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3-Phase Induction Motor Control using Space Vector and Sinusoidal Pulse Width Modulation Technique

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***Abstract:** This paper deals with the control of the induction motor using two different control methods: Space Vector and Sine wave pulse width modulation technique. The objective of the project is to find the most appropriate technique for induction motor control for industrial application. The scalar v/f method offers good performance only in the course of the steady-state and not under transient conditions. This important downside may be rectified by the vector control technique. The method provides high dynamic performance for velocity and torque-controlled AC machines.*
***Keywords:** SVPWM, SPWM, Total Harmonic Distortion, Induction Motor, 3 Phase Inverter, Modulation technique*

I. INTRODUCTION

With the three-phase Induction motor being one of the most widely used type of motor in the industry, the need for a better and more efficient control techniques is apparent. Simplifying three phase quantities like flux, current field into two-phase like in reference to arbitrary reference frame theory [1]. Sinusoidal Pulse Width Modulation and Space Vector Pulse Width Modulation are both evolutions of PWM techniques that offer lower harmonic distortion [2], better power factor etc. Conventionally a Sinusoidal Pulse Width Modulation (SPWM) technique is used but Space Vector Pulse Width modulation (SVPWM) is an up and coming, more efficient technique as understood in this paper. It is because of its characteristics like better power factor and higher efficiency. Also, the Total Harmonic Distortion (THD) is considerably lower in the case of SVPWM. The current components are divided into a torque controlled current component i_{qs} and flux controlled current component i_{ds}[3]. Hence, when flux is controlled using the i_{ds} component, the torque remains constant, which results in a faster transient response [4]. The effectiveness of SVPWM is compared against SPWM using MATLAB/Simulink. The results are compared for the percentage of total harmonic distortion of SVPWM against SPWM with the same motor specifications considered in both the simulations [5][6]. The speed control was carried out on the Induction motor block available in the MATLAB.

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II. SVPWM Technique

To derive a MATLAB/Simulink Model for a three- phase Induction Motor using Space Vector Pulse Width Modulation Technique following block diagram is followed.

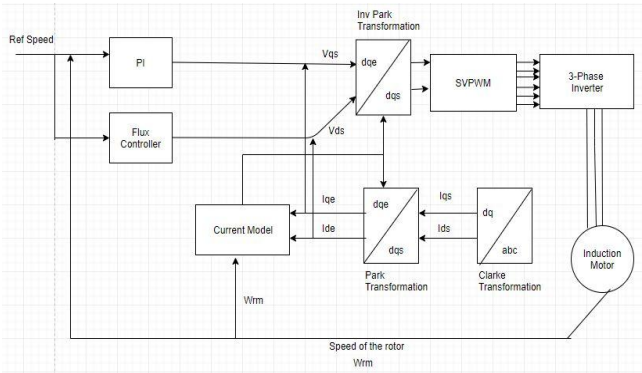


Fig 1: Block diagram to implement induction motor control using SVPWM

A. MATHEMATICAL MODEL

An analytical approach was taken to derive the Mathematical model for a three phase Induction Motor [7]. The following assumptions were made before deriving the Mathematical Model:

- The air gap is uniform
- Squirrel cage rotor construction
- Balanced stator and rotor windings, and sinusoidal winding distribution
- Change of parameters and saturation are neglected.

The mathematical model of our IM is modeled by space vector phase theory of electrical machines.
Steps involved in the mathematical modeling:

i. Find d-q voltage (V_d, V_q) and V_{ref} with the corresponding angle.
ii. Find the time duration T_1, T_2 and T_0 and switching state.
iii. Sector judgment and calculation.

At wt=Π/2

3-PHASE VOLTAGE CALCULATION

$V_a=\sqrt{2} * \text{Vrmssi n wt}=650.5$……(1)

$V_b=\sqrt{2} * \text{Vrms sin}(\text{wt} - 2\Pi/3) = -325.25$….,(2)

$V_c= \sqrt{2} * \text{Vrms sin}(\text{wt} -$

$4\Pi/3) = 563.35$……(3)

α-β CALCULATION:

$V_\alpha=2/3(V_a+1/2*V_b-1/2*V_a)$ =137.46……..(4)

$V_\beta=2/3(\sqrt{3}/2*V_b-\sqrt{3}/2*V_a)$ =-507.90……..(5)

d-q CALCULATION:

The d–q dynamic model has been modeled using Park's transformation,

Vd=Van-Vbncos60-Vcncos60……(6)

Vq=Vbncos30-Vcncos30,……(7)

