Simulate V/f control for traction load utilizing 3 phase induction motor under acceleration/braking mode utilizing an inverter fed from a large DC source of appropriate rating using MATLAB Simulink

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***Abstract*— In this project we are trying to explaining the variation range of speed by varying the frequency and voltage with help of an IGBT full bridge inverter fed from a high voltage dc source and analyzing of the maximum starting torque so that we can overcome the traction load (internal friction + external friction+ acceleration torque)**

***Keywords*—Induction motor, Inverter, VSI, CSI, IGBT, Variable frequency control, Scalar Control, Simulink, MATLAB.**

I. INTRODUCTION

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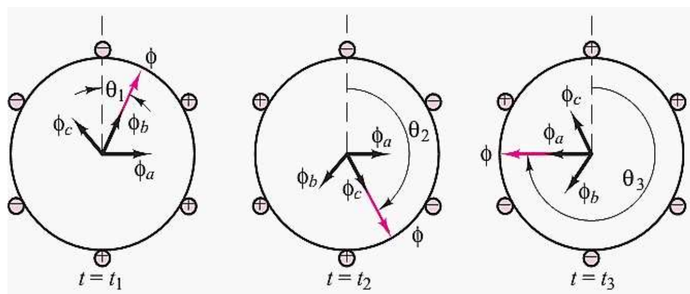
A. *Induction Motor*

It is a type of ac motor which works on the principle of relative speed between the rotor magnetic field and stator magnetic field flux(RMF). And also we can say that induction machines work on the basis of rotating magnetic fields(RMF).

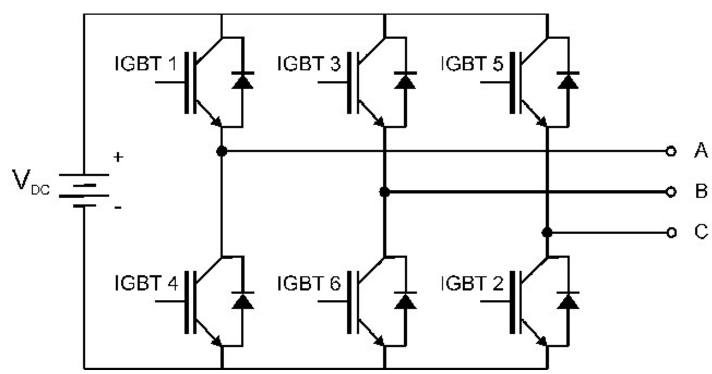


In the induction motor AC supply are connecting to the stator side and the an rotating magnetic field flux was produced due to alter whose magnitude is 1.5Φ and rotating with the synchronous speed

Ns = 120*f/p, where p is number of poles and f is the frequency

B. *Inverter*

It is the switching mode converter which converts a dc source into an AC source.



It is of two types:

1. VSI (voltage source inverter)
2. CSI (current source inverter)

In Simulink we are using a VSI inverter. It contains:

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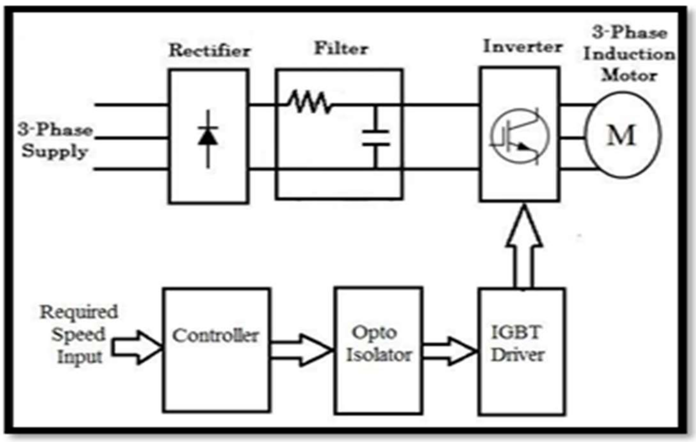
1. 6 IGBT switch
2. High dc power source
3. AC load

II. Variable Frequency Control of Induction Motor Drive

A. *Introduction*

In this method of speed control, we do not change the frequency but we change the Voltage/frequency ratio for the speed control.



Earlier the speed control was tried to done with the frequency but we started to face the problem of the core saturation during the low frequency. When the core is saturated then the magnetic field will not be increasing upon increasing current in the winding coil.

