DELHI TECHNOLOGICAL UNIVERSITY

MTE PROJECT

SPEED CONTROL OF 3 PHASE INDUCTION MOTOR USING VARIABLE FREQUENCY DRIVER

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DECLARATION

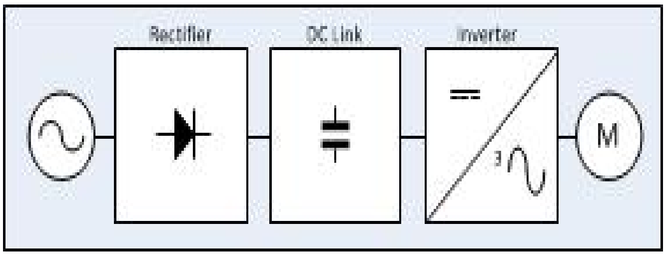
We, ANUJ KUMAR JHA[2K20/EE/49] and AMAN KUMAR [2K20/EE/30] students of B.Tech. hereby declare that the project dissertation titled
“**SPEED CONTROL OF 3 PHASE INDUCTION MOTOR USING VARIABLE FREQUENCY DRIVER**” which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in complete fulfillment of the requirement for the middle term evaluation of Bachelor of Technology is correct and has taken references from different sources with proper citation.

ACKNOWLEDGEMENT

In performing our project, we had to take the help and guideline of some respected persons, who deserve our greatest gratitude. The completion of this assignment gives us much pleasure. We would like to show our gratitude to **Prof. S.T. NAGARAJAN**, our mentor for the project. Giving us good guidance for reporting throughout numerous consultations. We would also like to extend our deepest gratitude to all those who have directly and indirectly guided us in completing this assignment. In addition, we would like to thank the Department of Electrical Engineering, Delhi Technological University, Delhi for giving us the opportunity to work on this topic for the project.

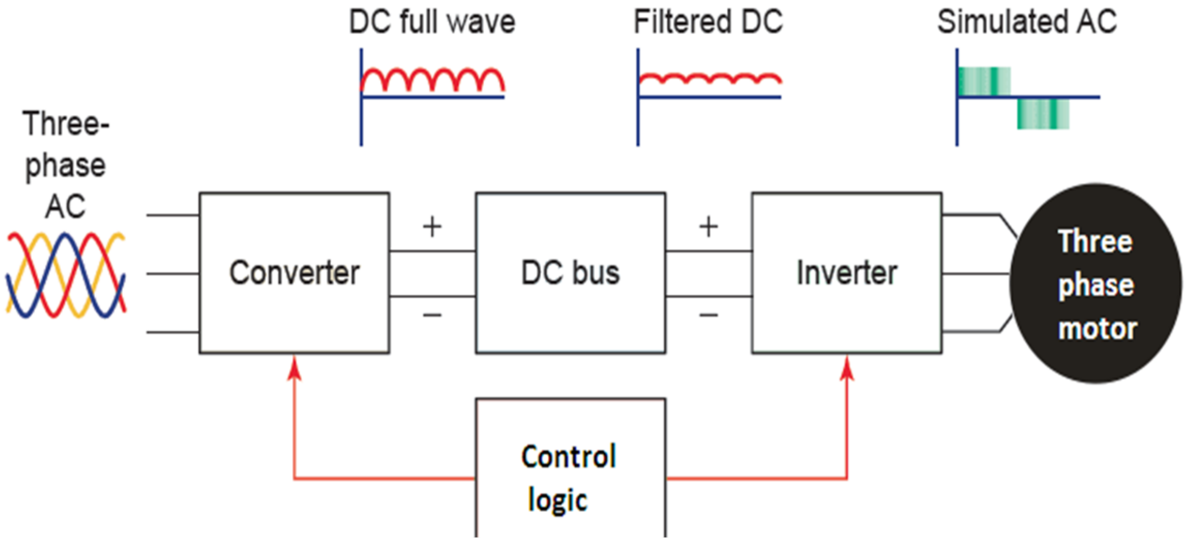
WHAT IS A VARIABLE FREQUENCY DRIVER

VFD (Variable Frequency Drive) is a power electronics-based device that converts a basic fixed frequency, fixed voltage sine wave power (line power) to a variable frequency, variable output voltage used to control the speed of the induction motor.