Or

$V_d=V_\alpha\cos\Theta+V_\beta\sin\Theta=507.90$……(8)

$V_q=-V_\alpha\sin\Theta+V_\beta\cos\Theta=-137.46$……..(9)

$V_{ref}=\sqrt{Vd^2+Vq^2}$

Fig 2: Space Vector Voltage and its components in d-q axis

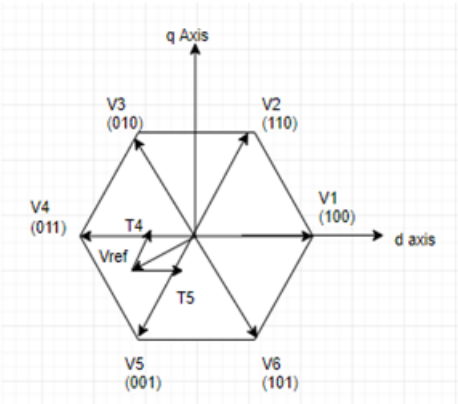


Fig 3: Space vector sector specification

Sector determination can be done through the following flowchart:

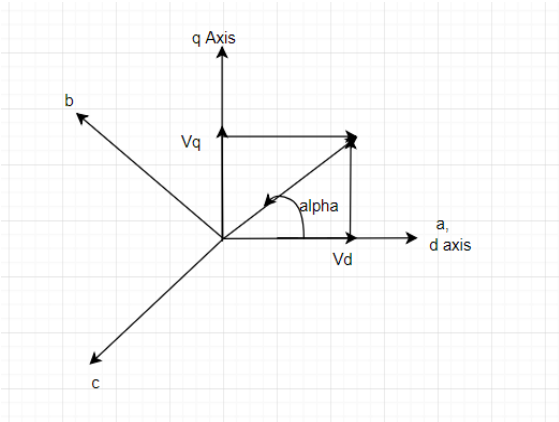
=526.17

ANGLE CALCULATION:

$\alpha=\tan^{-1}(Vq/Vd)=15.14$

Fundamental frequency=60 Hz

SWITCHING STATE AND VECTOR DETERMINATION:



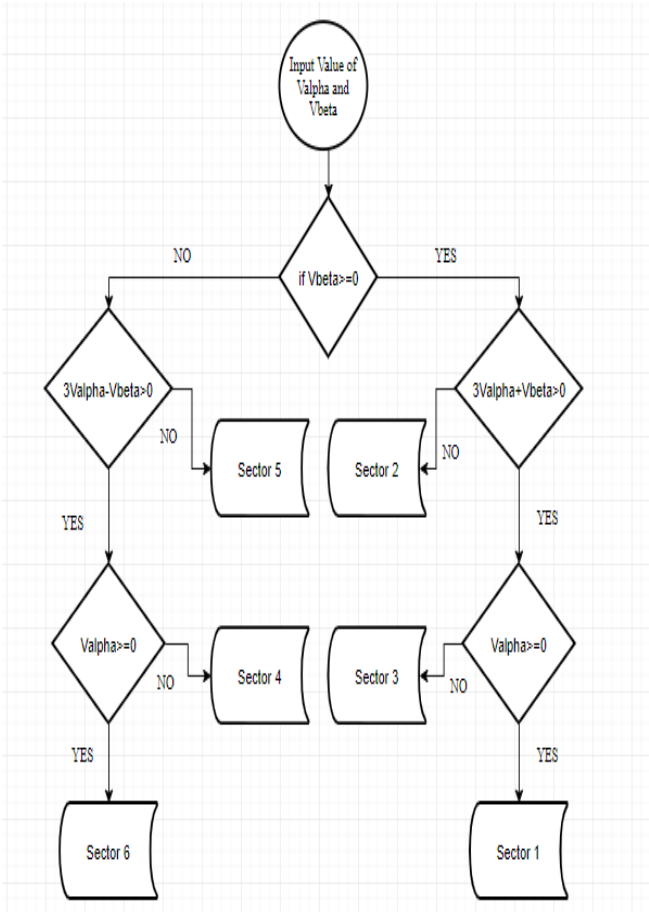


Fig 4: Flowchart to determine the sector

According to the calculation, our space vector is in **sector 4.**

Table 1: Switching state and Voltage

Vlotage Vectors	Switching Vectors			Line to Neutral Voltage			Line to Line Voltage		
	A	B	C	Van	Vbn	Vcn	Vab	Vbc	Vca
V0	0	0	0	0	0	0	0	0	0
V1	1	0	0	353.33	-176.66	-176.66	530	0	-530
V2	1	1	0	176.66	176.66	-353.33	0	530	-530
V3	0	1	0	-176.66	353.33	-176.66	-530	530	0
V4	0	1	1	-353.33	176.66	176.66	-530	0	530
V5	0	0	1	-176.66	-176.66	353.33	0	-530	530
V6	1	0	1	176.66	-353.33	176.66	530	-530	0
V7	1	1	1	0	0	0	0	0	0

