Speed and Frequency Control of AC Induction Motor Using Variable Frequency Drive

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Abstract--- In a country like Pakistan energy saving is of great importance. In order to overcome energy crisis the only possible solution with minimum cost is to save energy. It has been stated that 25% of the world's electricity is consumed by AC motors. And there is a big problem associated with these motors that is, large starting inrush current. As the motor starts a large current is drawn by the motor which is of no use until motor reaches it synchronous speed. This high current not only produces heat but also reduces the life time of electrical equipment and power consumption also increased. Thus there is a need to reduce this current somehow or the other .This current can be reduced by making use of variable frequency drive. Variable frequency drive is a technique used to control the speed and frequency of AC induction motors thus it is also known as adjustable speed drive or variable speed drive.in this phenomenon voltage and frequency of the motor is controlled using a technique named as PWM (Pulse Width Modulation). There are so many other techniques used to reduce the current of motor like soft starters. But the benefits of variable frequency drive are more than soft starters. Like it provide energy to electrical appliance according to demand, It enhances the life time of equipment but the biggest advantage is, It is energy saving device, and such device is greatly needed in a country like Pakistan where energy crisis has halt the economic wheel of the country.

I. HISTORICAL BACK GROUND

Variable frequency drive is typically a tool of power electronics without having a great understanding of power electronics we can never get the depth of variable frequency drive.

The history of power electronics tells us that its evolution started in the very beginning of 20th century. And the first invention that was brought before the world by Peter Cooper was mercury-arc rectifier.[1] Then with the passage of time power electronics had under gone many changes and in the 3rd and 4th decade of 20th century it was evolved to gas tube electronics [1],[2] and saturated core magnetic amplifiers.in the mid of 20th century many advancement were seen in field of power electronics and the work which came forward was silicon controlled rectifier (SCR) and thyristor.[1] After that power electronics has shown countless advancement in research and development field till today. The history of variable frequency drive is not much older as that of power electronics. Rather its evolution was very rapid and, in a very short period of time it has gain a very important place in industry. The first variable frequency drive was based on mechanical principals because power electronics had not made great advancements till that day. It was consist of adjustable pitch diameter pulleys.[3] AC induction motors were firstly designed in 1924 [3]and the speed of motors were dependent upon frequency and poles of motors. After the invention of motors it was thought that motors could be run on variable speed, for that matter the only possible solution was to vary the frequency, In order to run the motor on a variable speed, because frequency has direct relation with motor speed. Variable frequency dive based on pulse width modulation was firstly invented in early 60's in Finland.[4] But on commercial scale a great achievement was made by Martti Harmoinen at Helsinki Metro in 1972.[4] Initially variable frequency drives were based on 6 step voltage design.[3] But after some time a modified form was introduced. This was designed and presented by Phillips in mid-80's it consisted of sine coded PWM chip set.[3],[4] now there arises a point why variable frequency drive is used only for ac induction motors. The answer is as follow. Universally for induction motor's optimum working a slip is required and this slip produces required utilizable torque. Different techniques and methods used to improve the efficiency and working of ac induction motors like soft starters[5], voltage reduction method [6], slip compensation [7], and vector control.[8] But all these methods are not proved feasible for avoiding slip already present in the motor. Because this slip in the motor signifies the amount of energy that is dissipated in the form of heat and may harm many other sensitive component and windings of the motor thus the life time of motor is reduced.[9] Therefore a need of variable frequency drive based on pulse width modulation arises in application which does not require high torque and dynamic response.[10] Price is a very important factor for which this adjustable speed drive is being used because it has comparatively less cost associated with the installation and maintenance of the systems.[11] In last 10 years a great advancements has been made in variable frequency drives that are undoubtedly dependent upon the progress in power electronics field.[1] Now the drives coming in market have several better features unlike the previous ones. In the drives high efficiency capacitors are being used which are used to remove ripples in the voltage coming in to the DC bus this advancement in capacitors is leading the drive towards more energy savings as newly made capacitors offer 80% less power loss as compared to the older technology.[12] Furthermore the new drives comprises of DC choke which are used to prevent from unwanted harmonics.[2],[10] An extra feature added in the ac motor drives is heat management system by using this system heat is monitored properly and autonomous actions are performed accordingly.[13] The advancements in semiconductor devices have improved the efficiency of drives up to a greater extent.[14] Power management control which deals with sleep functionality of the device is a very key feature it save energy and unwanted power loss are prevented.[15] Many new advancements in layout of these drives like speed adjustment, keypad for input, and meters for providing information about maintenance and communication with other devices. These characteristics incorporated in the drive have not only beautified the product but also enhanced its ability and utilization.

