Effect of PWM Inverter Used In VFD on Induction Motor Performance and Comparison with Direct on Line Start

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Abstract— In this paper, at first, operating principle of variable frequency drive. A component of VFD, starting and stopping operation of VFD is described. It also simulink the PWM control of induction motor and result analyzed.It also describe the comparison with direct on line starter.

Keywords— Operating principle of VFD, PWM, Modulation Index,direct on line starting.

I. Introduction

The speed of the motor can be changed by various methods such as changing poles, controlling voltage, connecting resistance in rotor circuit etc., but most efficient method is changing the supply frequency and voltage to the motor. The variable frequency drive (VFD) varies the frequency and hence varies the speed of the motor as per the requirements of the load.
Speed control of AC/DC motors can be achieved by the variable speed drive (VSD) unit. DC drives are used for special applications such as few low-speed, low-to-medium power applications because of problems with mechanical commutation and expensive at large size. Usually AC drives especially squirrel cage induction motor is widely used due to its rugged construction, easy installation and maintenance, higher efficiency and low cost.

II. OPERATING PRINCIPLE

The variable frequency drive (VFD) converts the supply frequency and voltage to the required frequency and voltage to drive a motor. Hence, VFD converts the supply frequency and voltage to the frequency and voltage required to drive a motor at a desired speed other than its rated speed.

The synchronous speed of an induction motor is given by the equation as:

$$Ns = \frac{120f}{p}$$

The gap between synchronous speed and running speed is called the slip.

$$\%S = \frac{Ns - N}{Ns} \times 100$$

Running speed, N = Ns (1-S)

$$= \frac{120f}{p}(1 - S)$$

So, $N \alpha f$.

Thus the running speed of induction is directly proportional to the supply frequency. If the frequency changes the actual running speed of motor also changes. VFD controls the frequency from supply and it is adjusted to the present requirement.

The basic functions of variable speed drive are to control the frequency of the supply to the motor and power transfer efficiently from supply mains to the motor drive.

III. COMPONENTS OF VFD

The variable speed drive consists of rectifier, inverter and control components.

Rectifier: A full-wave, solid-state rectifier converts three-phase 50 Hz power from a standard 220, 440 or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used.

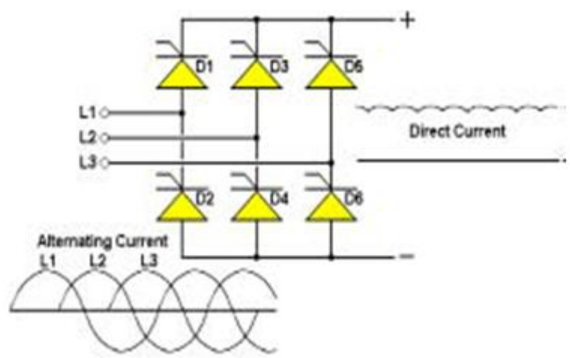

Figure 1 Rectifier Circuit

Inverter: Electronic switches - power transistors or thyristors - switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency. The amount of distortion depends on the design of the inverter and filter.

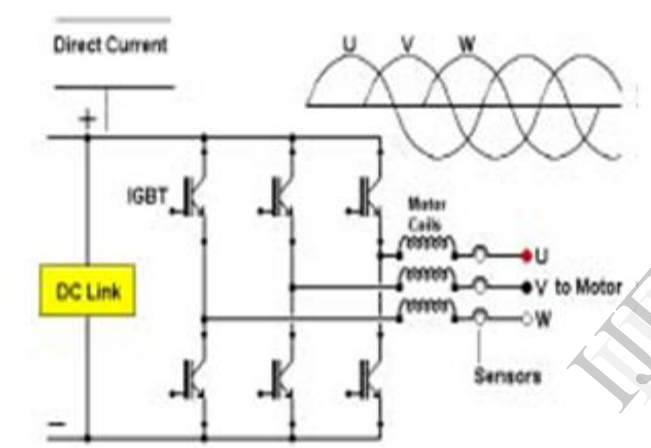

Figure 2 Inverter Circuit

Control system: An electronic circuit receives feedback information from the driven motor and adjusts the output voltage or frequency to the selected values. Usually the output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz). Controllers may incorporate many complex control functions.