$$\int_0^{Tz} Vref = \int_0^{T4} V4\,dt + \int_{T4}^{T4+T5} V5\,dt + \int_{T4+T5}^{Tz} V0dt \ldots\ldots\ldots\ldots(10)$$

Time duration Calculation:

$T_zV_{ref}=T_4V_4+T_5V_5$……(11)

$T_z=1/f$ =16.6 ms

$T_5=\sqrt{3}T_z|V_{ref}|(-\cos\alpha\sin\Pi+\sin\alpha\cos\Pi)/V_{dc}$……..(12)

=-7.45 ms

$T_4=\sqrt{3}T_z|V_{ref}|(-\cos\alpha\sin4\Pi/3-\sin\alpha\cos4\Pi/3)/V_{dc}$……..(13)

=-19.4 ms

$T_0=T_z+T_4+T_5$ =43.45 ms

B. SIMULATION MODEL

The suggested system consists of three main segments:

i. The load
ii. The control scheme
iii. phase inverter

The model has many more additions than just the Vector Control system, Current feedback and speed feedback has been implemented with the help of goto blocks which are redirected inside of the vector control blocks. The speed control is adjusted mid simulation with the help of a step function. In this control scheme the angles u_{alpha} and u_{beta} are calculated with the help of ordinary PID controllers with modified values and parameters. Torque and flux are independently controlled, whereas speed and currents are observed in a closed loop. The controllers are ordinary PID controllers with modified values and parameters.

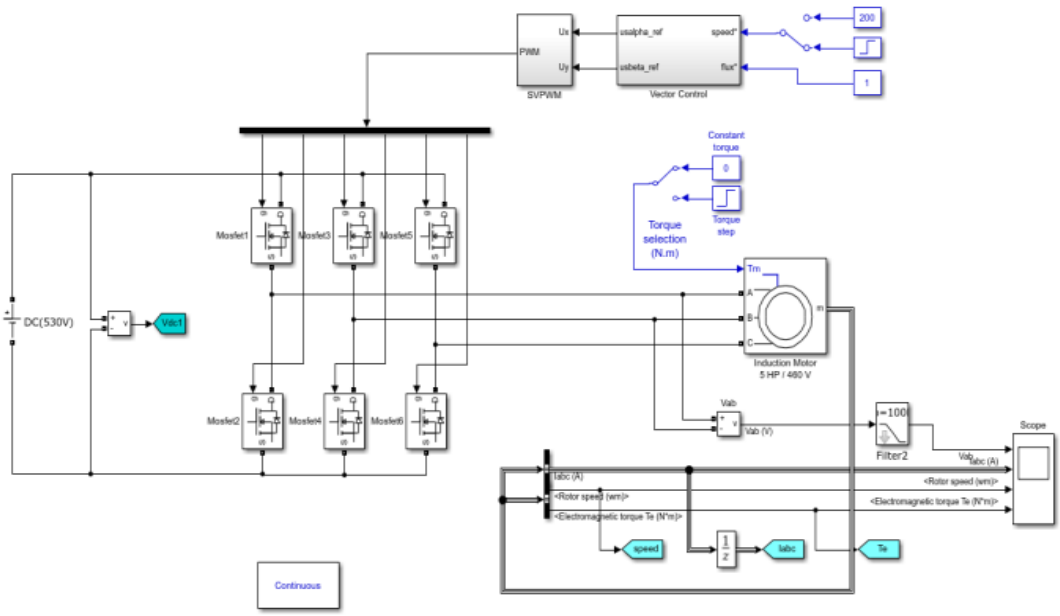


Fig 5: SVPWM SIMULINK Model using Vector control

III. SPWM technique

Sinusoidal pulse width modulation a digital waveform is produced and the duty cycle is modulated such that the average voltage of the waveform corresponds to a pure sine wave. SPWM moves the voltage harmonics components to the higher frequencies. The following simulation is conducted at a modulation index of the SPWM at m = 0.9.