II. INTRODUCTION

Motors are being used worldwide on industrial or domestic level. Electricity is the most power full tool in order to run any motor. Among all the motors ac induction motors are used most commonly and extensively due to their large no of applications. But there is a need to eliminate the problem associated with ac induction motor and to run it in a very efficient way. For that matter many devices are used but the best among all the devices is Variable Frequency Drive which is used to control the speed and frequency of the motor and by reducing speed motors can be run at various loads. There is a direct relation between speed of motor and the frequency of motor operation. Therefore by varying the frequency of ac voltage the motor speed can be adjusted according to desirable value.

$$N = f*120/P \qquad (1)$$

N = Speed of motor (RPM)
F = Electrical Frequency of motor
P = No of poles of motor

These variable frequency drives are very important for HVAC systems where a very large power is consumed before motor reaches at its full speed and a very huge amount of inrush current is being drawn by motor causes this great loss of energy.[11],[5] This starting current can be reduced by making use of variable frequency drive and thus it saves energy up to a large extent. There are various application of variable frequency drive in different appliances like fans,[16],[17] pumps,[17] tower cooling systems,[18] micro wave ovens,[19] air conditioners and ship propulsion systems.[20] it has been said that from the energy consumed by ac motors 10% goes idle and 12% - 15% is lost when motor does not run at full load.[21] So there is a great desire of user to reduce this energy wastage and this can be possible only by making use of device like variable frequency drive because its biggest advantage is its energy saving.[11]
Variable frequency drive is basically comprises of three portions. These are as follow.[22]

- AC to DC Converter
- DC Bus
- Invertor (DC to AC convertor)

When a fixed AC voltages are fed into AC to DC rectifier the AC voltages are converted in DC voltages. Which are further directed towards DC bus which comprises of capacitors and used to store voltages and removes ripples in the DC voltage thus it smooth out the waveform.[23] Invertor is the last section which is the most important one because it performs the DC to AC conversion by approximate the square waveform with that of sine wave form whose pulse is adjusted in order to control the voltages and frequency of motors.[24] A very important tool of variable frequency drive is PWM which is the key technique for controlling motor speed.[25] There are so many other techniques as well but in this paper only PWM methodology is being discussed.

III. WORKING PRINCIPLE

Variable frequency drive comprises of three major sections as described above and each section has its key importance. First section is rectifier section then a dc bus and finally we have an inverter section with which load is connected. An illustration of these sections is given below in figure 1.

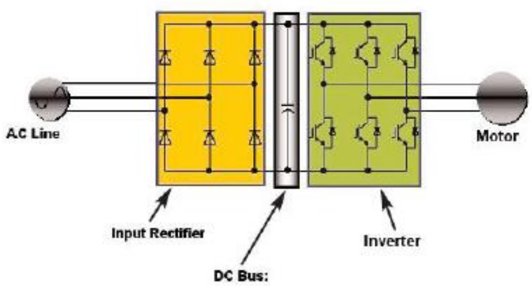

Figure 1: Block Diagram of VFD

A. Rectifiers

This section can comprises of diodes, transistors or silicon controlled rectifiers. But usually diodes are used because of their lower cost.[26] AC voltages coming from main line have positive and negative peaks. When these voltages are fed in to bridge type configuration of diodes of this rectifier section the negative peaks are vanished only positive peaks retain. In this way the frequency of the coming voltages doubles. This rectifier section also called AC to DC converter.[27] Further this pulsating dc is passed through a capacitor in order to remove ripples present in the waveform.[23] These ripples cause distortion and prevent smooth working of electrical appliances so they must be removed using a filter.[28] The circuit diagram of AC to DC converter is shown in figure 2.

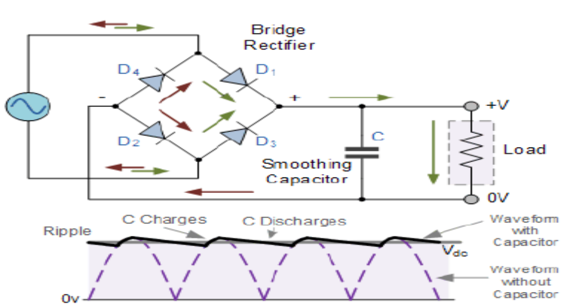

Figure 2: AC to DC Converter

B. DC bus

DC bus is used to store voltages coming from AC to DC converter. This consist of capacitors and some other items like inductors or chokes[29] in order to smooth the power supply coming from the previous section. Thus ripples are further removed by storing voltages in this DC bus. Thus this DC bus can be of great use not only for removing ripples but also helps in improving power factor correction.[30]

C. Microcontroller based PWM

Pulse width modulation is the basic technique used very widely for controlling motor speed and frequency.[31] This can be done by using microcontroller. In this research we selected a range of 5Hz to 50Hz frequency using PWM. The basic principle of PWM is a sine wave is generated in the microcontroller which is super imposed on a triangular wave.[32] This results in a square wave which is then fed to inverter section. The width of this square wave can be controlled by changing the duty cycles of the pulse. Basically duty cycles describes the time for which pulse waveform turned on and off thus by switching the waveform between two discrete levels the square wave is approximated with a sine wave of desired duty cycles. A PWM representation is shown in figure 3.