Saturation happens because of the increment in the magnetic flux upon reducing the supply frequency.

$$E \ or \ V = 4.44\phi K.T.f \ or \ \phi = \frac{V}{4.44KTf}$$

K=Winding Constant

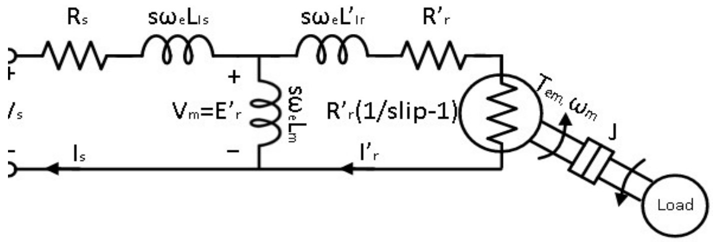
T=Turn per Phase

f=Frequency of Supply

Here you can see Magnetic Flux(ϕ) is inversely proportional to the supply frequency so to vary the speed without changing the magnetic flux we have to control V/f ,if V and f both increase and decrease by the same ratio then the flux will be constant and speed will vary as govern by the frequency..

B. *Theory*

Variable Frequency Control of Induction Motor Drive – Synchronous speed, therefore, the motor speed can be controlled by varying supply frequency. Voltage induced in the stator is proportional to the product of supply frequency and air-gap flux. If stator drop is neglected, terminal voltage can be considered proportional to the product of frequency and flux



Any reduction in the supply frequency, without a change in the terminal voltage, causes an increase in the air-gap flux. Induction motors are designed to operate at the knee point of the magnetization characteristic to make full use of the magnetic material. Therefore, the increase in flux will saturate the motor. This will increase the magnetizing current, distort the line current and voltage, increase the core loss and the stator copper loss, and produce a high-pitch acoustic noise. While an increase in flux beyond the rated value is undesirable from the consideration of saturation effects, a decrease in flux is also avoided to retain the torque capability of the motor. Therefore, the Variable Frequency Control of Induction Motor Drive below the rated frequency is generally carried out at rated air-gap flux by varying terminal voltage with frequency so as to maintain (V/f) ratio constant at the rated value. From Eq. (6.13)

$$T_{max} = \frac{K(V/f)^2}{\frac{R_s}{f} \pm \left[\left(\frac{R_s}{f}\right)^2 + 4\pi^2(L_s + L_r')^2\right]^{1/2}} \tag{6.69}$$

where K is a constant, and Ls and L′ r are, respectively, the stator and stator referred rotor inductances. Positive sign is for motoring operation and negative sign is for braking operation.

When frequency is not low, (Rs/f) ≪ 2π(Ls + Lr) and therefore,

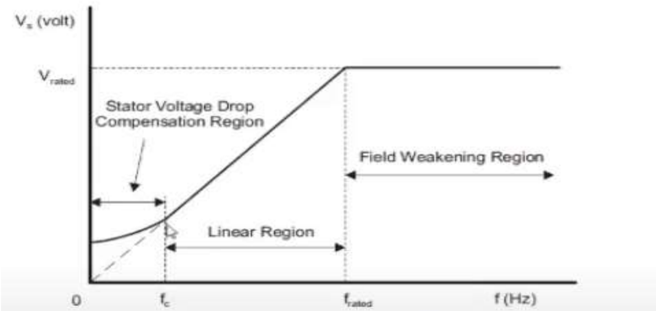
Tmax = K(V/f) ² / 2π.(Ls + Lr')

suggests that with a constant (V/f) ratio, the motor develops a constant maximum torque, except at low speeds (or frequencies). Motor therefore operates in constant torque mode. for low frequencies (or low speeds) due to stator resistance drop [i.e. when (Rs/f) is not negligible compared to 2 π (Ls + Lr)] the maximum torque will have lower value in motoring operation (-Eve Tmax = K(V/f) ² / 2 π .(Ls + Lr') sign) and larger value in braking operation (-ve sign). This behavior

is due to reduction in flux during motoring operation and increase in flux during braking operation. When it is required that the same maximum torque is retained at low speeds also in motoring operation, (V/f) ratio is increased at low frequencies. This causes further increase in maximum braking torque and considerable saturation of the machine in braking operation.

When either V saturates or reaches rated value at base speed, it cannot be increased with frequency. Therefore, above base speed, frequency is changed with V maintained constant. According to with V maintained constant, maximum torque decreases with increase in frequency (or speed).

