# PROJECT REPORT

# Use 3 phase induction motor model from Simpower system toolbox of Simscape of MATLAB to demonstrate the efficacy of V/f control methods under constant torque region through simulation results.

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# 1. INTRODUCTION

- Rapid advancements in Induction motor research allowed it to surpass DC Motors in terms of industrial and transportation applications. In 1985, with the introduction of Power Electronics-based drives, particularly IGBT-based PWM Inverters for efficient frequency-changing, the latter made a comeback. Some of the most recent advancements in induction motor drives are as follows:
  i. More accurate analytical models for design and research.
  ii. Magnetic and insulating materials, as well as cooling systems, that are more effective.
  iii. Design optimization tools are available.
  iv. IGBT-based PWM Inverters with low losses and high power density for efficient frequency change.
  v. Improved production and testing techniques.
  vi. Applications require a lot of speed and power.

- The speed control of an induction motor may be done in a variety of ways. These are:
  i. Pole Changing
  ii. Variable Supply Frequency Control
  iii. Variable Supply Voltage Control
  iv. Variable Rotor Resistance Control
  v. V/f Control
  vi. Slip Recovery
  vii. Vector Control

- Because of its simplicity, V/f Control is the most popular of the systems discussed above and has found broad usage in both industrial and home applications. However, as compared to vector control, it has a weaker dynamic performance. As a result, V/f Control is rarely employed in areas where accuracy is essential.

# 2. CONSTRUCTION AND WORKING OF INDUCTION MOTOR

- There are two parts to an induction motor: a stator and a rotor. Three phases and a predetermined number of poles are coiled into the stator. The three-phase windings are carried by stampings with uniformly spaced slots.
- The rotor's speed is inversely proportional to the number of poles. A moving magnetic field is created when the stator is fueled, and currents are made in the rotor winding by electromagnetic induction.

- Wound-rotor induction motors- The ends of the rotor are attached to rings on which the three brushes make sliding contact with wound-rotor induction motors. Brushes glide over the rings as the rotor rotates, providing a connection to the external circuit.

- Squirrel-cage induction motors- The stator is encased in a "cage" of copper or aluminium bars in squirrel-cage induction motors. The length of these bars is then reduced by brazing a ring at the end that connects all of them. This type is the Induction Motor's more durable and sturdy counterpart.

- When a three-phase supply is used to power the stator winding, a revolving magnetic field is created that revolves around the stator at synchronous speed Ns. This flux causes an electromotive force in the rotor winding by cutting the stationary rotor. A current of 8 runs through the rotor windings because they are short-circuited.

- When these conductors are put in the magnetic field of the stator, Lenz's law imposes a mechanical force on them. According to Lenz's law, rotor currents will endeavor to counter the cause of their generation. As a result, a torque is generated, attempting to lessen the relative speed of the rotor and the magnetic field. As a result, the rotor will revolve in synch with the flux. The rotor is therefore driven by the difference in speed between the rotor and the magnetic field. As a result, the rotor speed Nr is always lower than the synchronous speed Ns. As a result, Asynchronous Motors are also known as Induction Motors.

## 3. TORQUE-SPEED ANALYSIS

The equivalent circuit of an induction motor is represented in the diagram below:

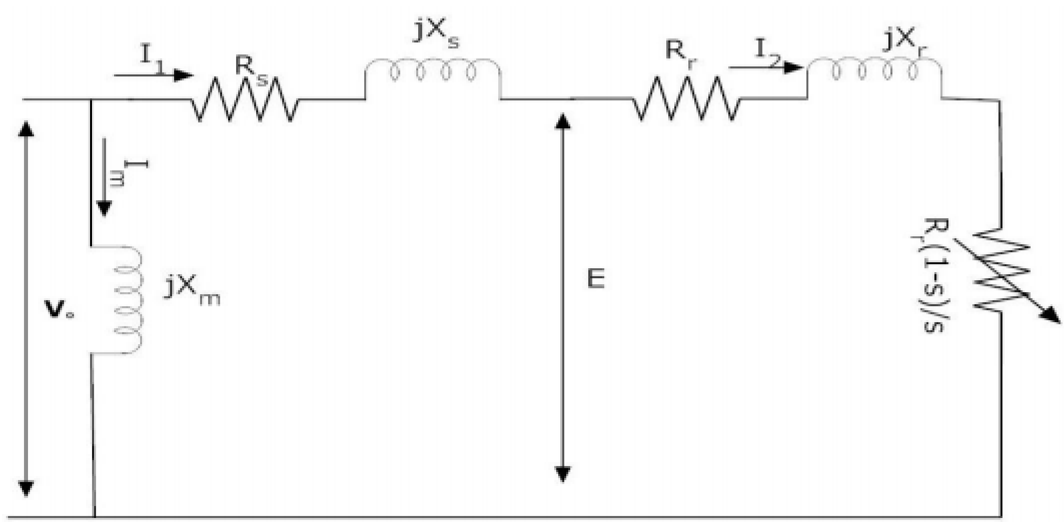



**Figure 1: Equivalent Circuit of an Induction Motor**

Where Xm= Magnetizing Reactance
Xs= Stator Reactance
Xr= Rotor Reactance
Rs= Stator Resistance