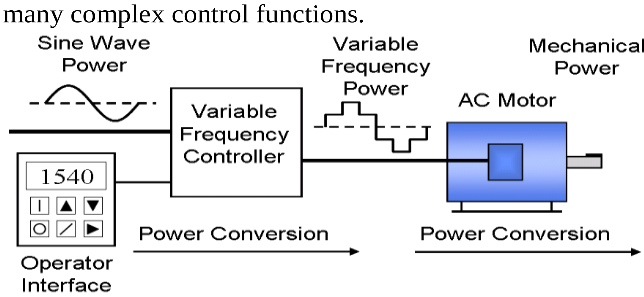

Figure 3 VFD System

Converting DC to variable frequency AC is accomplished using an inverter. Most currently available inverters use pulse width modulation (PWM) because the output current waveform closely approximates a sine wave. Power semiconductors switch DC voltage at high speed, producing a series of short-duration pulses of constant amplitude. Output voltage is varied by changing the width and polarity of the switched pulses. Output frequency is adjusted by changing the switching cycle time. The resulting current in an inductive motor simulates a sine wave of the desired output frequency (see Figure below). The high-speed switching of a PWM inverter results in less waveform distortion and, therefore, lower harmonic losses.

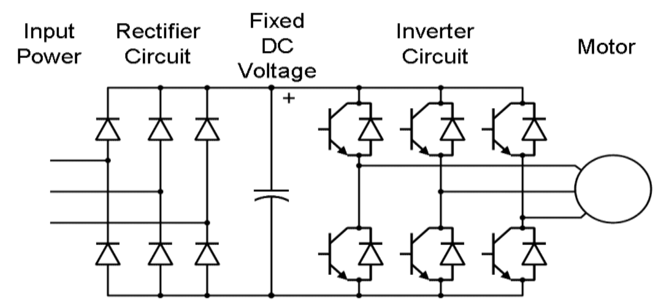

Figure 4 Pulse width modulations

Charging Resistor

The charging resistor is included in the DC bus to provide current limiting during the initial power up stages of the VFD. When a fully discharged VFD is switched on to the power supply, the capacitors on the DC bus are seen by the power supply as a very low impedance load. If the design does not include a charging resistor, the current surge magnitude would be so high that the input bridge can be damaged, or require up-rating far beyond that required for normal running.

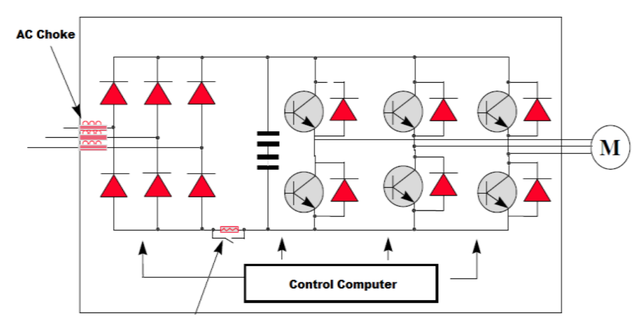

Figure 5 VFD Construction

AC Line Choke

The AC Line choke design provides some smoothing on the DC bus and reduces the amount of ripple current that must be tolerated by the main capacitors. This has an effect of extending the life of these components. The choke provides a limiting function to the magnitude of the DC bus current during normal operation. This results in an improved overall power factor of the VFD and reduced harmonic currents flowing in the power distribution network.