Variation in terminal voltage with frequency is therefore as shown in . V is kept constant above the base speed. Below the base speed (V/f) ratio is maintained constant, except at low frequencies where (V/f) ratio is increased to keep maximum torque constant. Corresponding speed torque curves are shown in Fig. 6.33(b) both for motoring and braking operations. The curves suggest that speed control and braking operation are available from nearly zero speed to above synchronous speed.



Stator Voltage Versus Frequency Profile Under V/Hz Control

A given torque is obtained with a lower current when the operation at any frequency is restricted between the synchronous speed and the maximum torque point, both for motoring and braking operations. Therefore, the motor operation for each frequency is restricted between the synchronous speed and maximum torque point as shown by solid lines in Fig. 6.33(b).

The Variable Frequency Control of Induction Motor Drive provides good running and transient performance because of the following features:

- Speed control and braking operation are available from zero speed to above base speed.
- During transients (starting, braking and speed reversal) the operation can be carried out at the maximum torque with reduced current giving good dynamic response.
- Copper losses are low, and efficiency and power factor are high as the operation is restricted between synchronous speed and maximum torque point at all frequencies.
- Drop in speed from no load to full load is small.

The most important advantage of Variable Frequency Control of Induction Motor Drive is that it allows a variable speed drive with above-mentioned good running and transient performance to be obtained from a squirrel cage induction motor. The squirrel cage motor has a number of advantages over a dc motor. It is cheap, rugged, reliable and longer lasting. Because of the absence of commutators and brushes, it requires practically no maintenance, it can be operated in an explosive and contaminated environment, and can be designed for higher speeds, voltage and power ratings.

As we already discussed in the variable frequency method the maximum torque remained the same (does not depend on the frequency)but starting and running (load)torque varied as we varied the frequency .

Ts is also vary as we discussed in the next heading traction load.

➢ Traction Load

Traction load :- A load on a structure exerted by a moving vehicle in the direction of its motion, caused by friction, tractive effort, or braking.

First we try to understand what does the traction means :

Traction, or tractive force, is the force used to generate motion between a body and a tangential surface, through the use of dry friction, though the use of sheer force of the surface is also commonly used.

Nature of Traction Load:

Nature of Traction Load describes as when the train runs at a constant velocity on level track, a number of frictional forces oppose its motion. The friction at bearings, guides etc. is classified as Internal Friction.

The rolling friction between wheels and rails, and friction between wheel-flanges and rails is termed as External Friction.

A third category consists of air friction which is independent of the weight of the train but depends upon its size and shape, and velocity and relative direction of wind. All these frictional forces together are known as Train Resistance.

Variation of train resistance (Fr) with speed (V); load torque vs speed curve will have similar nature. The train resistance (or load torque) can also be identified in terms of common classification of friction such as windage, viscous friction, coulomb friction and stiction. Stiction has a large value and the influence of air friction, which varies as the square of speed, is quite prominent at high speeds.

When deciding torque requirements of driving motors, the torque components required to provide acceleration and to overcome gravity must also be considered.

Owing to large inertia, particularly of electric trains, accelerating torque forms a major proportion of the total torque in accelerating range. Because of large values of stiction and accelerating torque, the torque requirement at start and during acceleration is much higher than the torque needed for running at the highest speed.

Therefore, only those drives which develop large torque from zero to the base speed are suitable for Nature of Traction Load application. hence we required a condition in the induction motor at which found maximum starting torque so as we all know that the starting torque relation with voltage and frequency ratio

$$\mathbf{Tstart \propto V^2 / f^3}$$

hence here we can say that by decreasing frequency we can increase the starting torque to overcome the traction load torque by keeping V/f ratio constant

we are adding high initial (starting) load torque to add traction load with the induction motor in the Simulink.

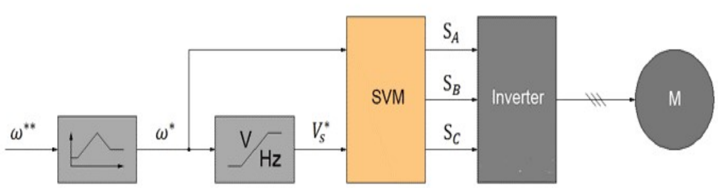
III. SCALAR CONTROL OF INDUCTION MOTOR(USING V/F)

The scalar control method is based on wearing two parameters simultaneously the speed can be varied by increasing or decreasing the supply frequently but this result in change of Impedance. The change of Impedance eventuates the increase or decrease of current. If the current is small, the torque of motor decreases. If the frequency decreases or the voltage increases, the coil can be burnt or saturation can occur in the iron of coil. To avoid these problems, it is necessary to vary the frequency and the voltage at the same time. In this way, the occurring disadvantages of changing frequency and voltage can be compensated.