Rr = Rotor Resistance
s= slip

$$s = \frac{Ns - Nr}{Ns}$$

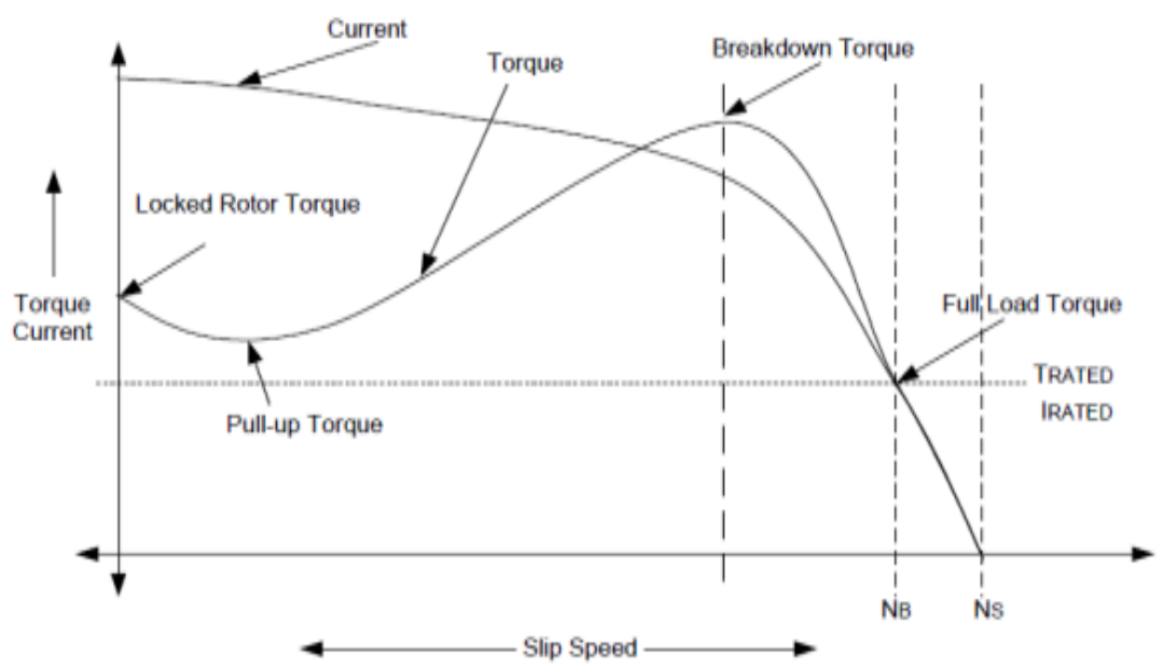
Where, Ns= Synchronous speed
Nr= Rotor speed

Rotor Current and Torque is given below :

$$I2 = \frac{Vo}{\left(Rs + \frac{Rr}{s}\right) + j\,(Xs + Xr)}$$

$$T = \pm \frac{\left(\frac{3Vo^{2}Rr}{s}\right)}{ws\left[\left(Rs + \frac{Rr}{s}\right)^{2} + (Xs + Xr)^{2}\right]}$$

The torque and speed characteristics for an Induction Motor is shown below :




- The ideal torque-speed characteristics of an induction motor are shown in Figure. Speed and slip are shown on the X-axis, while torque and current are shown on the Y-axis. The stator and rotor flux cause the motor to draw a considerable amount of current when it is started, up to seven times the rated current. In addition, the beginning torque is approximately 1.5 times the motor's rated value.

- The current decreases gradually as the speed rises, then lowers dramatically when the speed approaches 80 percent of the specified speed. The rated current flows in the motor at the base speed, and the rated torque is supplied.

- If the load is increased above the rated torque amount at base speed, the speed lowers and the slip increases. The load increases up to 2.5 times the rated torque at 80 percent of the Synchronous speed, which is known as the breakdown torque. When the load is increased any further, the torque drops fast and the motor stalls.

## 4. PWM INVERTER

- For the transmission of information, many types of modulation are employed. AM, or Amplitude Modulation, is the process of changing the amplitude of a high frequency signal in response to a low frequency input. FM, or Frequency Modulation, is when the frequency of a transmission is changed in response to the modulating signal. In radio broadcasts, these are the two most prevalent systems. Since the introduction of pulse transmission, the message signal has begun to alter the amplitude, frequency, and breadth of pulses. PWM, or Pulse-Width Modulation, is the result of the latter.

- Inverters employ **Pulse Width Modulation (PWM)** technology to maintain a constant output voltage of 230 or 110 V AC regardless of the load. Inverters based on PWM technology are more advanced than ordinary inverters. These inverters are appropriate for all sorts of loads due to the usage of MOSFETs in the output stage and PWM technology. The PWM Inverters feature extra circuits for protection and voltage control in addition to the pulse width modulation.

- The efficiency of an inverter is determined by the quality of its output waveform (230 / 110 volt AC). To compute the Total Harmonic Distortion, Fourier analysis data is used to indicate the quality of the inverter output waveform (THD). The square root of the sum of squares of the harmonic voltage divided by the fundamental voltage equals THD.

$$THD = \sqrt{V_2^2 + V_3^2 + V_4^2 \ldots\ldots\ldots\ldots V_n^2} \,/\, V_1$$

- There are three types of inverters based on the output waveforms.
  - i. Sine wave inverters
  - ii. Modified Sine wave inverters
  - iii. Quasi sine wave, and Square wave inverters.

## ADVANTAGES OF PWM INVERTER

- The output voltage of a typical inverter without PWM technology fluctuates in response to the load's power usage.
- By adjusting the width of the switching frequency in the oscillator portion, PWM technology adjusts the output voltage according to the load value. As a result, the Inverter's AC voltage varies based on the width of the switching pulse.
- The PWM Inverter contains a PWM controller IC that takes a portion of the output via a feedback loop to create this effect. Based on the feedback voltage, the PWM controller in the inverter adjusts the pulse width of the switching pulse. This will balance out any variations in output voltage, and the inverter will provide a constant output voltage regardless of load characteristics.

## WORKING OF PWM INVERTER

- Many power circuit topologies and voltage control approaches are utilised to create an inverter. The output waveform is the most significant part of inverter technology. Capacitors and inductors are used to filter the waveform (Square wave, quasi sine wave, or Sine wave).
- To minimize harmonic components, low pass filters are utilised. If the inverter has a fixed output frequency, a resonant filter can be utilised. The filter must be adjusted to a level above the maximum fundamental frequency if the inverter's output frequency is changeable. When the switch is turned off, feedback rectifiers are employed to bleed the peak inductive load current.
- A square wave has odd harmonics such as the third, fifth, and seventh only if it is anti-symmetrical> about the 180 degree point, according to Fourier analysis. The extra harmonics will be eliminated if the waveform comprises steps of a specified width and height. The harmonics that are divisible by three can be avoided by introducing a Zero voltage step between the positive and negative halves of the square wave. For each positive and negative step, the pulse width should be 1/3 of the period, and for each Zero voltage step, it should be 1/6 of the period. This transitions to the fifth, seventh, eleventh, and thirteenth harmonics, among others.
- Pulse Width Modulation (PWM) is a technique for altering the properties of a square wave. Before being given to the load, the switching pulses modulate and regulate. Fixed pulse width can be utilised when the inverter does not require voltage regulation.