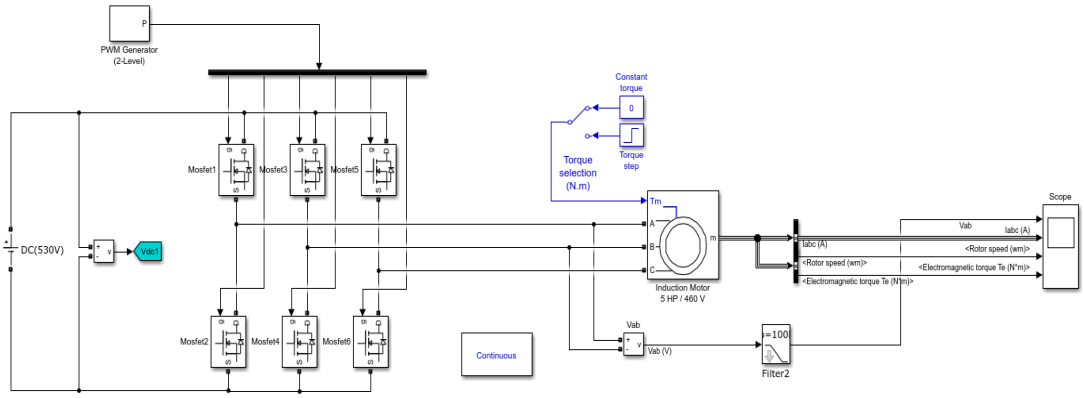


Fig 6: SPWM SIMULINK model

IV. Result and Discussion

Output Graph of SPWM Model:

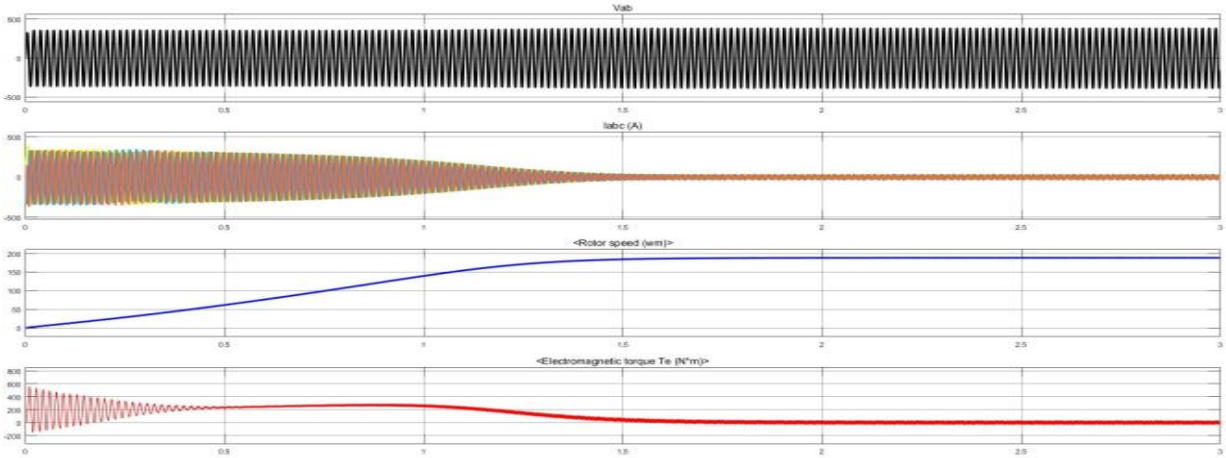


Fig 7: Output (a) Voltage (b) Current (c) Speed (d) Electromagnetic Torque

It can be observed from the graph that V_{rms} = 267.1 V and I_{rms} = 125.2 A
As can be seen in the graph, speed increases from 0-188wm in 1.54 second. As the rotor speed increases, the electromagnetic torque increases till the speed reaches 135wm and then starts decreasing as the speed reaches its maximum value of 188wm, reaching 0 around the same mark as the speed approaches 188wm at 1.54s.