Scalar control is based on the steady-state model of the motor. The control is due to the magnitude variation of the control variables only and disregards the coupling effect in the machine. For example, the voltage of a motor can be controlled to control the flux, and frequency or slip can be controlled to control torque. However, flux and torque are also functions of frequency and voltage respectively. This method is simple and easy to implement, but the inherent coupling effect (i.e., both torque and flux are functions of voltage or current and frequency) gives sluggish response and the system is prone to instability because of a high-order (fifth-order) system effect. As a result, the scalar control technique has poor dynamic performance. The scalar controller is usually used in low-cost and low-performance drives..

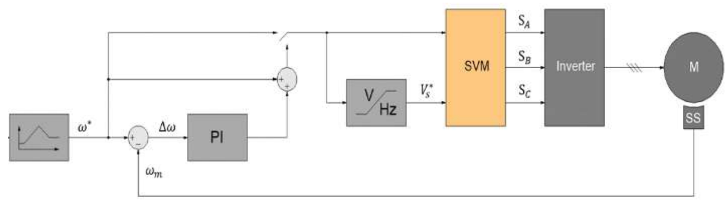
A. *As applied to induction motors*

At the scalar control method, the induction motor speed is controlled by setting the voltage and frequency of the stator, so that the magnetic field in the gap is maintained at the desired value. To maintain a constant magnetic field in the gap, the V/Hz ratio must be constant at different speeds.



Scalar control without speed sensor

As the speed increases, the stator supply voltage must also increase proportionally. However, the synchronous speed (frequency) of the induction motor is not equal to the rotation speed (frequency) of the shaft, and the slip of the induction motor depends on the load. Thus, the controller with scalar control without feedback cannot accurately control the speed when there is a load. To solve this problem, speed feedback and, therefore, slip compensation can be added to the control system.



Scalar control with speed sensor

B. *Assumptions*

• The scalar control input u is assumed to take values on the finite closed interval [−U,U] and the amplitude W of the switching part of the control input u satisfies W<U.

• The directional derivative Lfh(x) and a finite number of its time derivatives, say (Lfh(x(t)))(k), k=0,1,2,…,m, for a sufficiently large m, are assumed to be uniformly absolutely bounded for any feedback control input stabilizing the sliding surface coordinate dynamics.2

• Lgh(x) is perfectly known and locally strictly positive..

C. *Scalar Control*

The principle of the scalar control method consists in maintaining Vsfs constant. This allows maintaining the flux constant. The torque control is done through the slip variation. In permanent state, the expression of the maximum torque is given by Eq. (10.8):

$$C_{em} = \frac{3p}{2Nr}\left(\frac{Vs}{ws}\right)^2 \tag{10.8}$$

where Vs is given (using phase diagram) by Eq. (10.9).

$$V_s = \frac{\sqrt{2}}{3} I_{s(re)} r_s + \sqrt{\left(\frac{v_{s0} f_s}{f_b}\right)^2 + \frac{2}{9}\left(I_{s(re)} r_s\right)^2 - \left(I_s r_s\right)^2}$$

- (10.9)

Fig. 10.2 presents the regulation method of the machine speed by reconstituting the stator pulsation.