## SINGLE-PHASE PWM INVERTER

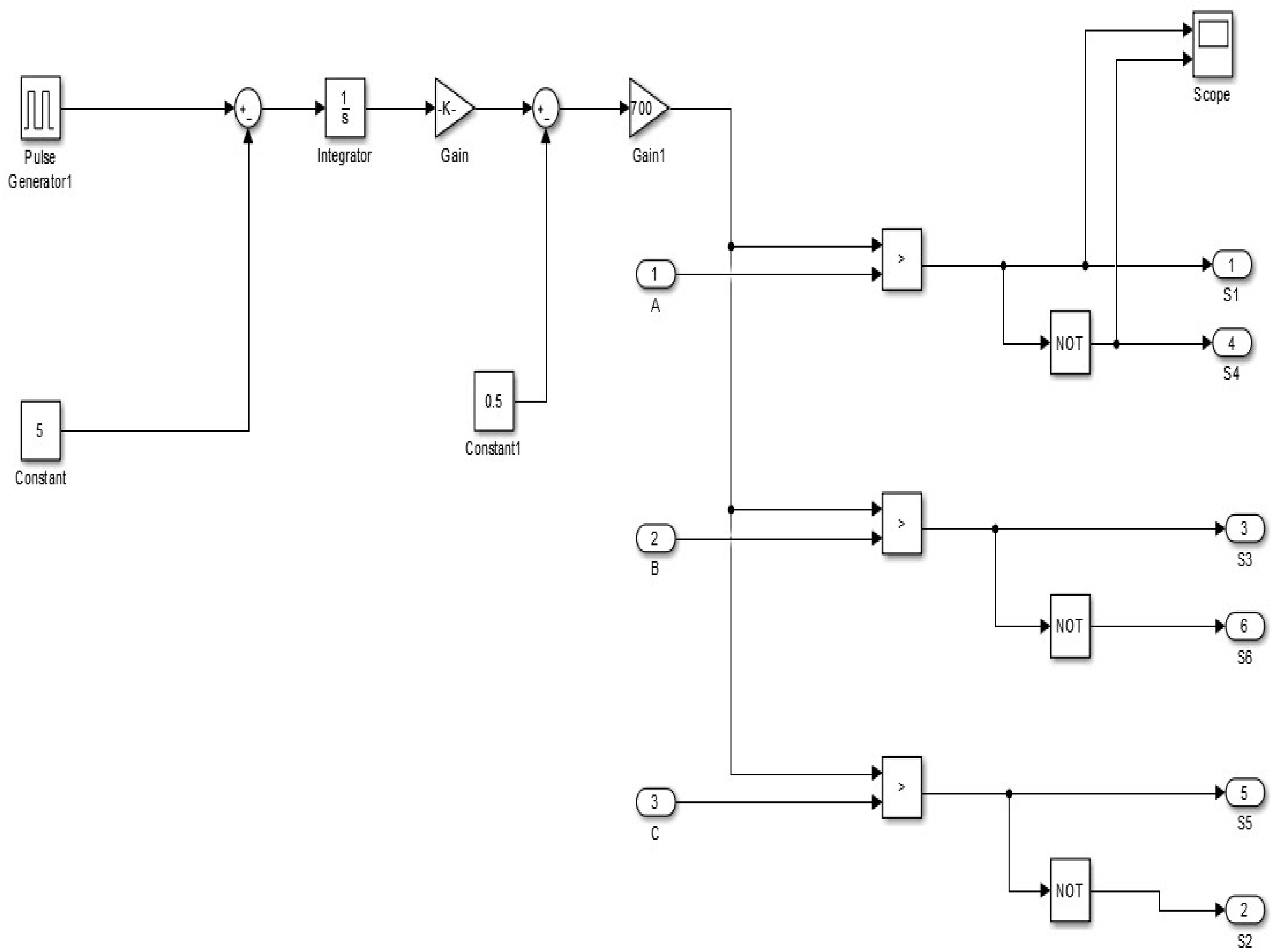
- An inverter is a circuit that changes DC electricity into AC power at a certain output voltage and frequency. Controlled turn-on and turn-off devices, such as IGBTs, are used to accomplish this conversion. An inverter's output voltage should ideally be precisely sinusoidal.
- However, the outputs are virtually invariably non-sinusoidal and have a lot of harmonics. Voltages that are square-wave or quasi-square-wave are allowed.

- A battery, a fuel cell, a solar cell, or any other DC source can provide DC power to the inverter. Most industrial applications employ a rectifier, which converts AC power from the mains to DC and feeds it to the inverter.