This is a method of controlling the speed of an induction motor by varying the input AC line frequency to the motor. These are further classified into -

1. Variable frequency method keeping voltage as constant
2. Constant V/F method (V/F control method)

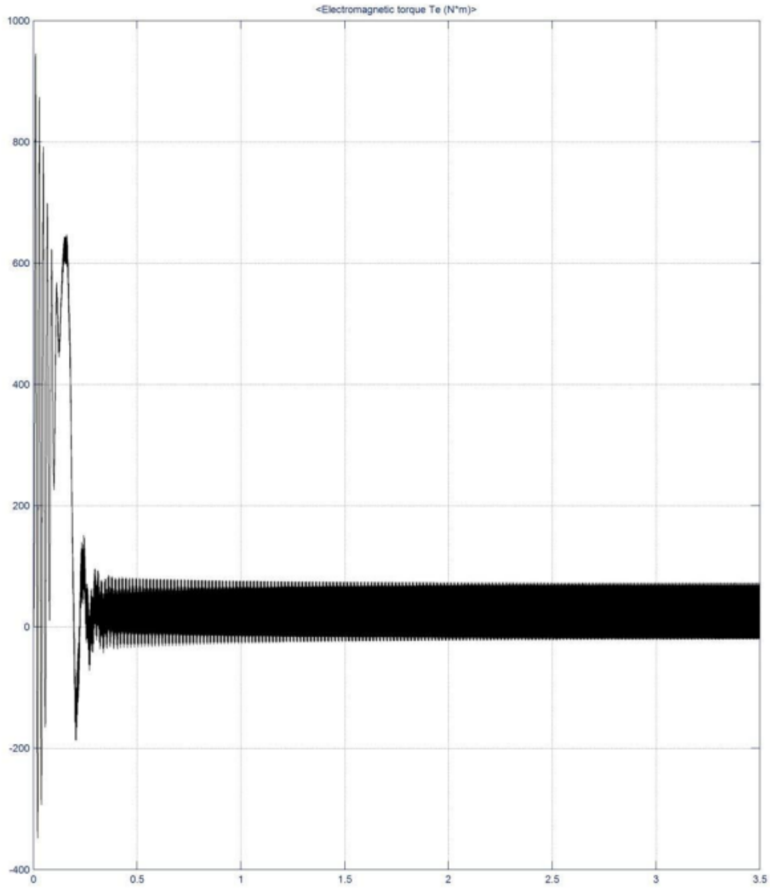


VARIABLE FREQUENCY AT CONSTANT VOLTAGE

Synchronous speed (Ns) is given by (120*f)/P,
where f is the input AC line frequency to the motor and P is the number of poles in the motor.
This relation implies that changing f allows us to change Ns which interim allows us to change the rotor speed N. The difference between Ns 6 and N 6, Ns 1 and N 1 is very small; this implies that the slip is always low, giving a higher efficiency over line voltage control. Line frequency control also gives a high-speed range. The disadvantage of this method is that the available torque keeps decreasing as the frequency increases.

The RMS value of induced voltage in AC machines is given by - ERMS = 4.44 f (N) ϕ

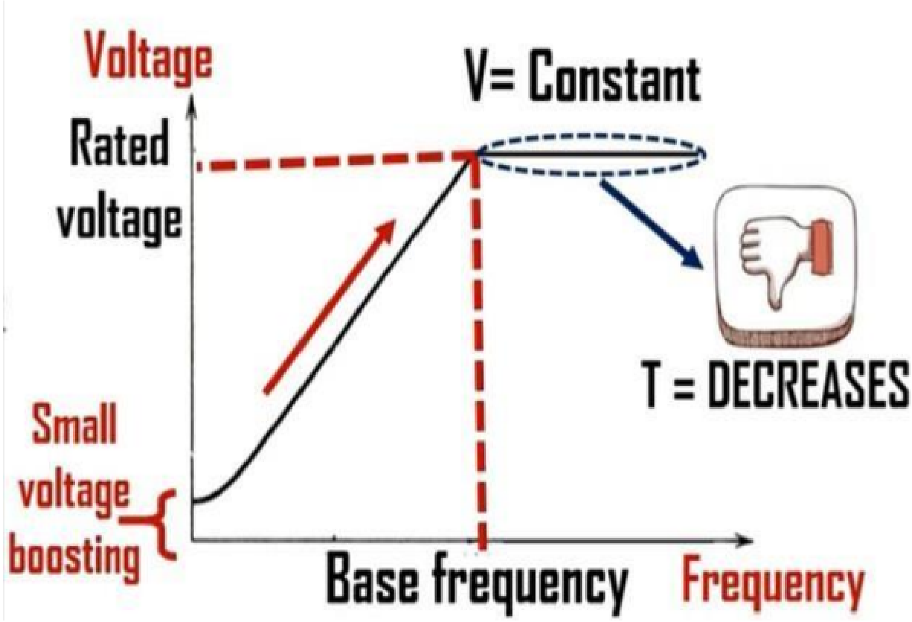
And as Torque (T) is produced by the interaction of fluxes
T a ϕ a V / f
Assuming voltage drop across the stator reactance and resistance are small ERMS = V, where V is the line voltage. As the frequency keeps increasing the available torque decreases. To overcome the problem of low torque V/f ratio has to be constant. This is more practical than the variable frequency constant voltage method and is used in industries.
In the V/F method, voltage is varied according to the frequency such that we always have a constant V/F ratio and constant torque - T a ϕ a V /f (Constant)
The change in frequency is completely dependent upon the desired rotor speed (N*) and will change according to N* and when the frequency falls or rises accordingly the voltage will also rise and fall hence a linear relation is expected for the voltage frequency curve of the induction machine for V/F control.