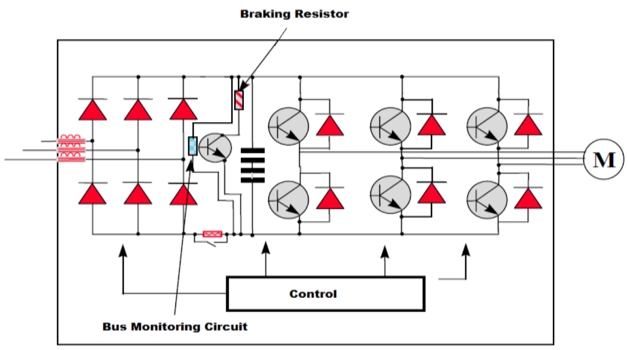

Figure.6 VFD braking Resistor

VFD Voltage to Frequency Ratio

When connected to a VFD, motor speed is no longer fixed by supply frequency, since the VFD can vary its output frequency. Under perfect conditions, at zero speed the terminal voltage would also be zero. Obviously if this was the case then the motor would produce zero torque and in many cases this would be unacceptable. Also at very low speeds the motor winding appears more like a resistive load than an inductive load. To overcome this problem with a general purpose VFD, a degree of fixed voltage boost is applied at zero speed. As the motor accelerates, a proportion of fixed boost is replaced by normal V/F ratio until, at some speed above zero, governed by the amount of fixed boost applied, all boost is replaced by the normal V/F ratio. If an excessive amount of fixed boost is applied, the motor can become overheated due to over fluxing.

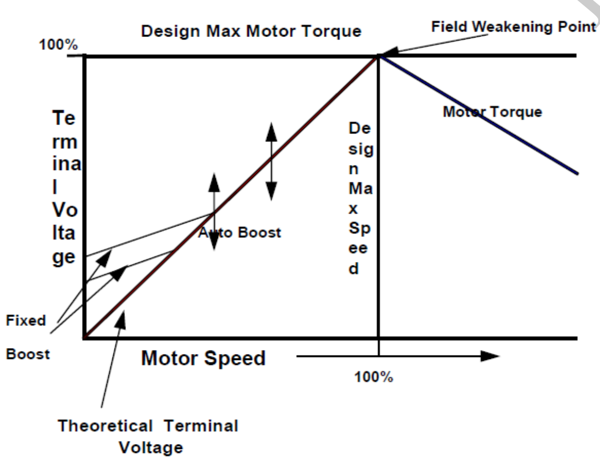

Figure .7 VFD Voltage to Frequency Ratio

IV. VFD OPERATION

Starting

When a VFD starts a motor, it initially applies a low frequency and low voltage to the motor. This reduces the starting inrush current of the motor. Typical starting frequency is just 2 Hz or less. When the motor starts to run, the applied voltage and frequency are gradually increased at controlled rate or ramped up to accelerate the load without drawing excessive current.

The starting method by VFD usually allows a motor to develop 150% of its rated torque while drawing only 150% of its rated current when motor is switched on to its full rated voltage.

As the load accelerates, the available torque generally drops a little and then increases to a maximum value while the current remains very high until the motor approaches full speed. A VFD can be adjusted to produce a steady 150% starting torque from standstill to full speed condition while drawing only 150% current.

Stopping

The stopping sequence is just the opposite of the starting sequence. The frequency and voltage of the motor are reduced or ramped down at a controlled rate. When the frequency approaches zero, the motor is shut off. A small amount of braking torque is available to help faster decelerate the load. This additional braking torque can be obtained by adding a braking circuit to dissipate the braking energy or return it to the power supply.

V Selection of Variable Speed Drive

The following factors/criteria should be considered for selection of appropriate VSD and its successful implementation.

Type of Load

It is very important to know the type and characteristics of the load that is driven by the motor before selecting the variable speed drive.