Output Graph of SVPWM Model:

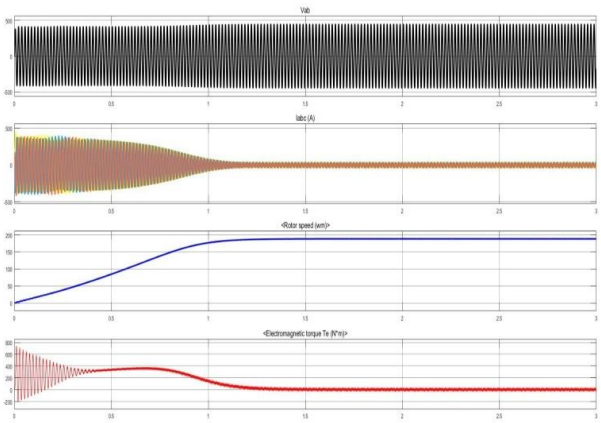


Fig 8: Output of SVPWM with MATLAB Block (a) Voltage (b) Current (c) Speed (d) Electromagnetic Torque

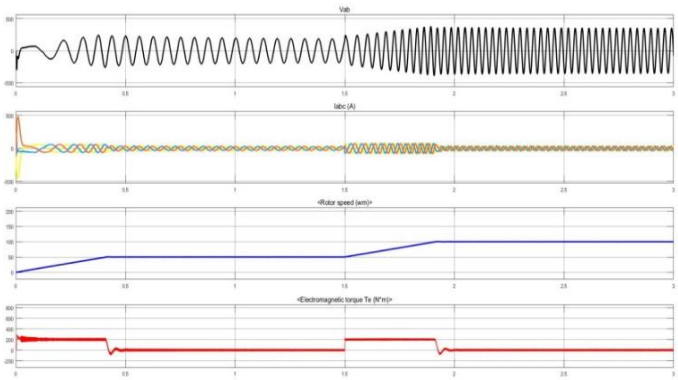


Fig 9: Output of SVPWM using Vector Control (a) Voltage (b) Current (c) Speed (d) Electromagnetic Torque

It can be observed from the graph that V_{rms} is 311 V and I_{rms} is 125.8 A

As can be seen in the graph, speed increases from 0-188wm in 1.15 second. As the rotor speed increases, the electromagnetic torque increases till the speed reaches 135wm and then starts decreasing as the speed reaches its maximum value of 188wm, reaching 0 around the same mark as the speed approaches 188wm at 1.15s.

A. FFT Analysis

FFT analysis of SVPWM Model:

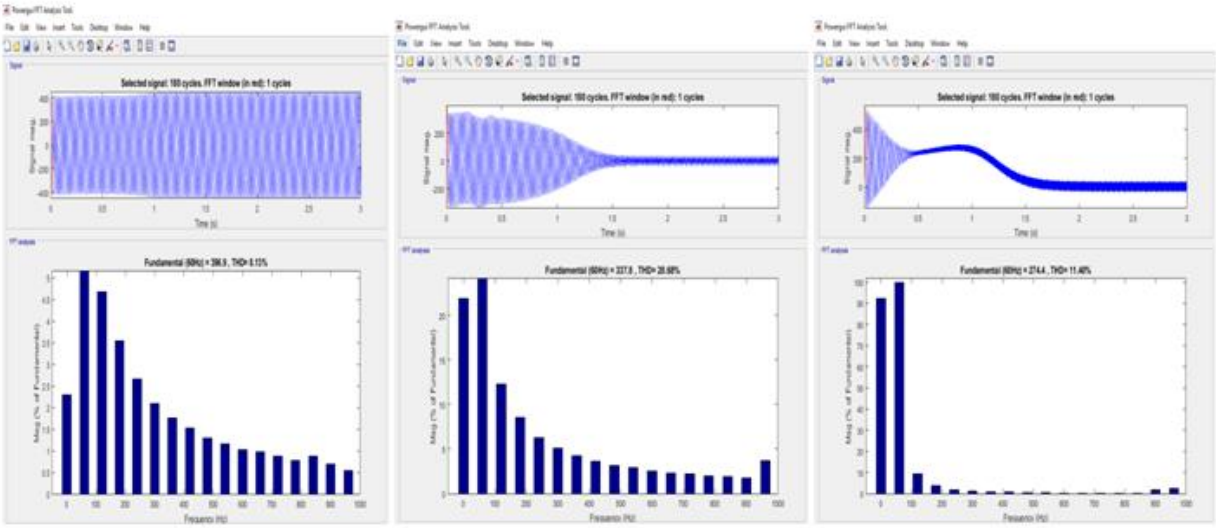


Fig 10: FFT analysis of (a) Voltage signal, (b) Current Signal, (c) Electromagnetic torque signal, SVPWM

FFT analysis of SPWM Model:

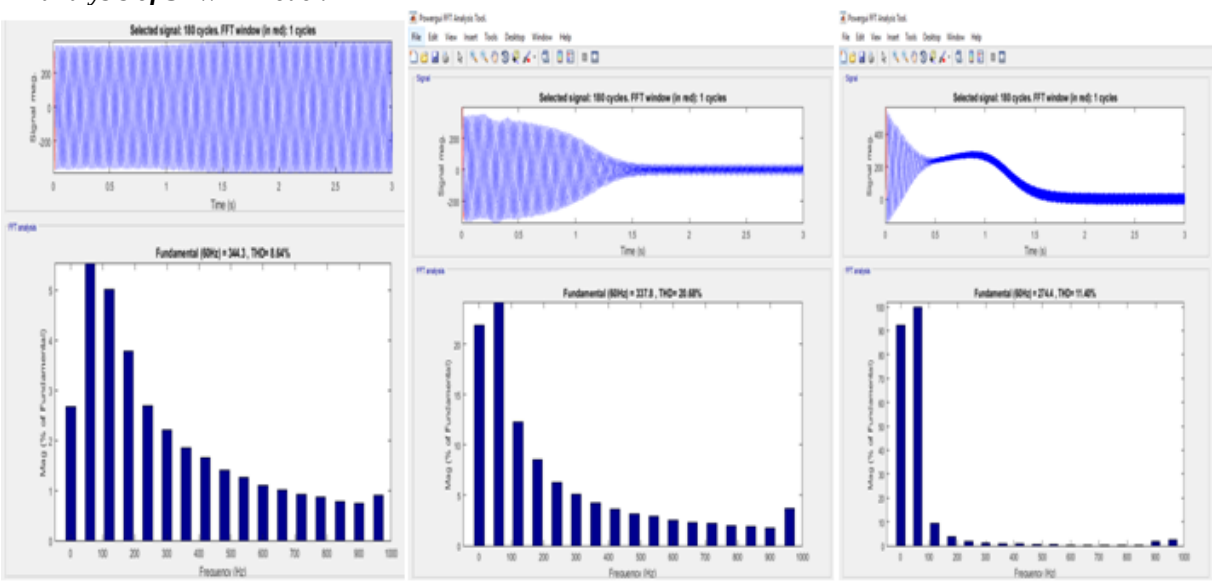


Fig 11: FFT analysis of (a) Voltage signal, (b) Current Signal, (c) Electromagnetic torque signal, SPWM

B. COMPARISON OFTOTAL HARMONIC DISTORTION (THD) in %

After carefully study of FFT analysis of various signals we came to the following conclusion:

Table 2: Comparison Table

	SPWM	SVPWM
Current	20.78	19.57
Voltage	8.74	8.01
Electromagnetic Torque	11.72	11.17

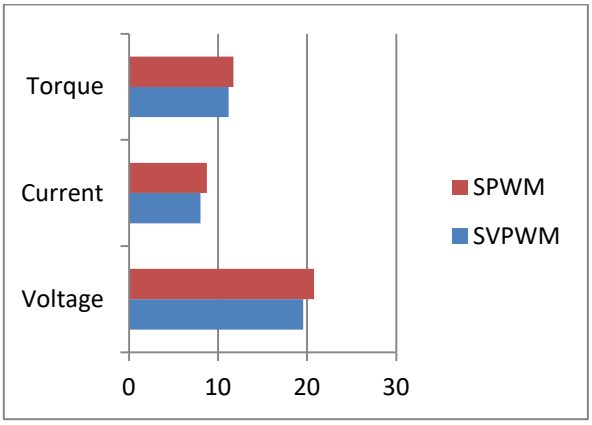


Fig 12: THD Comparison graph

C. COMPARISON OFMODULATION INDEX OF INVERTER

From FFT analysis, the following data was obtained about the modulation of SPWM and SVPWM inverter:
SPWM = 0.823 SVPWM = 0.958

Fig 13: Comparison graph on the basis of modulation index

CONCLUSION

After the comparative evaluation of Space Vector PWM with existing SPWM for Inverter fed IM it can be said that SVPWM has better control approach. The simulation outcomes with THD obtained from the FFT analysis of the output signal were contrasted in the previous segment. After careful study of FFT graphs, it can be seen that SVPWM offers 14.4% improved output. Also, SVPWM method overcomes the major drawback of conventional SPWM in order to control an induction motor is that it has high-harmonic distortion owing to irregular nature of the PWM switching characteristics. In our result it can also be seen that MOSFET provides faster switching speed than IGBT and reduce the cost of the design for medium voltage input devices. SVPWM offers better end result at the inverter output in terms of lesser THD in voltage, current, and electromagnetic torque compared to SPWM. Hence, SVPWM provides a better fundamental output voltage.

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