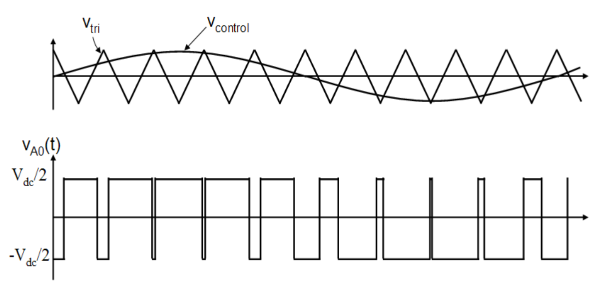

Figure 3: PWM Representation

D. Software and hardware based PWM

The above mentioned technique was programmed using microcontroller firstly on proteus and simulated. The pictorial representation is given below in figure 4.

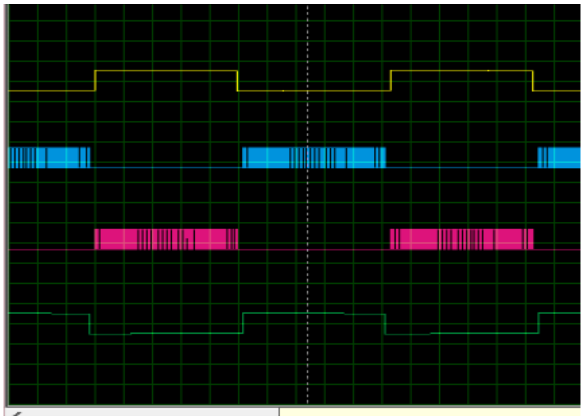

Figure 4: Software Representation of PWM

Further this was implemented on controller hardware and the results were observed and matched with software results on oscilloscope. The figure 5 below shows the results.

Figure 5: Hardware Results of PWM

E. Inverters

The square wave generated using PWM is then fed into inverter section. This section consists of insulated gate bipolar junction transistor (IGBT's) which are power transistors.[1] These IGBT's have very fast switching speed and their voltage and current ratings are also high so they are preferably used in variable frequency drives.[33] In inverter sections these IGBT's are connected in H-bridge configuration. These IGBT's are fed by two PWM's one is normal while the other one is its complement. This is because first we need to excite number 1 and 4th IGBT this will create a waveform rising in clock wise manner. While the complement of the PWM is used to create a waveform rise in anti-clock wise manner thus a complete cycle of the waveform would be achieved. But there is one important thing to note that there is a need to introduce a small dead time.[34]

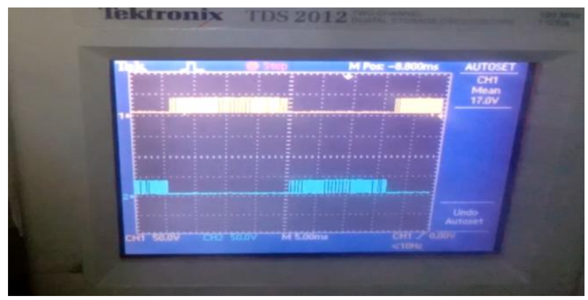

Figure 6: Dead time Representation in PWM wave

The reason is quite simple but important that the time to turn off a power device is quite longer than time to turn on that device. For this reason this dead time is inserted switching action of complementary channels.[35]The power transistors turn on at a time when the square wave is feed into them. As the pulse width of this square waveform is varied from microcontroller at a very high switching speed so this square pulse is approximated with a sine wave when it is applied at load. The inductance of the load also helps in shaping this wave form into sine wave. Thus the desired goal is achieved using invertors and PWM.

IV. ADVANTAGES OF VFD

There are so many benefits associated with this drive. A few of them are listed below.[36]

- Saves energy
- Reduce inrush current
- Easy and simple installation

- Improved power factor
- Reduction in KVA
- High efficiency of motor
- Low thermal and
- Mechanical losses

A very common problem in motors is their low power factor when they don't run at full load this leads to serious damages.[37] So this power factor must be improved. For this purpose capacitors are being used. But there is an extra advantage of using VFD's is the capacitors used in DC bus perform the same action. So without adding extra equipment this power factor correction can be made. These attributes of variable frequency drive tempt the industries to choose it and enjoy extra savings in terms of energy and fewer losses.

V. VFD AS ENERGY SAVING DEVICE

The biggest advantage of VFD as mentioned previously is its energy saving capabilities.[11] Which not only tempt the costumer but also very helpful in our country where energy consumption needs to be reduced. For this sake a simple example of pump and water flow is described to illustrate the working of energy savings.[38] The equations mentioned below show the relationship between power and speed of pump.

