Research to study Variable Frequency Drive and its Energy Savings

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Abstract: ***This paper presents the working principle of Variable Frequency Drive. The performance of VFD is also described. The simulation model is simulated using MATLAB Simulink and their results are also analyzed. The Total Harmonic Distortion (THD) in waveforms is also analyzed. The use of Variable Frequency Drive has been increased dramatically in the field of HVAC applications. The common applications of VFDs are in air handler, chiller, pumps and tower fans. A better understanding of Variable Frequency Drives with leads to improve in application and selection of both equipment and HVAC system. This paper is intended to provide a basic understanding of VFD terms, VFD operations and Power Factor improvement, Harmonics mitigation by VFD and a simulation project to show how VFD is beneficial for energy savings. In addition to this paper will discuss the comparison between Variable Frequency Drives and other technologies with respect to industrial standards.***

Keywords: Working Principle of VFD, Simulation Circuit and Analysis of results.

1. Introduction

The Variable Frequency Drive (VFD) industry is growing rapidly and it is now more important than ever for technicians and maintenance personnel to keep VFD installations running smoothly. Variable Frequency Drives (VFD) change the speed of motor by changing voltage and frequency of the power supplied to the motor. In order to maintain proper power factor and reduce excessive heating of the motor, the name plate volts/hertz ratio must be maintained. This is the main task of Variable Frequency Drive.

1. Variable Frequency Drive (AC drives) are used to stepless speed control of squirrel cage induction motors mostly used in process plants due to its ruggedness and maintenance free long life.
2. VFD control speed of motor by varying output voltage and frequency through sophisticated microprocessor controlled electronics device.
3. VFD consists of Rectifier and inverter units. Rectifier converts AC in DC voltage and inverter converts DC voltage back in AC voltage.

2. VFD Operation

For understanding the basic principles behind VFD operation requires understanding three basic section of VFD: the Rectifier unit, DC Bus and the Inverter unit.

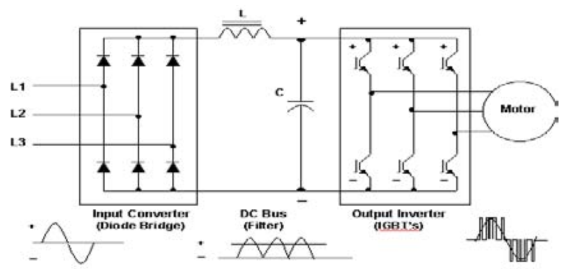

Figure 1: VFD Circuit Diagram

The supply voltage is firstly pass through a rectifier unit where in gets converted into AC to DC supply, the three phase supply is fed with three phase full wave diode where it gets converts into DC supply. The DC bus comprises with a filter section where the harmonics generated during the AC to DC conversion are filtered out. The last section consists of an inverter section which comprises with six IGBT (Insulated Gate Bipolar Transistor) where the filtered DC supply is being converted to quasi sinusoidal wave of AC supply which is supply to the induction motor connected to it.

As we know that the synchronous speed of motor (rpm) is dependent upon frequency. Therefore by varying the frequency of the power supply through VFD we can control the synchronous motor speed:

$$\text{Speed (rpm)} = \frac{\text{Frquency (Hertz)}\times 120}{\text{No. of Poles}}$$

Where;
Frequency = Electrical Frequency of the power supply in Hz.
No. of Poles = Number of electrical poles in the motor stator.
Thus we can conveniently adjust the speed of a motor by changing the frequency applied to the motor. There is also another way to change the speed of the motor by changing the no. of poles, but this change would be a physical change of the motor. As the drive provides the frequency and voltage of output necessary to change the speed of a motor, this is done through Pulse Width Modulation Drives. Pulse width modulation (PWM) inverter produces pulses of varying widths which are combined to build the required waveform.

As the frequency can easily variable as compared with the poles of the motor therefore speed control drive is termed as Variable Frequency Drive (VFD).