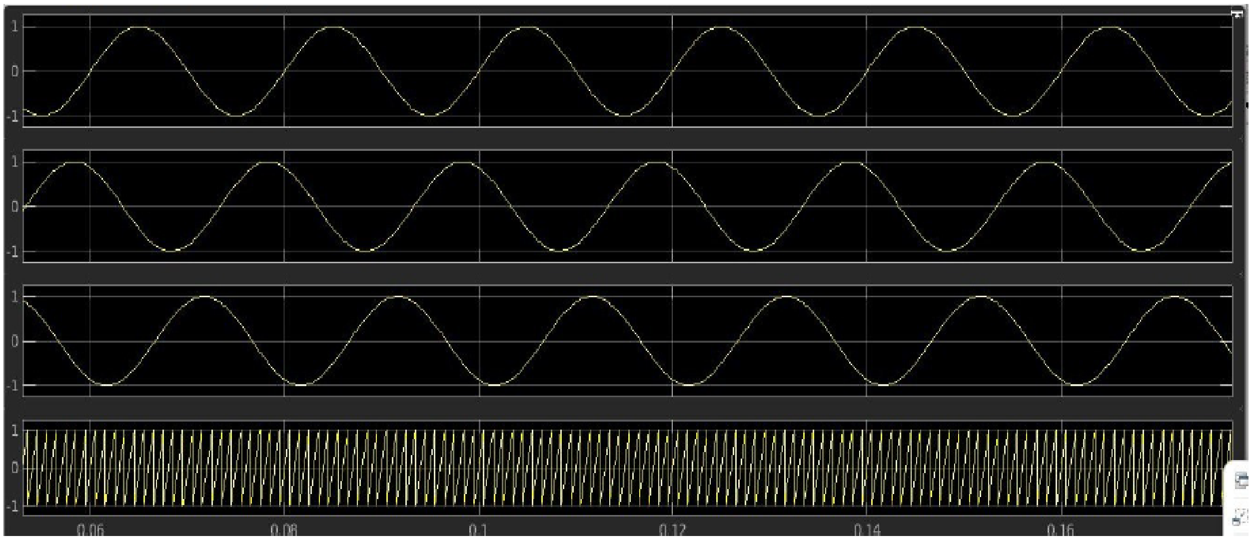
**THREE-PHASE PWM INVERTER**

- The power circuit in this example consisted of three arms, each with two IGBT/Diodes. The circuit was run in 120-degree mode, which meant that IGBTs 1, 2, 3, 4, 5, and 6 were fired 60 degrees apart in that sequence. This resulted in a three-phase output with a 120-degree phase variation between the three phases.
- The control circuit was an expansion of the one utilized in the Single-Phase Inverter type earlier.

**SIMULINK MODEL OF SPWM ( SINE PULSE WIDTH MODULATION )**

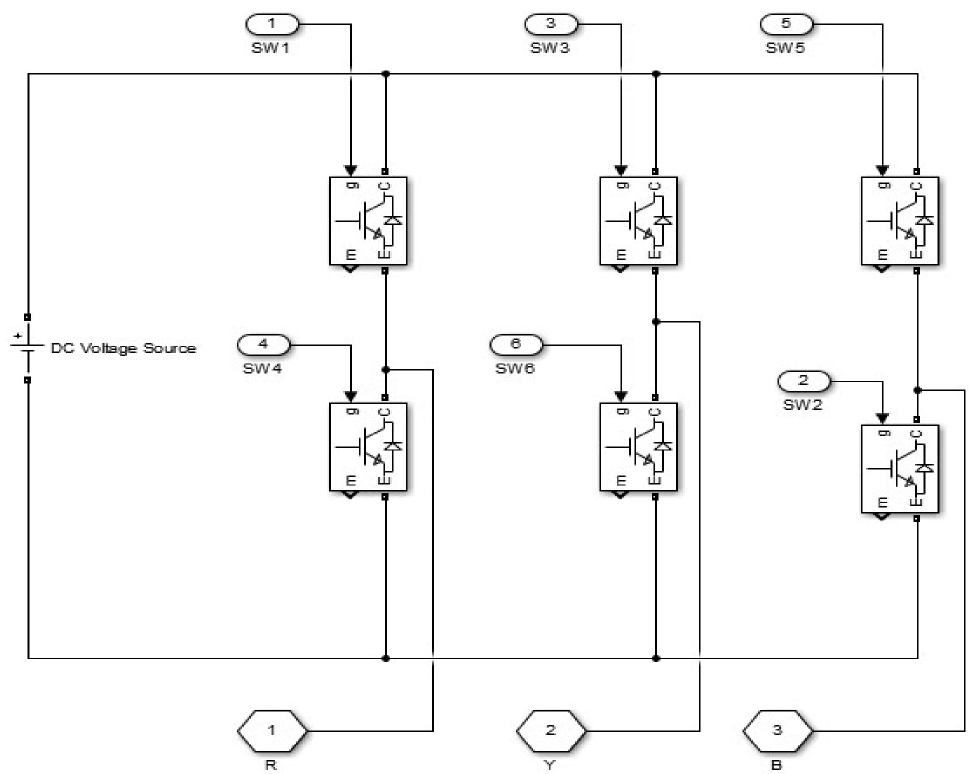


**OUTPUT SIGNAL :**

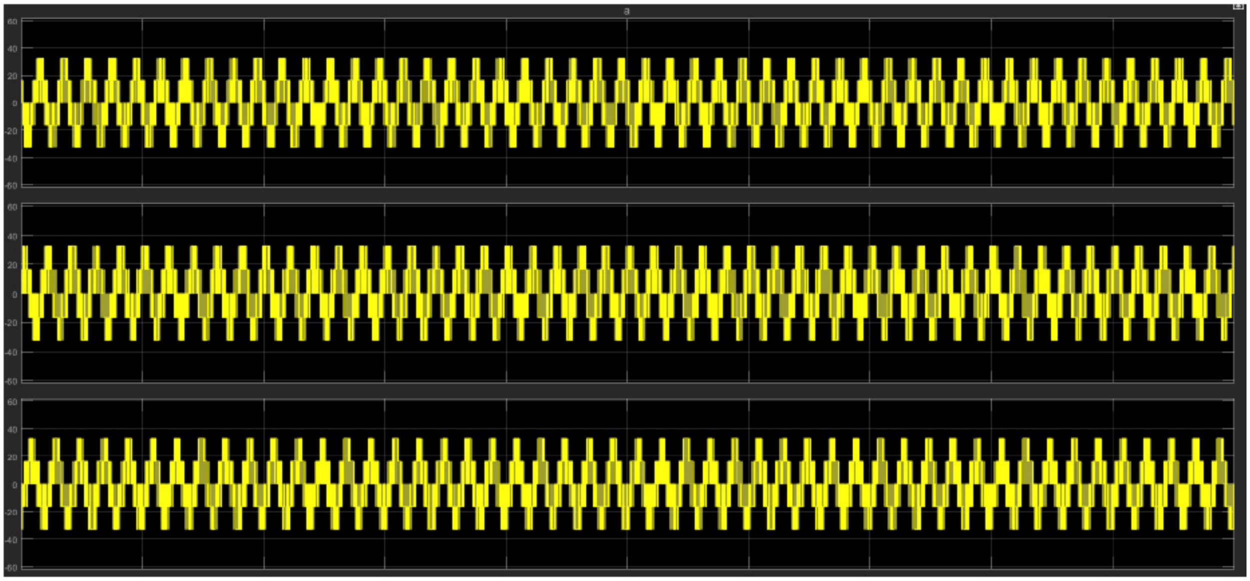



# 5. DC TO AC THREE-PHASE INVERTER

## SIMULINK MODEL



**OUTPUT SIGNAL**



## 6. INDUCTION MOTOR DRIVE

- Three-phase induction motors are most commonly used in adjustable-speed drives than three-phase synchronous motors. Three-phase induction motors are of two types, squirrel cage induction motors (SCIMs) and slip-ring (or wound-rotor) induction motors (SRIMs). Stator windings of both types carry three-phase windings. The rotor of SCIM is made of copper and aluminum bars short-circuited by two end rings. The rotor of SRIM carries a three-phase winding connected to three slip rings on the rotor shaft.