A. For constant Torque Load

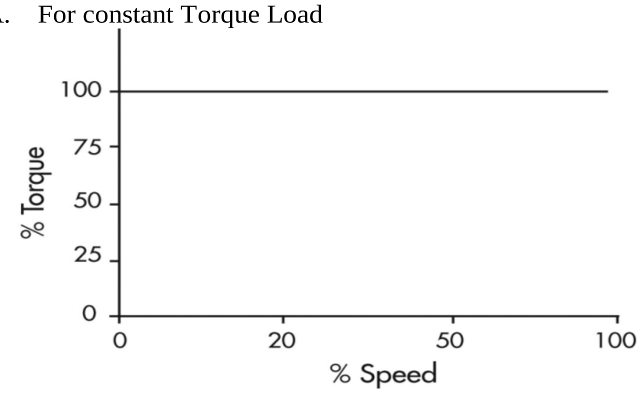

Figure 8 Constant Torque Load

A constant torque load is characterized as one in which the torque is constant regardless of speed. As a result the horsepower requirement is directly proportional to the operating speed of the application and varied directly with speed. Since torque is not a function of speed, it remains constant while the horsepower and speed vary proportionately. Typical examples of constant torque applications include: Conveyors, Extruders, Mixers, Positive displacement pumps and compressors. Some of the advantages VFDs offer in constant torque applications include precise speed control and starting and stopping with controlled acceleration/deceleration.

B. For constant Horsepower load

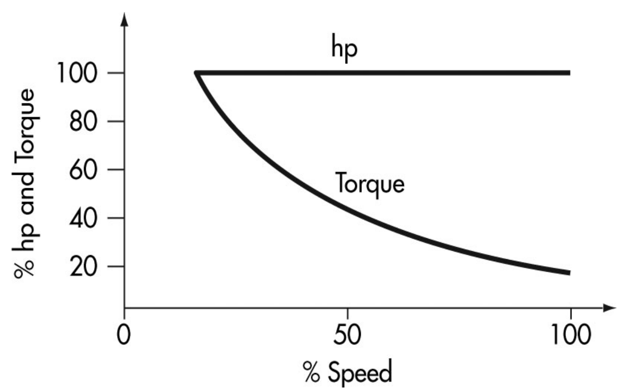

Figure .9 Constant Horsepower Load

The second type of load characteristic is constant power. In these applications the torque requirement varies inversely with speed. As the torque increases the speed must decrease to have a constant horsepower load. The relationship can be written as:

Power = speed x torque x constant

Examples of this type of load would be a lathe or drilling and milling machines where heavy cuts are made at low speed and light cuts are made at high speed. These applications do not offer energy savings at reduced speeds.

C. For variable torque load

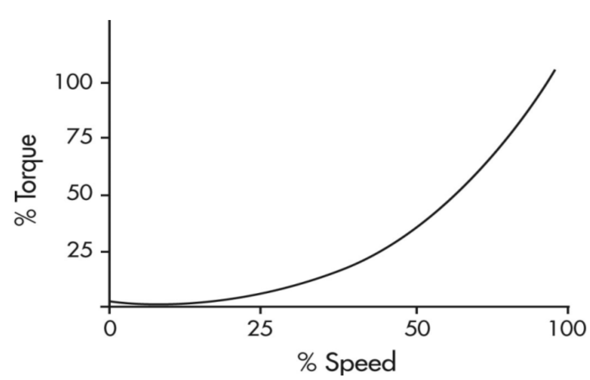

Figure 10 Variable Torque Load

The third type of load characteristic is a variable torque load. Examples include centrifugal fans, blowers and pumps. The use of a VFD with a variable torque load may return significant energy savings.

In these applications:

- Torque varies directly with speed squared
- Power varies directly with speed cubed

This means that at half speed, the horsepower required is approximately one eighth of rated maximum.