TORQUE CHARACTERISTICS OF UNCONTROLLED INDUCTION MOTOR

But in practice, a small voltage boost is required at low frequencies. At high frequencies voltage drop at stator reactance and resistance is negligible but at low frequencies, the voltage drop across the stator resistance R1 is comparable to the V1. To compensate for this, a boost is required to ensure V1 = E1.

To avoid an insulation breakdown the voltage is never increased over the rated voltage of the machine hence in the region of frequency greater than rotor frequency, the voltage remains constant as the frequency keeps increasing. This again leads to a problem of lower available torque in this region.



The V/F method ensures constant maximum torque and a high-speed range. It also grants a higher efficiency due to lower slip. Beyond the rated voltage the flux and the torque reduce due to increasing frequency and constant voltage. Hence this region is called the Flux weakening region. This region has a lower available torque, and lower efficiency due to comparatively high slip and hence needs to be avoided.

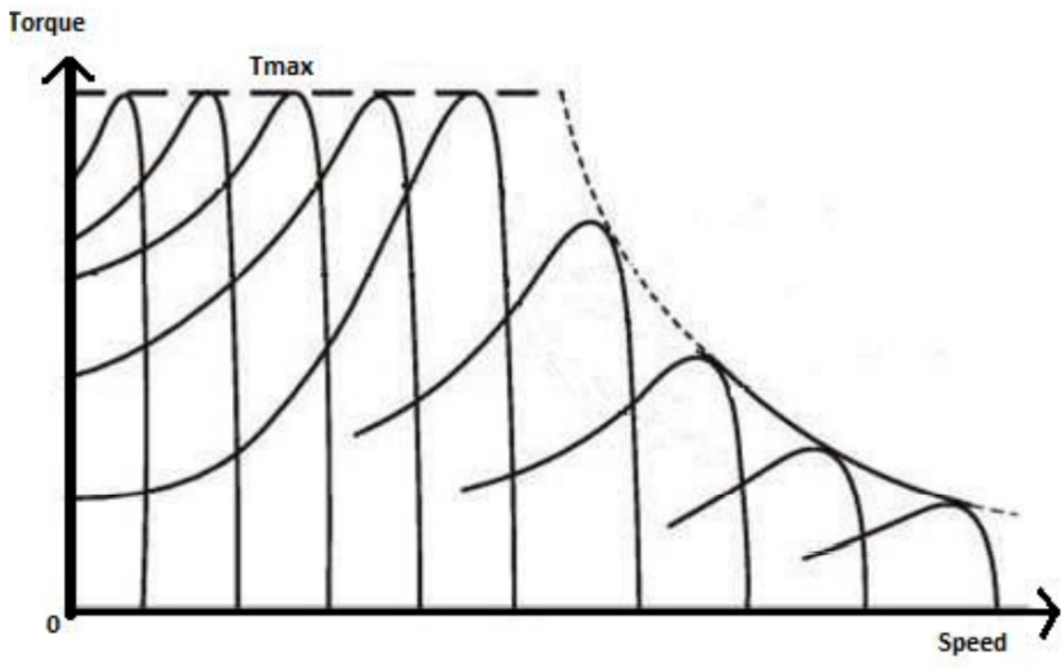
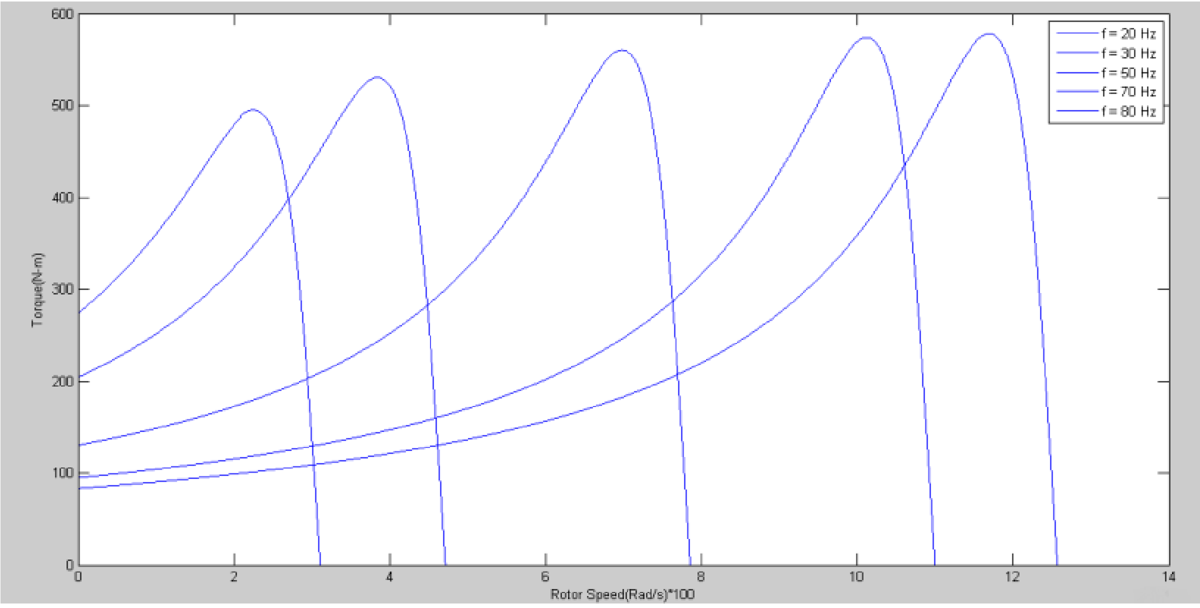