- When a three-phase supply is connected to a three-phase stator winding, a rotating magnetic field is produced.

- The speed of this rotating field is known as synchronous speed and it is given by

$$\mathbf{N = 120f1/P\ rpm}$$
$$\boldsymbol{\omega = 4\pi f1/P\ rad/sec}$$

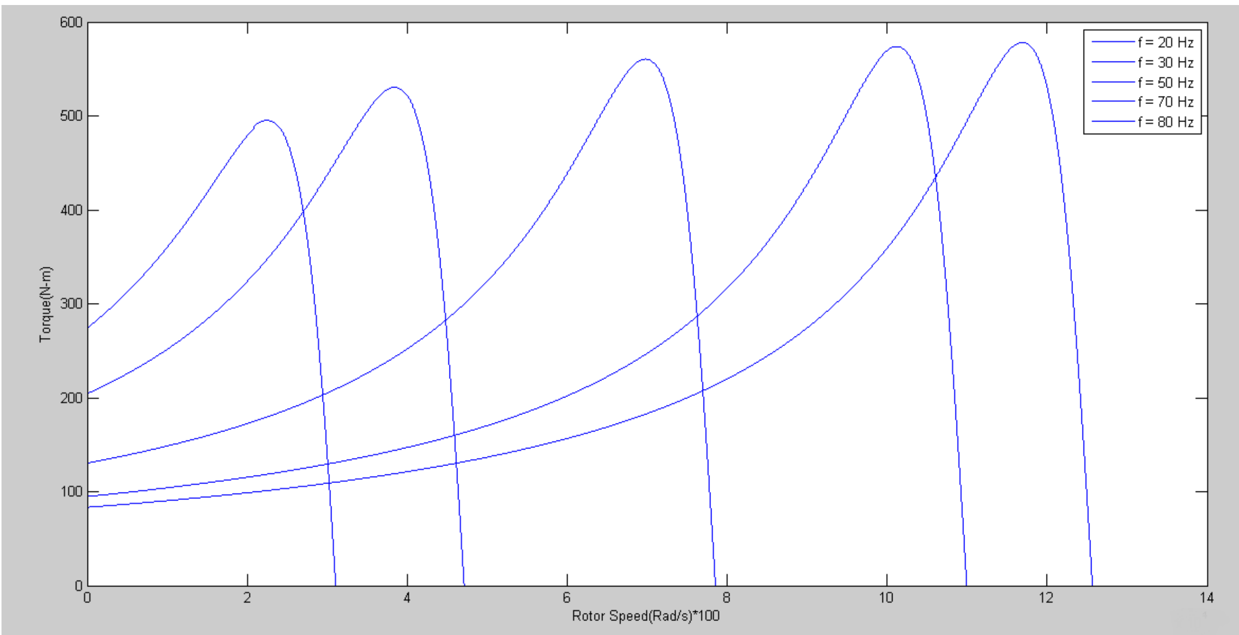
where, P = No. of stator poles
f1= supply frequency in Hz

**SPEED CONTROL OF THREE-PHASE INDUCTION MOTOR**

- Three-phase induction motors are mostly suited to fulfil the demand of loads requiring substantially a constant speed. Several industrial applications, however, need adjustable speeds for their efficient operation. Below are principles of speed control techniques employed to three-phase induction motors through the use of power-electronics converters. The various methods of speed control through semiconductor devices are as under:

1.) Stator voltage control
2.) Stator frequency control
3.) Stator voltage and frequency control
4.) Stator current control

## 7. V/f CONTROL OF INDUCTION MOTOR




### WORKING OF V/f CONTROL OF INDUCTION MOTOR

- For a three-phase induction motor, stator per phase voltage is given by

$$V = 4.44f1.Nph1.\Phi.kw1 \quad ...(1)$$

- For a three-phase induction motor, starting torque is given by

$$Te,st = (3P/2\omega 1).[(V1/\omega 1)^2].[r2/(l1+l2)^2] \quad ...(2)$$

- For a three-phase induction motor, starting torque is given by

$$Te,st = (3P/4).[(V1/\omega 1)^2].[1/(l1+l2)] \quad ...(3)$$

- Eq. (3) shows that if V1/ω1 or air-gap flux, is kept constant, the maximum torque remains unaltered. The starting torque is inversely proportional to supply frequency ω1 if air-gap flux is kept constant. At low values of frequencies, the effect of resistances cannot be neglected as compared to the reactances, This has the effect of reducing the magnitude of maximum torque at lower frequencies. In practice, at low frequencies, the supply voltage is increased to maintain the level of maximum torque This method of speed control is also called V/f control.

- If stater resistance is neglected), the slip at which maximum torque occurs is given by

$$S_m = r_2/\omega_1(l_1+l_2)$$

- As the supply frequency is reduced, the slip at maximum torque increases.As both voltage and frequency are varied (usually below their rated values), speed of the drive can be controlled. The control of both voltage and frequency can be carried out in order to keep V/f constant through the use of three-phase inverters or cycloconverters. Inverters are used in low and medium power drives whereas cycloconverters are used for high power drives like cement mills, locomotives, etc.

- Variable voltage and variable frequency can be obtained from voltage-source inverters. Three-phase ac is converted to constant dc by a diode rectifier. Voltage and frequency are both varied by PWM inverter. The circuitry between the rectifier and the inverter L and capacitor C called filter circuit. The function of the filter circuit is to smooth the dc output. This circuitry in between rectifier and inverter is called dc link. Regeneration is not possible because of diode rectifier. Also, the inverter would inject harmonics into the three-phase ac supply.

- The three-phase ac is converted to dc by diode rectifier. Chopper varies the dc input voltage to the inverter and frequency is controlled by the inverter. The use of a chopper reduces the harmonic injection into the ac supply. Regeneration is not feasible in this scheme.