VI .Building and Simulation of PWM Motor with Drive

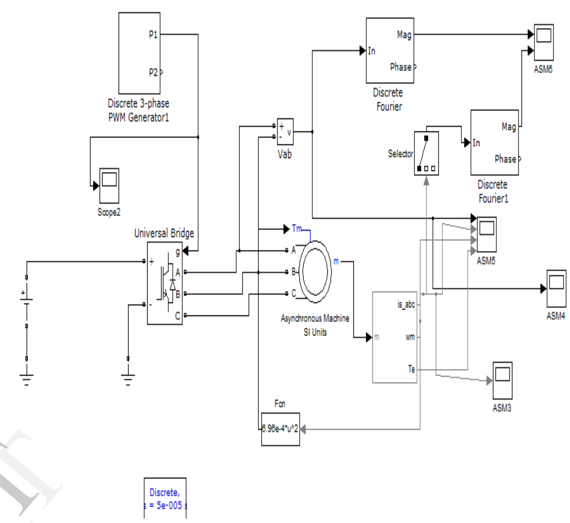

Fig 11 PWM control of an induction motor

In this matlab simulation we have use discrete 3-phase PWM generator, the discrete 3-phase PWM generator blocks generates pulses for carrier base PWM converters. The block is used to fire the IGBT of 2 level or 3 level converters. Using a single bridge or two bridge connected in twin configuration vector its output of P1 & P2 either 6 pulses(2 level) or 12 pulses (3 level).

In our case we have use output P1 when operating in single bridge configuration for 6-pulses.

Carrier frequency= 900 Hz.

Modulation Index=0.9.

Power	5.4 Hp
Voltage	400
Frequency	50 Hz
Synchronous Speed	1430 rpm
Snubber resistance	1e5
Inverter	IGBT
Rectifier	Thyrister bridge

TABLE 1.1 DESIGN VALUES FOR PROPOSED MATLAB MODEL

Sr no	Parameter	Value
1	Stator resistance and inductance	1.405Ω , 0.005839H
2	Rotor resistance and inductance	1.395Ω, 0.005839H
3	Mutual inductance	0.1722 Ω
4	Inertia	0.0131kg-m^2
5	Friction factor	0.002985
6	Poles pair	2
7	Intial condition	1 0 0 0 0 0 0 0

TABLE 1.2 DESIGN VALUES FOR ASYNCHRONOUS MACHINE

$$w = \frac{2\pi n}{50}$$

$$= \frac{2*3.14*1430}{50}$$

=179.60 rad/sec.

$$T\alpha\ w_m 2 \Rightarrow T = kw_m 2$$

As motor is of 5.4 Hp motor,

$$\text{T} = \frac{5.4*746}{179.60}\left(\because T = \frac{p}{w}\right)$$

=22.42 N-m

As $T = kw_m 2$

$$k = \frac{T}{wm^2}$$

$$= \frac{22.42}{(179.60)^2}$$

$$= 6.96 \times 10^{-4}$$

$$\therefore T = 6.06 \times 10^{-4} w_m 2$$

Thus in MATLAB a MATH function is taken as 6.06 e - 4*U^2.

$$VLLrms = \frac{m}{2} \times \frac{\sqrt{3}}{\sqrt{2}} Vdc$$

$$= \frac{0.9}{2} \times \frac{\sqrt{3}}{\sqrt{2}} 400$$

$$= 220.45 Volt\ .$$

In our matlab program, modulation index m=0.9 & Vdc is the input voltage to the inverter which is 400v.

VII .WAVEFORM ANALYSIS

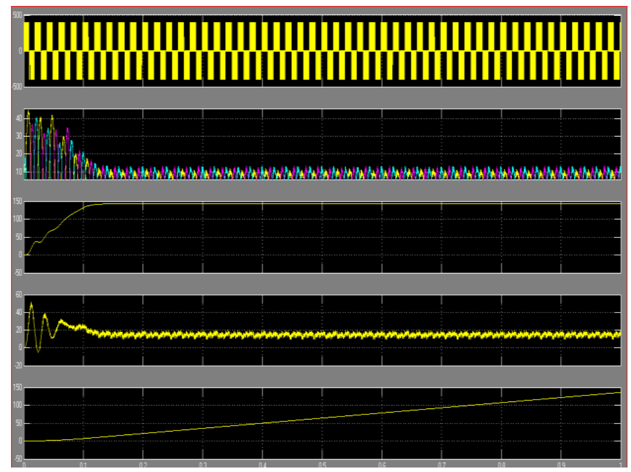

Fig 12 waveform of current, voltage, speed, torque and rotor angle.