Figure 9: Torque-Speed characteristics for V/f Controlled Induction Motor

Open-loop V/f Control

In this method, the stator voltage was varied, and the supply frequency was simultaneously varied such that the V/f ratio remained constant. This kept the flux constant and hence the maximum torque while varying the speed. A MATLAB code was developed which asked the user to input different frequencies and then varied the voltage to keep the V/f ratio constant. The different synchronous speeds corresponding to the different frequencies were calculated and the torque characteristics were plotted as the rotor speed was incremented from zero to the synchronous speed in each case. The resulting Torque vs

Speed graph was plotted. The following machine details were used to execute the code- RMS Value of line-to-line supply voltage= 415 V No. of poles= 4 Stator Resistance= 0.075Ω Rotor Resistance= 0.1Ω Frequency= 50 Hz Stator Reactance @ 50 Hz= 0.45Ω Rotor Reactance @ 50 Hz= 0.45Ω The MATLAB code was executed and the following plot was obtained



As can be seen, the Maximum Torque of the Induction Motor remains constant, across the speed range, while the frequency is varied The AC supply from the mains is supplied to a rectifier which converts into DC and is fed to the PWM Inverter. The PWM Inverter varies the frequency of the supply and the voltage is varied accordingly to keep the ratio constant. The electromagnetic torque is directly proportional to the flux produced by the stator which is in turn directly proportional to the ratio of the terminal voltage and the supply frequency. Hence by varying the magnitudes of V and f while keeping the V/f ratio constant, the flux and hence the torque can be kept constant throughout the speed range.

Closed-loop V/f Control

Closed-loop control is required in places where precise control is of importance and even if there are external disturbances in the system it corrects itself. The overall system will be the same as that of the open-loop system but an extra feedback path will be added. The error will be generated between the desired speed and the current speed and this will be fed into a PI (Proportional Integral) controller. Increasing and decreasing the torque will give control of the rotor speed of the induction motor.

In induction, machine torque is proportional to the slip frequency. Hence the PI controller will control the slip frequency to control the speed. Additionally, a regulation is applied to the slip frequency as it is error-dependent. This implies that at standstill the error will be high given high slip frequency. A high slip frequency results in a high stator frequency which will push the induction machine into the insulation breakdown region. To avoid crossing this breakdown frequency it is necessary to add this regulation.