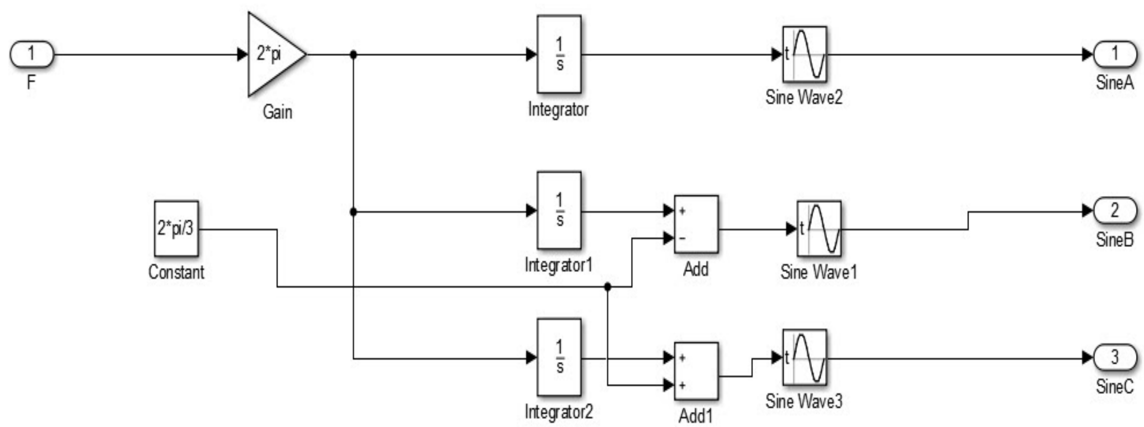
- A three-phase controlled rectifier, dc link consisting of L and C and force-commutated VSI. Voltage is regulated by a controlled rectifier and frequency is varied within the inverter. Here regeneration is possible if the three-phase full converter is used. Regeneration is also feasible in this scheme. It uses a three-phase dual converter, L-C filter and inverter. The level of dc input voltage to the inverter is regulated dual converter whereas frequency is varied within the VSI inverter.

- V/f control provides speed control from standstill upto the rated speed of the induction motor.

- The following are some of the benefits of V/f Control:
  i. It has a wide range of speed.
  ii. It performs well in both running and transitory situations.
  iii. It only requires a little amount of beginning current.

iv. It has a larger operational zone that is steady.
v. At base speed, voltage, and frequency approach their rated values.
vi. The rate of change in supply frequency can be used to regulate acceleration.

## SIMULINK MODEL OF FREQUENCY BLOCK




## 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.

- The open-loop V/F control of an induction motor is the most common method of speed control because of its simplicity and these types of motors are widely used in industry.

- Under Open-loop, induction motors have been used with 50Hz power supplies for constant speed applications. For adjustable speed drive applications, frequency control is natural. However, voltage is required to be proportional to frequency so that the stator flux remains constant if the resistance of the stator is considered to be negligible.

$$\boldsymbol{\Psi s = Vs/\omega 1}$$

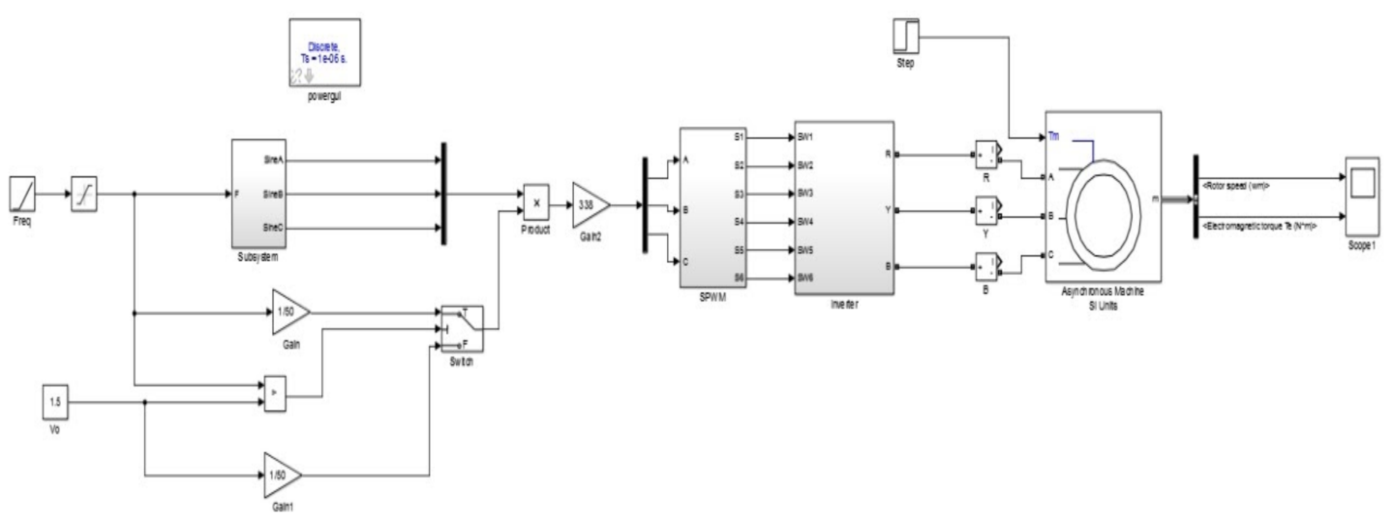
- The power circuit consists of a diode rectifier with a single or three-phase ac supply, LC filter and PWM voltage-fed inverter. Feedback is absent in this method for controlling purpose.

- The PWM converter is connected with the inverter block.

**Problems encountered in Open Loop V/f Control :**

- The speed of the motor cannot be controlled precisely, because the rotor speed will be slightly less than the synchronous speed and that in this scheme the stator frequency and hence the synchronous speed is the only control variable.
- The slip speed, being the difference between the synchronous speed and the electrical rotor speed, cannot be maintained, as the rotor speed is not measured in this scheme. This can lead to operation in the unstable region of the torque-speed characteristics.
- The effect of the above can make the stator currents exceed the rated current by a large amount thus endangering the inverter-converter combination.
- These problems are to be suppressed by having an outer loop in the induction motor drive, in which the actual rotor speed is compared with its commanded value, and the error is processed through a controller usually a PI controller and a limiter is used to obtain the slip-speed command.