3. Constant V/F Ratio Operation

All Variable Frequency Drives (VFDs) maintain the output voltage – to – frequency (V/f) ratio constant at all speeds for the reason that follows. The phase voltage V, frequency f and the magnetic flux ϕ of motor are related by the equation:-

$$V = 4.444\, f\, N\, \phi_m$$

$$\text{or } V/f = 4.444\times N\, \phi_m$$

Where N = number of turns per phase.

ϕ_m = magnetic flux

If the same voltage is applied at the reduced frequency, the magnetic flux would increase and saturate the magnetic core, significantly distorting the motor performance. The magnetic saturation can be avoided by keeping the ϕ_m constant. Moreover, the motor torque is the product of stator flux and rotor current. For maintaining the rated torque at all speeds the constant flux must be maintained at its rated value, which is basically done by keeping the voltage – to – frequency (V/f) ratio constant. That requires the lowering the motor voltage in the same proportion as the frequency to avoid magnetic saturation due to high flux or lower than the rated torque due to low flux.

4. How Drive Changes Motor Speed

As the drive provides the frequency and voltage of output necessary to change the speed of a motor, this is done through Pulse Width Modulation Drives. Pulse width modulation (PWM) inverter produces pulses of varying widths which are combined to build the required waveform. A diode bridge is used in some converters to reduce harmonics. PWM produce a current waveform that more closely matches a line source, which reduces undesired heating. PWM drive have almost constant power factor at all speeds which is closely to unity. PWM units can also operate multiple motor on a single drive.

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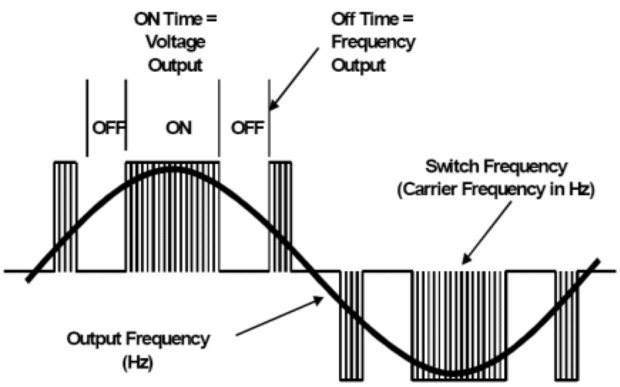

Figure 2: Drive Output Waveform Components

Thus the carrier frequency is derived from the speed of the power device switch remains ON and OFF. It is also called switch frequency. Therefore higher the carrier frequency higher the resolution for PWM (Pulse Width Modulation) contains. The typical carrier frequency ranges from 3KHz to 4 KHz or 3000 to 4000 times per second as compared with older SCR based carrier frequency which ranges from 250 to 500 times per second. Thus it is clear as much as higher the carrier frequency higher will be the resolution of output waveform. It is also noted that the carrier frequency decreases the efficiency of the drive because it led to increase the heat of the drive circuit.

5. Advantages of VFD

1. Large energy savings at lower speed.
2. Increased life of rotating components due to lower operating speed.
3. Reduced noise and vibration level.
4. Reduction of Thermal and mechanical stresses.
5. Lower KVA
6. High power factor