The motor start and reaches its steady state speed of 145 rad/sec as 3rd W/F of ASM5 scope

$$w = \frac{2\pi N}{50}$$

$$145 = \frac{2\pi N}{50}$$

N=1154 rpm

From 1st W/F of ASM5 scope, voltage is obtained 400 volt Ac.

From 2nd W/F of ASM 5 at starting maximum current is 40A, after 0.1 sec it stabilize to 10A.

From 3rd and 4th w/f of ASM 5 of speed and torque, initially the torque is 44 Nm and after 0.1 sec it reaches to 12 Nm at that time speed is 135 rad/sec.

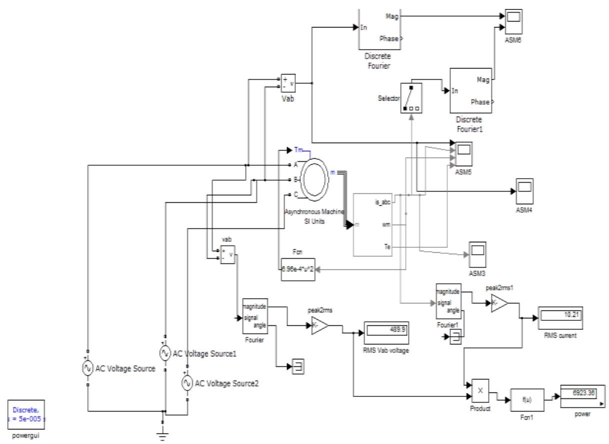

FIG 13 INDUCTION MOTOR START WITH D.O.L. START

In this matlab simulation induction motor is started with direct rated voltage and power, current and THD were measured.