**SIMULINK MODEL**




**CLOSE LOOP V/f CONTROL**

- In closed-loop V/f Control the speed of the rotor is measured using a sensor and it is compared to the reference speed. The difference is taken as the error and the error is fed to a Proportional controller. The P controller sets the inverter frequency. The frequency is taken as input for the Voltage Source Inverter which modifies the terminal voltage accordingly so as to keep the V/f ratio constant.

- The basis of constant V/F speed control of induction motor is to apply a variable magnitude and variable frequency voltage to the motor. Both the voltage source inverter and current source inverters are used in adjustable speed ac drives. The following block diagram shows the closed-loop V/F control using a VSI.

- A speed sensor or a shaft position encoder is used to obtain the actual speed of the motor. It is then compared to a reference speed. The difference between the two generates an error and the error so obtained is processed in a Proportional controller and its output sets the inverter frequency.

- The synchronous speed, obtained by adding actual speed ω and the slip speed ω, determines the inverter frequency The reference signal for the closed-loop control of the machine terminal voltage ω is generated from the frequency.

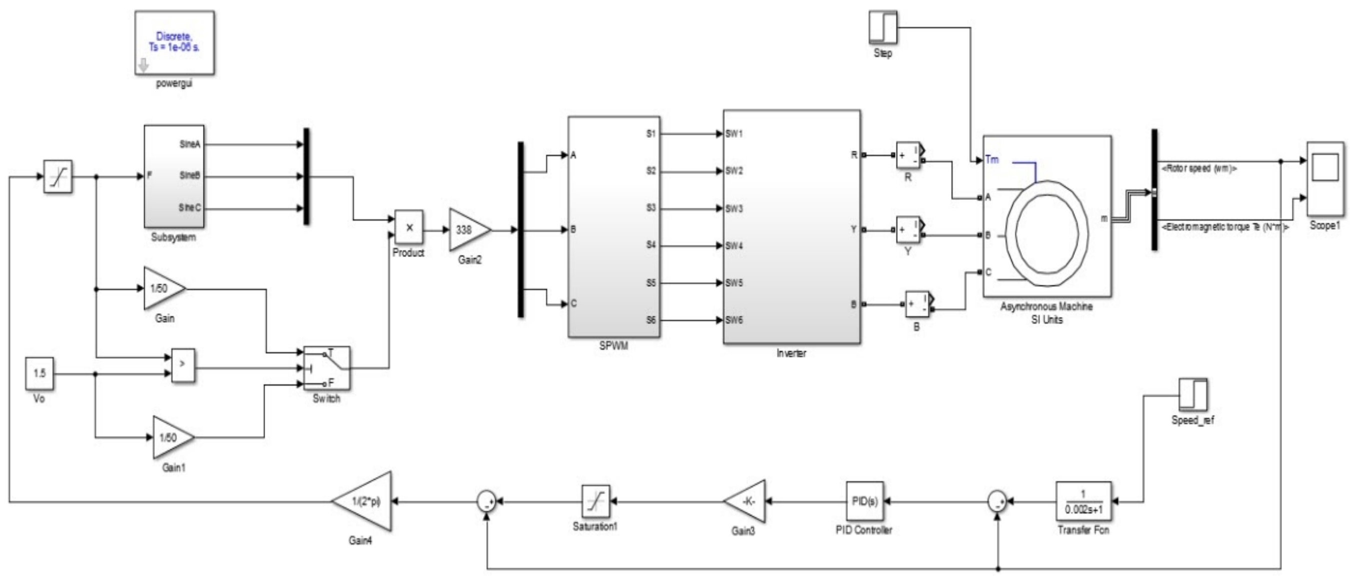
**OPERATING REGIONS OF INDUCTION MOTOR DRIVE**

- Constant Torque
- Constant Power
- Machine limit (Pullout Torque)

## 8. CONSTANT TORQUE OPERATION

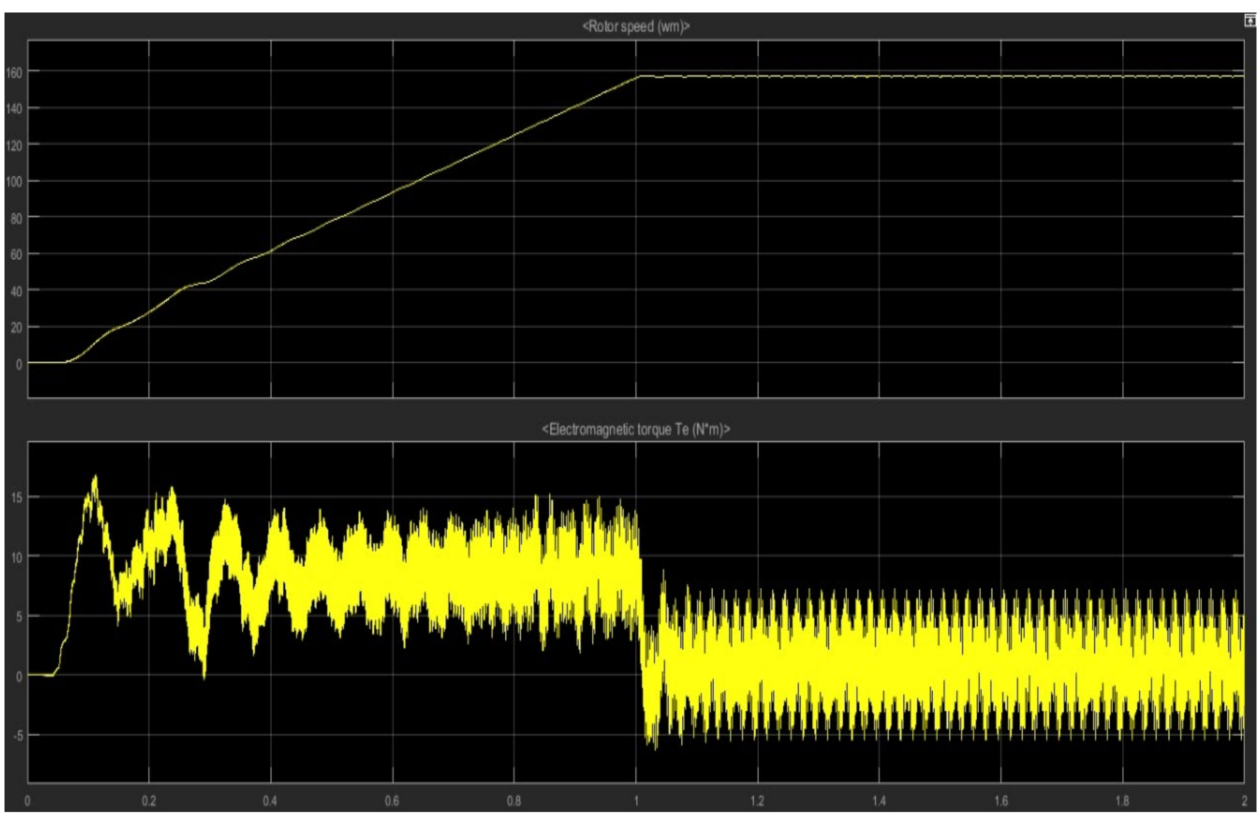
- The inverter voltage is controlled up to a maximum value limited by the supply voltage.
- As the motor speed and the voltage are increased in proportion, constant *V*/*F*, the rated flux linkage is maintained up to the base speed. Values of torque up to the maximum value can be produced at speeds up to about this base value.
- The maximum available torque is proportional to the square of the flux linkage.
- Typically, the induction motor is designed to provide a continuous torque rating of about 40%–50% of its maximum torque.
- Constant torque loads require the same amount of torque at low speeds as at high speeds. Torque remains constant throughout the speed range, and the horsepower increases and decreases in direct proportion to the speed.
- Constant torque loads include most positive displacement and reciprocating pumps and compressors as well as traction drives and conveyors. With constant torque loads, the torque is not a function of speed. As speed is changed, the load torque will remain fairly constant and the horsepower will change linearly with the speed.
- For example, if the speed increases by 50%, then the power required to drive the operation will increase 50% while the torque remains constant.