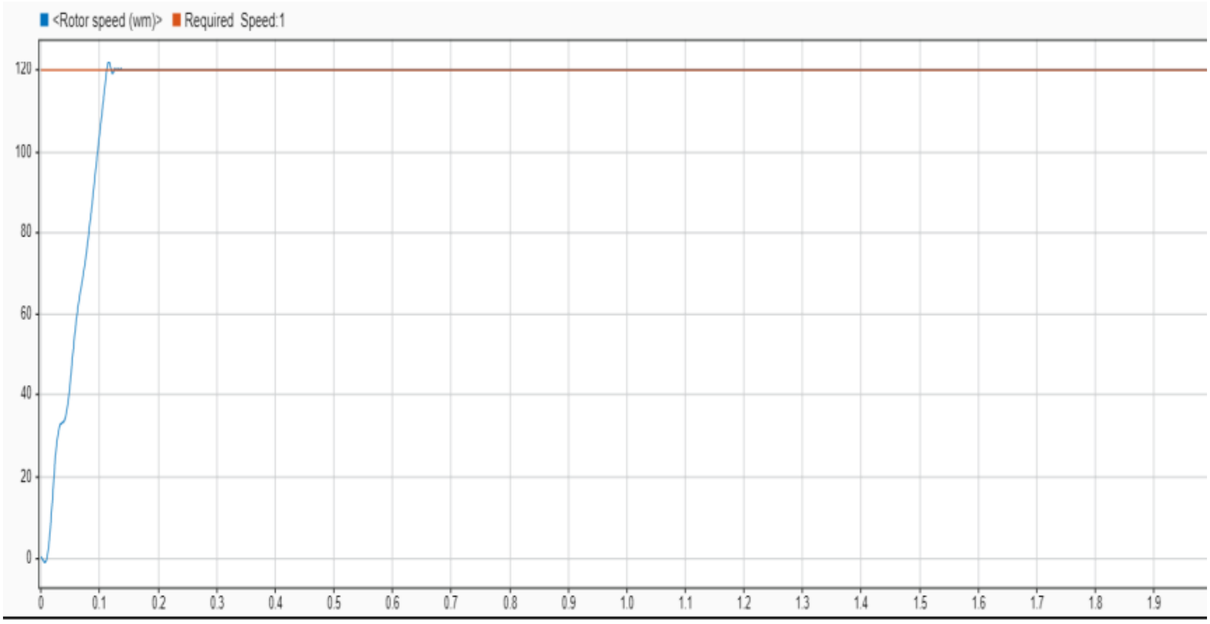


Fig. Rotor speed and desired speed with respect to time

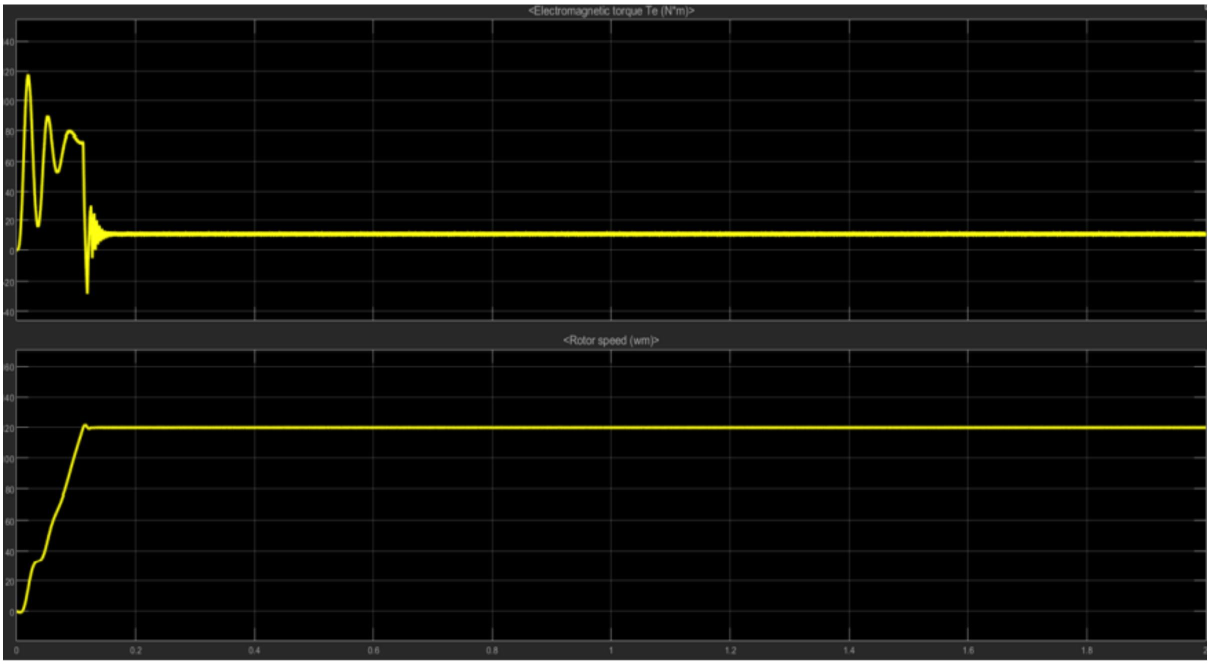
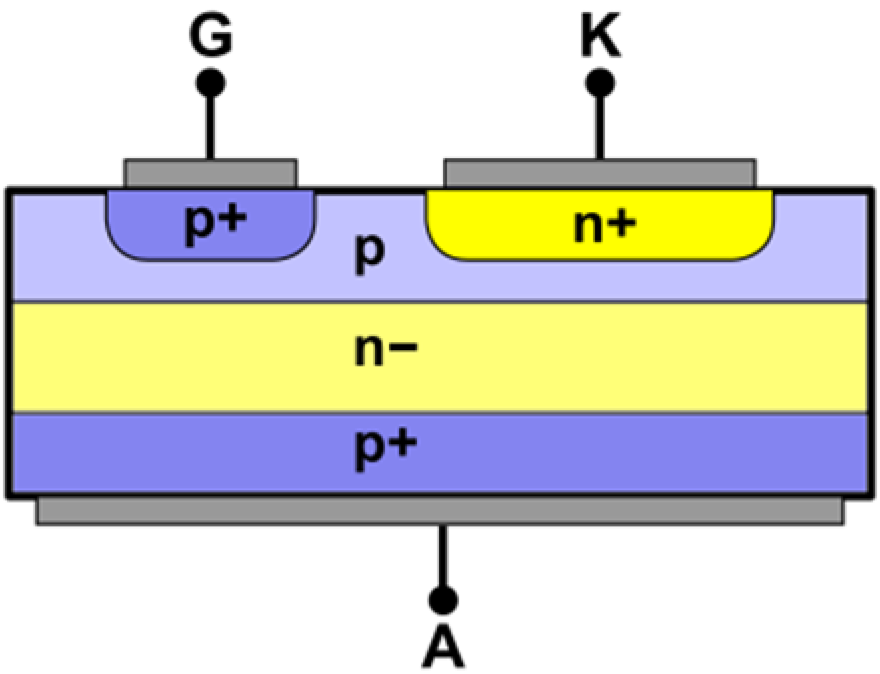