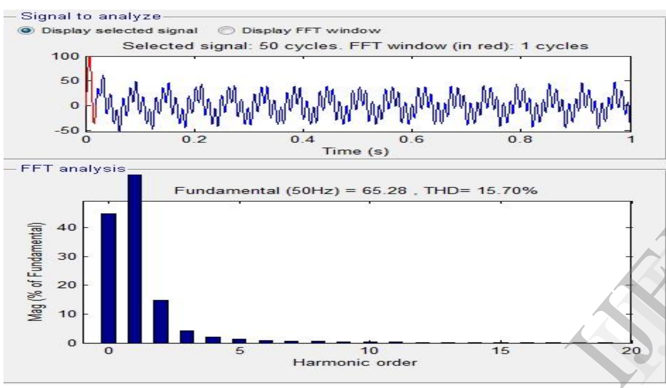

FIG 14 CURRENT WAVEFORM OF THD WITH D.O.L. START

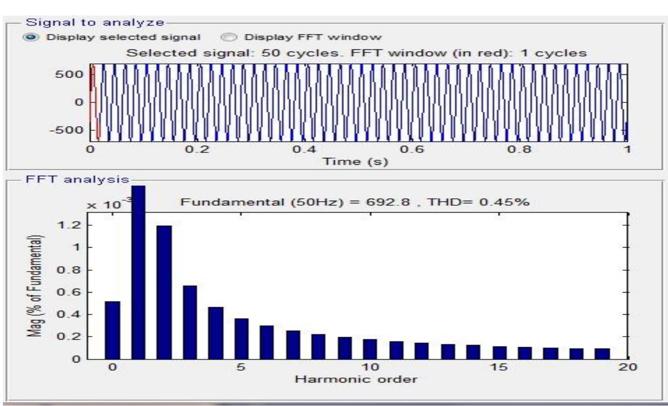

Fig 15 Voltage waveform of THD with D.O.L. start

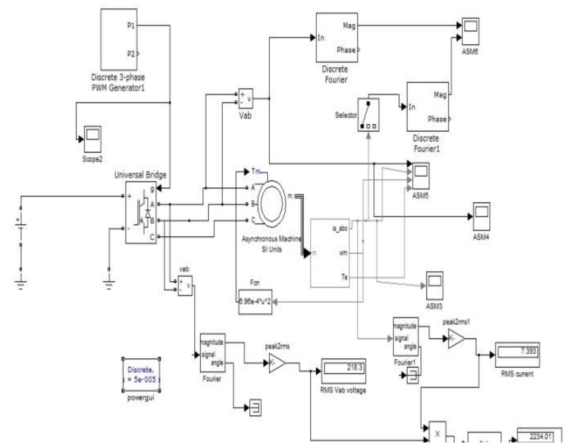

Fig 16 Induction motor with pwm inverter used in VFD

In this matlab simulation induction motor is started with PWM inverter used in VFD and power, current & THD were measured.

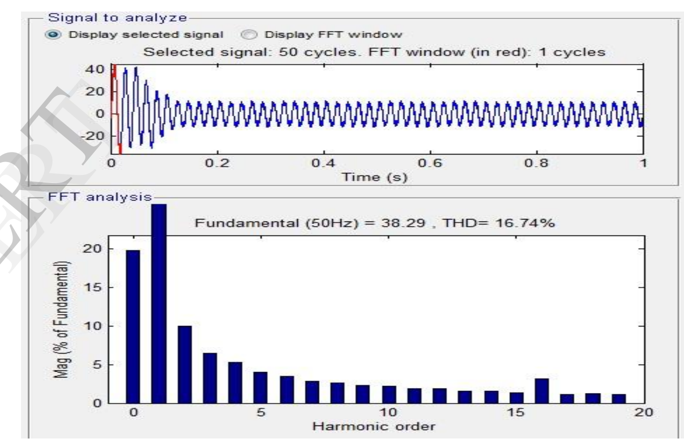

FIG 17 CURRENT WAVEFORM THD WITH PWM INVERTER

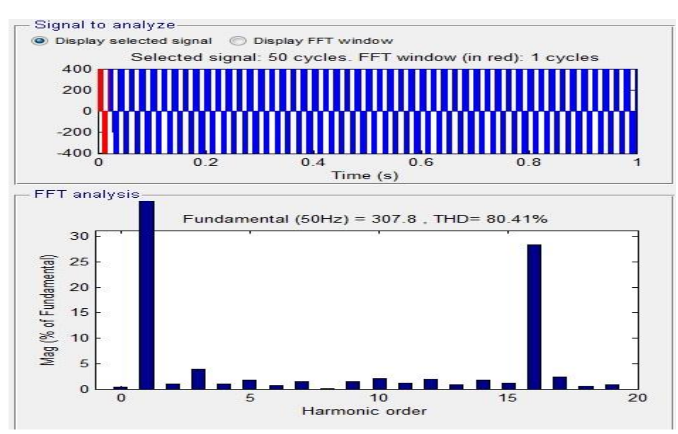

FIG 18 VOLTAGE WAVEFORM OF THD WITH PWM INVERTER

SR NO	POINT OF COMPARISON	POWER	CURRENT	THD OF VOLTAGE
1	MOTOR WITH D.O.L. START	6923 WATT	10.21 AMP	0.45%
2	MOTOR WITH PWM INVERTER USED IN VFD	2234 WATT	7.39 AMP	80.41%

TABLE 1.3 COMPARISON OF MOTOR WITH D.O.L & WITH PWM INVERTER

VIII. CONCLUSION

In this paper 6 pulse PWM inverter is studied for induction motor which is used for variable frequency drives. The effect on stator voltage; current, speed, torque, rotor angle is studied. Simulation of inverter is done used with vfds and we get the result of voltage and current waveform of THD but THD of voltage is higher than THD of current. Also simulation of induction motor with direct on line starter is compared with motor started with inverter as used in VFD the result shows that significant power saving is obtain with variable frequency drive. Also centrifugal pump type load, power is proportional to (speed)3 and power is proportional to speed. Industry can use VFD in this application then it can save considerable amount of power.

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