6. Simulation Circuit

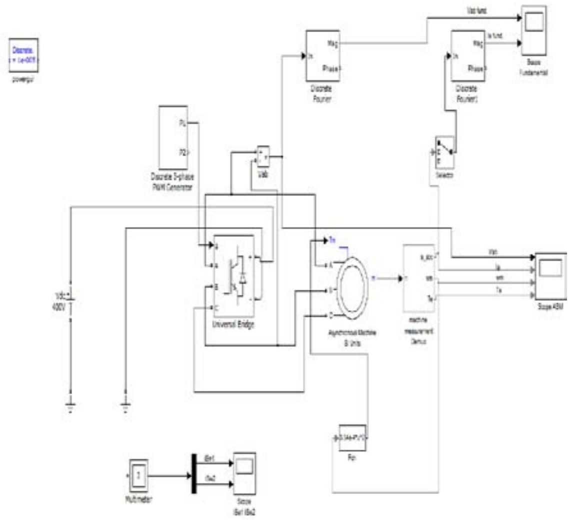

Figure 3: Simulation Circuit of VFD

For variable speed control of AC electrical machines several power electronics switches such as IGBTs, MOSFETs and GTO use as forced – commutation method. Earlier techniques such as the DC motor and Thyristor Bridge which are replaced with new techniques such as Voltage Sourced Converters (VSC) are fed by Pulse Width Modulation (PWM) to the asynchronous machine. As the flexibility of speed and torque control with DC machine, the same can be obtained by the combination of pulse width modulation technique with modern control technique such as Field Oriented Technique or Direct Torque Control methods. In this section a simulation of AC drive controlling an asynchronous machine is been described.

The machine library of simulation consists of four most common three phase machine asynchronous machine, permanent magnet synchronous machine, simplified and complete synchronous machine. The following machine can be used either used as generating mode or motoring mode. These machines can be used to simulate electromechanical transient in an electrical network when combined with linear and non linear elements such as transformer line loads, breakers, etc. for simulation of drives they are combined with power electronics devices. The power electronics library of simulation contains diodes, thyristors, GTO, MOSFET and IGBT. These several blocks interconnected with each other to form Three Phase Bridges.

Simulation of 3 HP, 4 pole motor is done with a inverter using Pulse Width Modulation (PWM) technique. Frequency and amplitude of output voltage is varied by using PWM technique and these controlled voltage and frequency are used to control motor speed.

7. Waveform Analysis

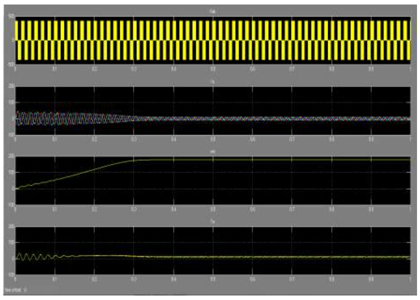

Figure 4: Waveforms of Voltage Current, Speed and Torque
The voltage, current, speed and torque waveform are analyzed.

8. Performing Harmonics Analysis using the FFT Tool

At the time of simulation is running the fundamental component of voltage and current are allowed by two Discrete Fourier Blocks. Thus for observing harmonics component we would require Discrete Fourier Block for each harmonic. This approach is not convenient.

For displaying the frequency spectrum of current and voltage waveform we require FFT tool of Powergui. With time variable generated by the scope block, the signals get stored in ASM structure and signals are saved into the ASM structure is sampled at fixed step which satisfy FFT tool requirements.

Thus the Powergui is opened and FFT analysis is selected. A new window is opened. The analyzed signal, the time window and the frequency range is parameters are set as follows:-

Table 1: Parameters of FFT present in powergui block

Structure	*ASM*
Input	Vab
Signal number	1
Start time	0.7 s
Number of cycles	2
Fundamental frequency	60 Hz
Max frequency	5000Hz
Frequency axis	Harmonic order
Display style	Bar (relative to Fund or DC)

As the Display option is clicked the analyzed signal is displayed. At the bottom window the frequency the frequency spectrum is displayed.

9. FFT Analysis of Motor Line to Line Voltage

As the fundamental complement and the Total Harmonics Distortion (THD) of Vab is displayed in the spectrum window the magnitude of inverter voltage fundamental is (312V) which compared with the theoretical value (311V for m=0.4).

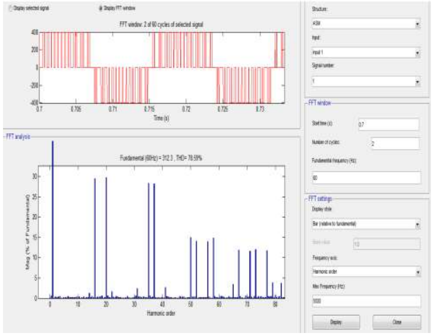

Figure 5: FFT analysis of Asynchronous motor

10. Result

The simulation result is being calculated from a 4 pole Asynchronous motor of 3 HP and the Harmonics analysis using FFT tool of simulation of maximum frequency 5000 Hz.