Fig. Torque and rotor speed with respect to time

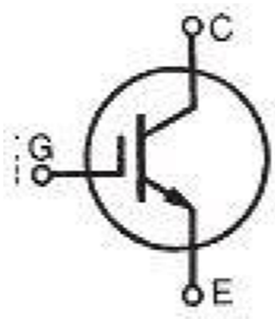
STAGES OF VFD TO CONTROL 3 PHASE INDUCTION MOTOR

The Inverter Stage

Power electronic switches such as IGBT, SCR, GTO, etc, switch the DC power from the rectifier on and off to produce a current or voltage waveform at the required new frequency. Presently most of the voltage source inverters (VSI) use pulse width modulation (PWM) because the current and voltage waveform at the output in this scheme is approximately a sine wave. Power Electronic switches such as IGBT; GTO etc. switch DC voltage at high speed, producing a series of short-width pulses of constant amplitude. The output voltage is varied by varying the gain of the inverter. The output frequency is adjusted by changing the number of pulses per half cycle or by varying the period for each time cycle. Resulting to the production of a sine wave.



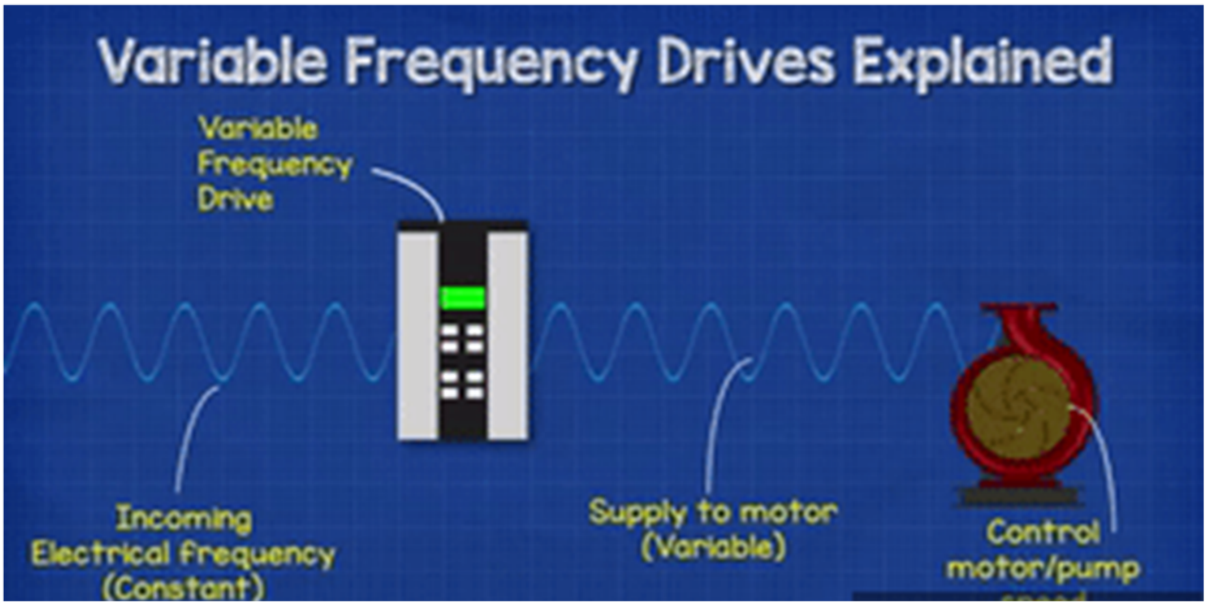
GTO SWITCH



IGBT SWITCH

Control System

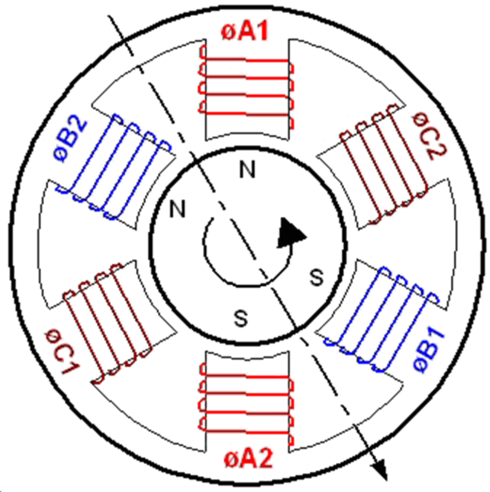
Its function is to control output voltage i.e. voltage vector of the inverter being fed to the motor and maintain a constant ratio of voltage to frequency (V/Hz). It consists of an electronic circuit which receives feedback information from the driven motor and adjusts the output voltage or frequency to the desired values. The Control system may be based on SPWM (Sine Wave PWM), SVPWM (Space Vector modulated PWM), or some soft computing-based algorithm.



