I_L (ampere)	DC LINK VOLTAGE V_{DC} (volt)	MODULATION INDEX
1496	234	1.4	324	0.97
1494	219	1.2	324	0.9

Table 2: Practical Reading for SVPWM (Load Condition of 2 Nm Torque)

Fig. 12 shows variation of line voltages of three phase inverter output or motor terminal voltages in no load condition with MI= 0 to 1.

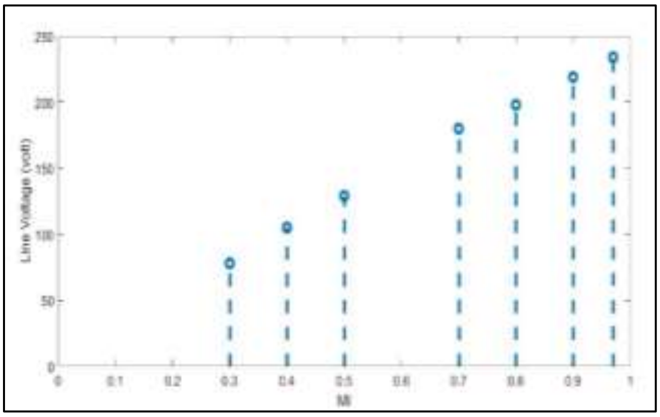

Fig. 12: Line voltage-Modulation Index

Fig. 8 shows relations of speed, line voltages and MI in no load condition of three phase induction motor.

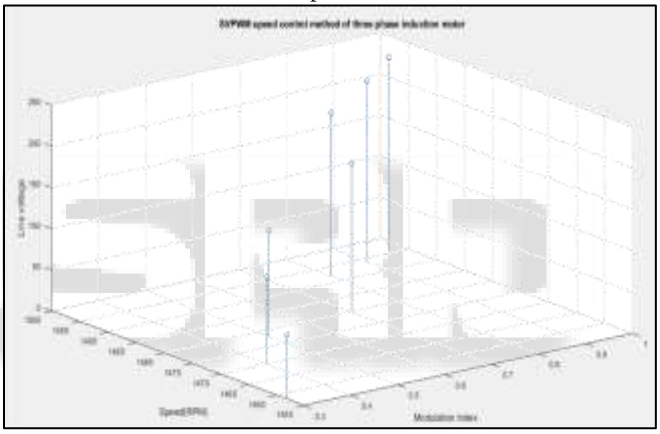

Fig. 13: MI- Line Voltage –Speed (RPM)

Fig.9. show practical set up for validation of SPWM technique for speed control of three phase induction motor using three phase inverter module, ammeter, voltmeter, single phase rectifier unit, 32-bit ARM Cortex microcontroller(STM32F4072F407XXMCU)etc.

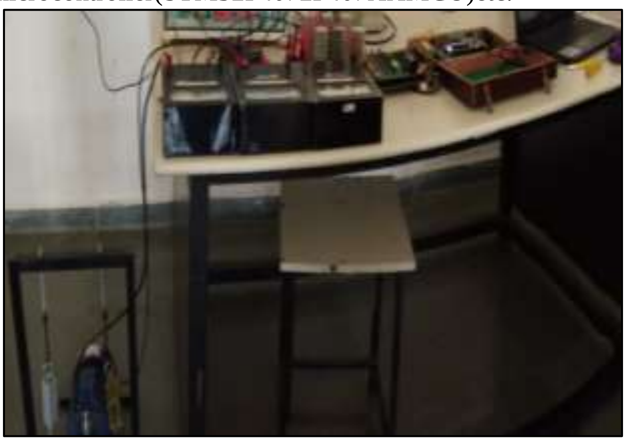

Fig. 9: Practical set up for Realization of SPWM Method

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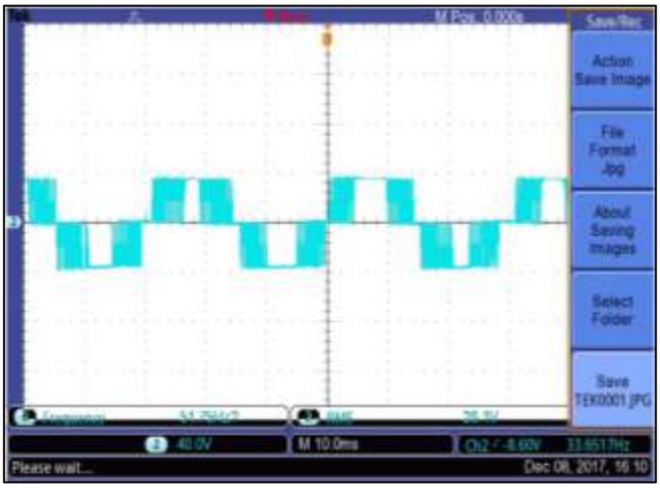

Fig. 14: Line Voltage SVPWM

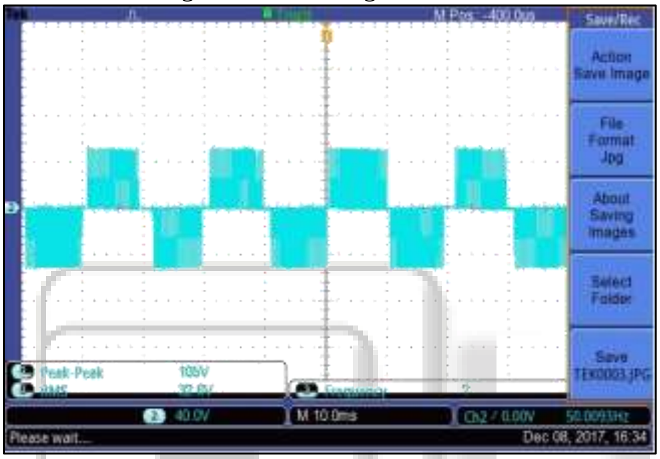

Fig. 15: Line Voltage

VI. CONCLUSION

In this paper, firstly MATLAB simulation SVPWM technique is carried out. Speed control of three induction motor also carried out by varying MI between 0 to1. Line voltages and speed are found linear with respect to MI. This method is very easy to implemented and control. It has been observed that the line voltage and speed decreases with the increase in load for the same MI (Table 1 and Table 2). It has been also observed that the selection of carrier frequency is depends on trade-off between inverter switching loess and and machine losses. Higher carrier frequency (same as switching frequency) increases inverter losses but reduces machine harmonies losses. It has been concluded that the optimum carrier frequency should be selected such that the total system losses should be minimal.

The SVPWM technique can only be applied to a three-phase inverter and it increases the overall system efficiency. The SVPWM is used for controlling the switching of the machine side converter. Advantages of this method include a higher modulation index, lower switching losses, and less harmonic distortion compared to SPWM. Therefore SVPWM research has been widespread in recent years, making it one of the most popular methods for three-phase inverters because it has a higher fundamental voltage output than SPWM for the same DC bus voltage. The SVPWM is significantly better than SPWM by approximately 15.5%

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