Table 2: Data analysis of Frequency

Fundamental Frequency	*Speed (RPM)*	*Order of Harmonics*	*THD of Voltage*	*THD of Current*
80	2400	62.5(even)	106.25%	30.49%
75	2250	66.66(even)	81.86%	19.65%
70	2100	71.42(odd)	67.89%	14.91%
65	1950	76.92(even)	55.46%	12.20%
60	1800	83.33(odd)	78.59%	11.46%
55	1650	90.90(even)	55.85%	18.72%
50	1500	100(even)	76.85%	32.86%
45	1350	111.11(odd)	126.29%	37.35%

It is clear that THD (V) level increases with as the value of fundamental frequency increases from 70Hz and also the fundamental frequency decreases 45 Hz or below. Thus the range of variations of fundamental frequency should be kept in between 70 to 45 Hz. It is also seen that the values of THD (V) in case of 70Hz, 60Hz and 45Hz is quit high as compared to other frequency presents in between them, this is because of presence of ODD Harmonics in these frequencies, as we know that the ODD harmonics is more harmful for the promotion of Distortion in the circuit than the EVEN Harmonics. Since the maximum frequency is set as 5000Hz therefore it can be easily calculated the order of Harmonics. Thus the consumption of electrical energy is depends on the load requirement. However the variation of frequency leads to the harmonics distortion which can be mitigate by several techniques of harmonics mitigation.

The variation of THD in between the fundamental frequencies is keep changing therefore there are variation for distortion which leads to the calculation of energy savings is quite possible as well as speed control of the motor. Further the introduction of filter techniques can lead to the mitigation of harmonics level in the circuit. Basically the application of Band Pass Active Filter is quite suitable for mitigation of harmonics in this level. It can be introduced as a future research work of this paper.

11. Conclusion

Thus from the analysis of table it is clear that the frequency variation leads to the harmonics change in the machine also as the speed decreases the Total Harmonics Distortion in voltage as well as in current increases and THD in voltage is lower than THD in current. It is also to be noted that too much variation in frequency also leads to increase in the THD voltage as well as THD current levels. Thus the Variable Frequency Drive can serve both in case of Speed Control of Motor as well as energy savings.

For high performance providing by the Variable Frequency Drive for maximum process productivity always required a complex engineering consideration. However rapid improvements in AC control technology combined with ready availability of standard fixed frequency of AC motor have increased the number of possible solution. With the process of pulse width modulation, the frequency given to the induction motor can be set in order to control the speed of the induction motor. Thus the consumption of electrical energy is depends on the load requirement. However the variation of frequency leads to the harmonics distortion which can be mitigate by several techniques of harmonics mitigation.

The elimination techniques of harmonics are generally applied to lowest harmonic because as the filtering is more practical at higher harmonics, the filtering component can be smaller and less expensive. Also application of several multilevel inverters provides another approach to harmonics cancellation. For the mitigation of harmonics from the circuit of the inverter application of active filters are required into the circuit such as Band Pass Active Filter.

Thus after the study of Variable Frequency Drive, it becomes possible to control the speed of electric motor as well as to conserve the electrical energy, as we know that the energy conservation has become an important subject to all over the world. Increase in efficient energy use, decrease in energy consumption and/or consumption from conventional energy sources is reduced that leads to the conservation of energy.

12. Acknowledgement

The author would like to express his great thank to Ms. Vishu Gupta (Asst. Prof. of Suresh Gyan Vihar University, India), Prof. R.K Gupta (Suresh Gyan Vihar University, India) and M. Sashilal (Head of Department, Suresh Gyan Vihar University, India) for their valuable technical suggestion and full guidance towards completion of this paper.

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