<u>Induction Motor Characteristic under Variable Frequency Drive</u>

¡In an induction motor induced in the stator, E is proportional to the product of the slip frequency and the air gap flux. The terminal voltage can be considered proportional to the product of the slip frequency and flux if stator drop is neglected. Any reduction in the supply frequency without a change in the terminal voltage causes an increase in the air gap flux which will cause magnetic saturation of the motor. Also, the torque capability of the motor is decreased. Hence while controlling a motor with the help of VFD or Variable Frequency Drive we always keep the V/f ratio constant. This keeps the magnetizing flux constant and keeps torque production stable, regardless of frequency.

Now define variable ‘K’ as $\frac{f}{frated}$

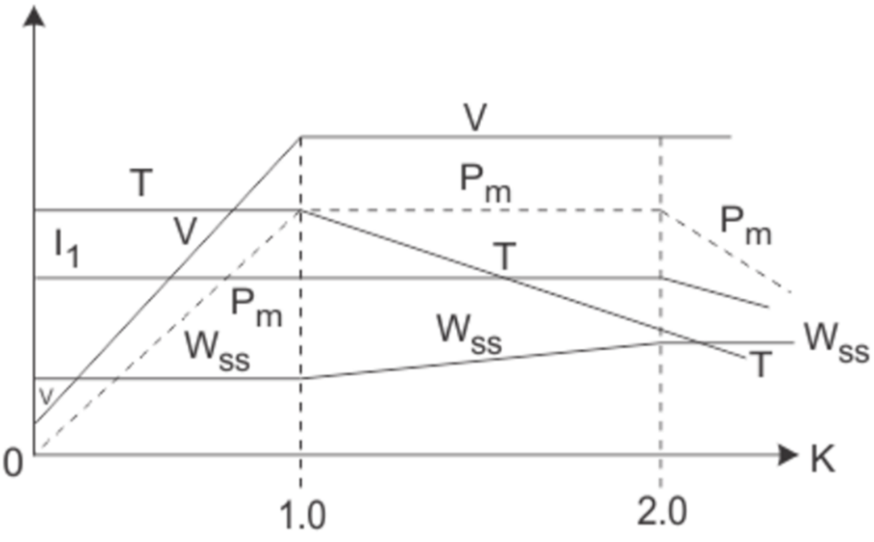


3 phase induction motor

For operation below K < 1 i.e. below rated frequency we have constant flux operation. For this, we maintain a constant magnetization current I_m for all operating points.

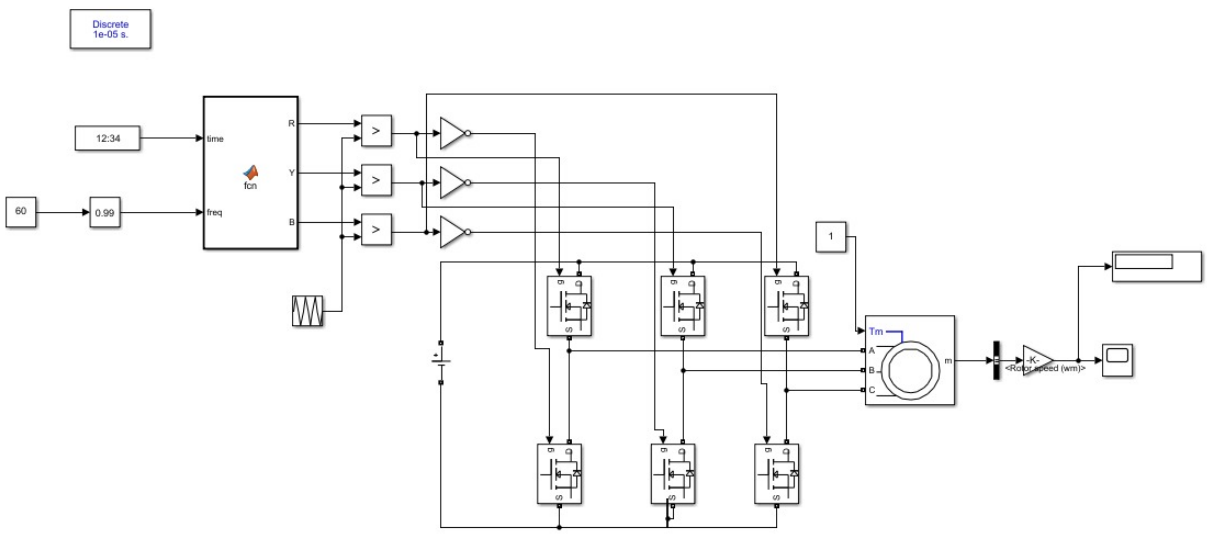
For K > 1 i.e. above rated frequency we maintain terminal voltage V rated constant. This field is weakened in the inverse ratio of per unit frequency ‘K’.