Flow2/Flow1=Speed2/Speed1 (2)

Head2/Head1= (Speed2)2/ (Speed1)2 (3)

Power2/Power1= (Speed2)3/ (Speed1)3 (4)

Here subscripts 1 and 2 show the different operation points. The above equation tells us by making use of variable frequency drive approximately 85% energy saving is possible at different operating points of pump.[38]

VI. VFD VS OTHER TECHNIQUES

To overcome current inrush problem in induction motors, various methods are used. Soft starter, autotransformer why-delta starter and VFD's are used. The reason behind choosing a VFD is that a VFD reduces the current inrush to the full load current. Soft starters and autotransformer are not that energy efficient. Both these methods operate at a fixed frequency (50 Hz in Pakistan) unlike a VFD which operates a motor at variable frequency. The following table is based on experimental results.

Table 1:Why VFD is preferable

Starter Type	**Inrush Current (A)**
VFD	$\mathbf{I_{FL}}$
Autotransformer	4 $\mathbf{I_{FL}}$
Why-Delta	2.5 $\mathbf{I_{FL}}$
Soft Starter	2 $\mathbf{I_{FL}}$
Direct Start	8 $\mathbf{I_{FL}}$

The above table is based on experimental results. Direct start refers to start the motor without any current reducing device directly on line voltages. IFL refers to the full load current of a motor and is unique for each motor..

VII. RESULTS

From the above discussion and findings we have deduced some useful results that this drive VFD is very beneficial for industrial and home appliances as it increases the efficiency of electrical equipment and saves great amount of energy.[17] And as we know that their exist a direct relation between energy and current i.e.

$$P=I^2 * R \qquad (5)$$

P= Power (watts)

I= Load Current (amperes)

R= Load Resistance (ohms)

So by reducing the current the power will also be reduced. There by VFD will give the desired results as show in figure 4.[39]

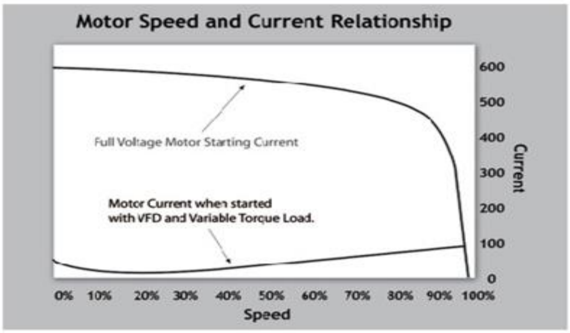

Figure 7: Speed VS Current Curve

VIII. FUTURE EXTENSION

By keeping in mind the present form of VFD it seems quite impossible that it will undergo any change in future. But as the technology is making progress rapidly and new researches are being put forwarded by people anything can be predicted.[40] Emerging technologies like FPGA's, advancement in DSP, genetic algorithm, Fuzzy logic, innovative PWM techniques and revolution in power electronics field can lead us to experience any miraculous device. Furthermore VFD's can also be miniaturized using NANO technology. This miniature form of VFD would be very helpful in small device and thus energy saving would be possible in small levels as well.

IX. PROPOSED IMPROVEMENT

By designing this device we can now bring a lot of improvements in this drive. Like we can introduce a numeric key pad through which desired value of frequency can be given as input. That's how load will be driven at frequency of our own choice. Furthermore we can remotely monitor the speed and frequency of drive using a GSM module. And start and halt operation of drive can also be controlled from distant place.

X. CONCLUSION

We have seen from the above discussion and results that variable frequency drive is the best solution for fixing inherent motor issues and energy saving can be best tackled by this drive. Other techniques like Soft starter does not prove as much efficient as does variable frequency drive because there are many benefits of variable frequency drive like it provides a control over motor starting and stopping, Likewise it gives versatility to motor action. Over load protection, power reduction when not needed and dynamic torque control are other key features of variable frequency drives. We can suggest that in a country like Pakistan this device is of great use because we strongly need energy consumption minimization and for that matter VFD should be used with HVAC systems in industries and house hold appliances. The only drawback associated with this device is cost. It's quite costly and maintenance is also required. But still the importance of variable frequency drive cannot be denied.

XI. ACKNOWLEDGEMENT

First of all we are Thank full to Almighty Allah who gave us courage to write this paper. Then we are grateful to our respected teacher Sheikh Zahoor Sarwar who guided us and encouraged us for writing a research paper on our Final Year Project. Without his help and guidance we could not fulfill this task. Research paper writing is quite a difficult task and without proper guidance and help this cannot be written at under graduate level so in this regard we acknowledge the efforts of our respected instructor who showed us new aspects of research and made a great effort to bring us at the stage where we find ourselves worthy of writing any kind of technical research work with proper formatting and styles.

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