## SIMULINK MODEL

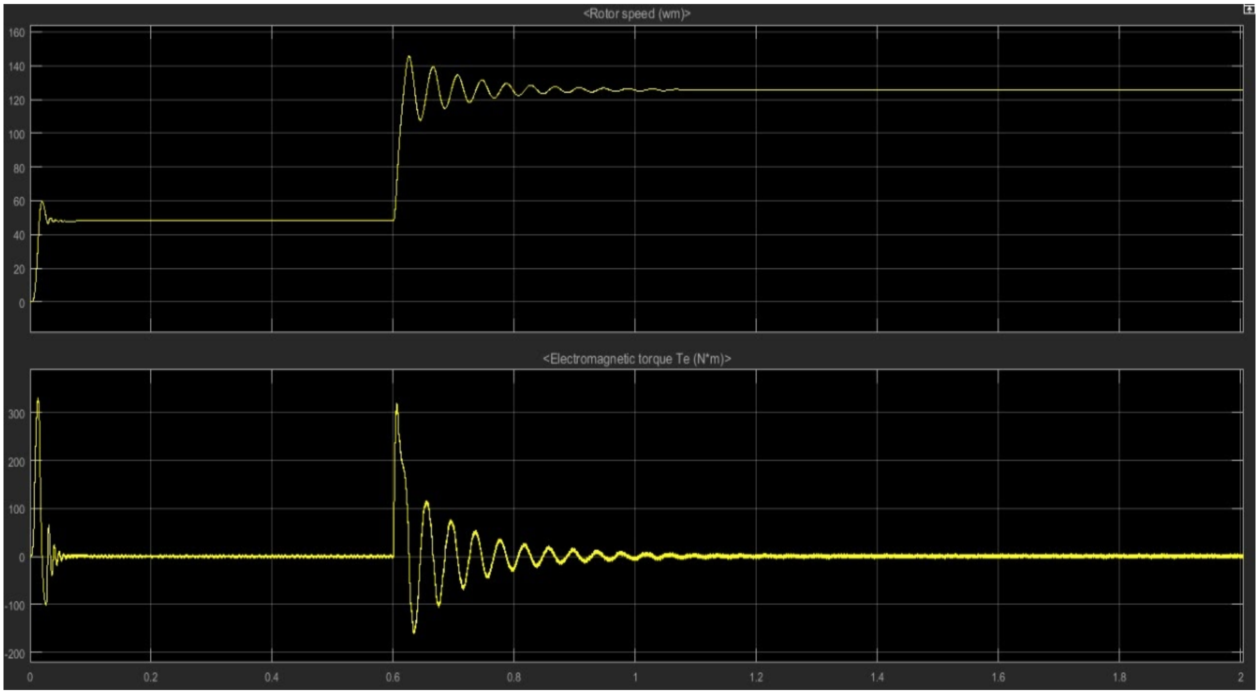



# 9. RESULT

## TORQUE AND SPEED CHARACTERISTICS OF OPEN LOOP V/f CONTROL



**<u>TORQUE AND SPEED CHARACTERISTICS OF CLOSE LOOP V/f CONTROL</u>**




## 10. CONCLUSION

- The various application of PWM Inverters has been studied. The PWM signals are produced by comparing a triangular waveform with a sinusoidal waveform through relational operators. Then these PWM signals are applied to the gates of forced-commutation devices like IGBT's in order to trigger them in a specific sequence so that they will be able to convert the DC supply voltage to an AC output voltage.

- A 3-Φ PWM Inverter is modeled using the Simulink Library blocks PWM Generator and Universal Bridge. Under all cases, successful inverter action is achieved.

- The Induction Motor runs with the help of a PWM Inverter without using any extra kind of speed control model and the various characteristic curves are obtained. It is observed that a large amount of transient currents are generated in the stator and rotor during starting and they take some time to settle down to their steady-state values. The lower the stator resistance, the quicker the transients settle down and hence, the stator resistance should be kept very low and should be neglected. In an uncontrolled Induction Motor, torque is incremented to a maximum value and then settle at the base value, while rotor speed is observed to increment to its rated value and remain constant there.

- Open-loop V/f Control is implemented using MATLAB SIMULINK and it was observed that by varying the supply frequency and terminal voltage such that the V/f ratio remains constant, 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 uses a Proportional Controller(P-controller) to process the error between the actual rotor speed and reference speed and this error signal is used 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 is observed that again the maximum torque remained constant across the speed range. Hence, the motor was fully utilized and successful speed control is achieved.

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