For values of K = 1, we have constant torque operation and above that, we have constant power application.

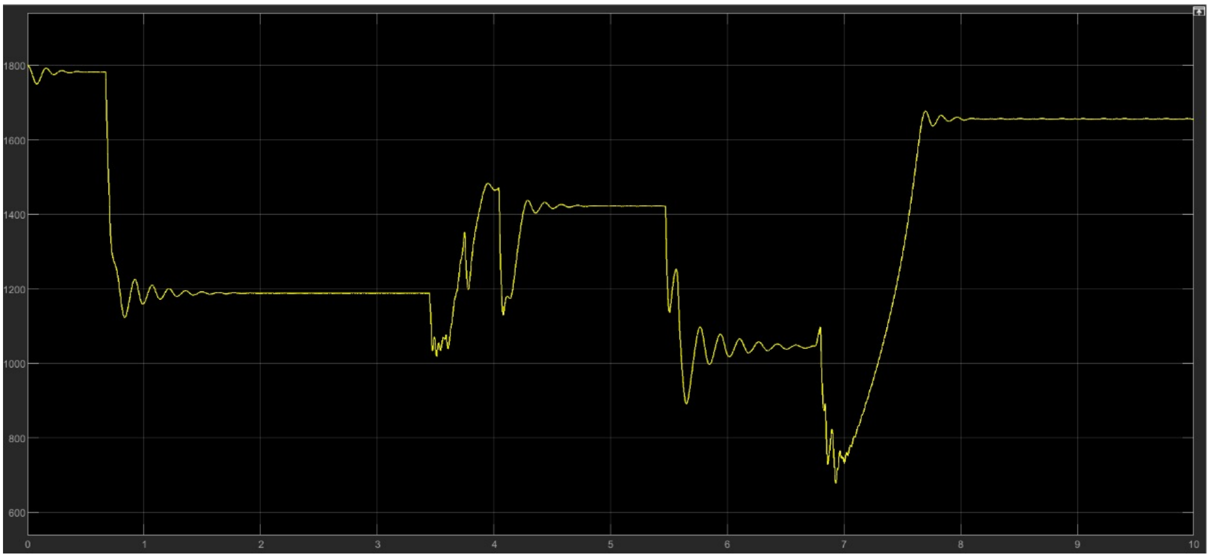


V(Terminal Voltage), T(Torque), P_m(Power), I_1(Stator Current) and W_{ss} vs. K plot

MATLAB CIRCUIT SIMULATION



CONTROLLED 3 PHASE INDUCTION MOTOR



APPLICATIONS

It is used in transaction system. In India it is being used in Delhi Metro Rail Corporation.

They are also used in modern lifts, escalators and pumping systems.

Nowadays they are being also used in energy efficient refrigerators, AC's and outside air economizers.

LIMITATIONS

The voltage cannot go beyond a limit in order to maintain the V/Hz ratio as at a certain voltage, insulation breakdown will take in the motor as high voltage leads to partial discharge (Corona discharge) in the air gap . This removes the insulation which can cause an immediate motor failure.

As the voltage cannot go beyond a certain value, the V/Hz ratio will eventually reduce and will no longer be constant. This causes a reduction in the available torque , flux and also causes high slips and poor efficiencies. For this reason this zone is known as the field weakening region. Hence we do not obtain a constant torque for all frequencies of operation.

Line voltage variation , incorrect V/HZ ratio , stator drop variation by line current and M/C parameter variation may cause weaker flux. If the flux is weak, the developed torque will decrease and the machine's acceleration/deceleration capability will reduce.

CONCLUSION

An Induction Motor was run with the help of a PWM Inverter without implementing any kind of speed control mechanisms and the various characteristic curves were obtained. It was observed that there were a lot of transient currents in the stator and rotor at the time of starting and they took some time to settle down to their steady-state values. The lower the stator resistance, the quicker the transients died down and hence, the stator resistance should be kept very low. In an uncontrolled Induction Motor, torque was observed to rise to a maximum value and then settle at the base value, while rotor speed was observed to rise to its rated value and remain constant there. Open-loop V/f Control was implemented using MATLAB and it was observed that by varying the supply frequency and terminal voltage such that the V/f ratio remains the same, the flux produced by the stator remained constant. As a result, the maximum torque of the motor remained constant across the speed range. Closed-loop V/f Control used a Proportional Controller to process the error between the actual rotor speed and reference speed and used this to vary the supply frequency. The Voltage Source Inverter varied the magnitude of the Terminal Voltage accordingly so that the V/f ratio remained the same. It was observed that again the maximum torque remained constant across the speed range. Hence, the motor was fully utilized and successful speed control was achieved

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