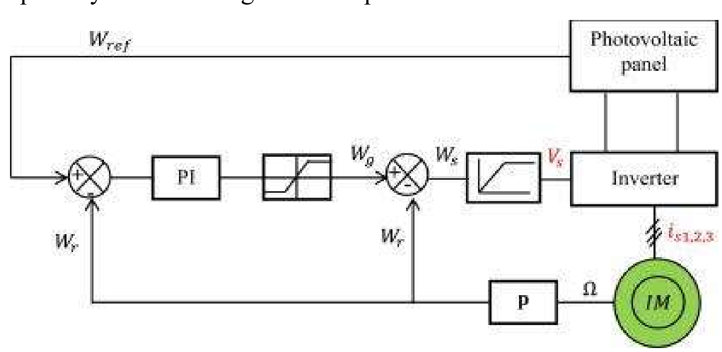
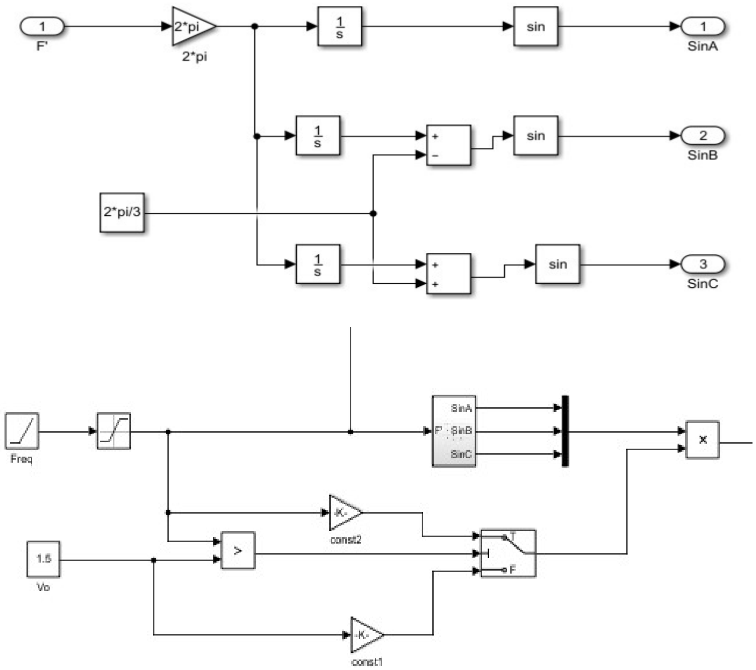


Figure 10.2. The block diagram of a scalar control of the induction machine.

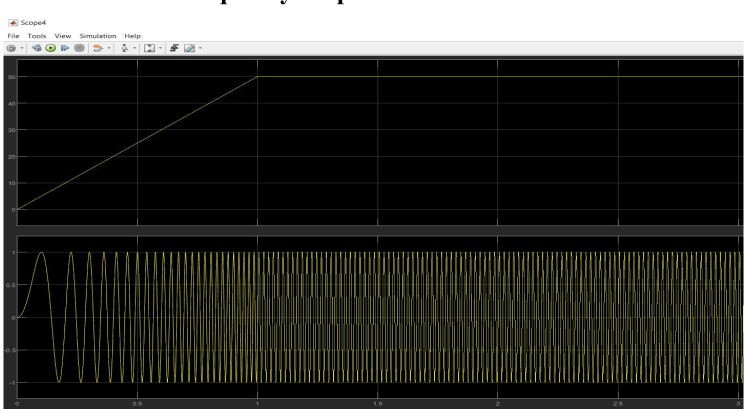
IV. SUBSYSTEM REQUIRED IN SIMULINK MODEL

1. Frequency and voltage varying Simulink circ

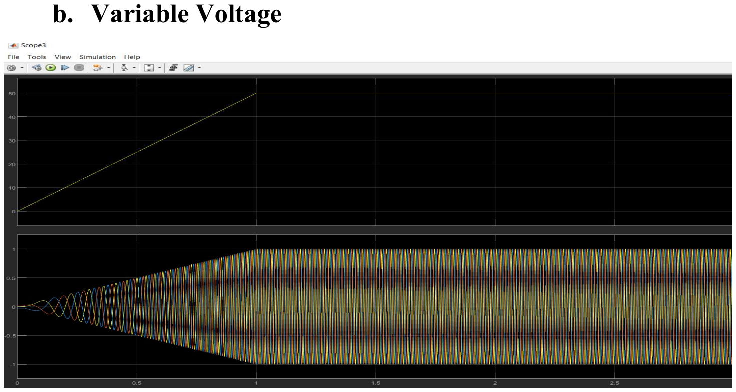


OUTPUT of Subsystem

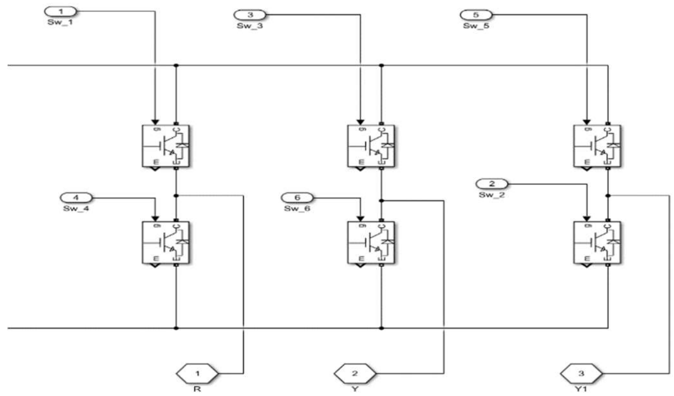
a. Variable frequency output



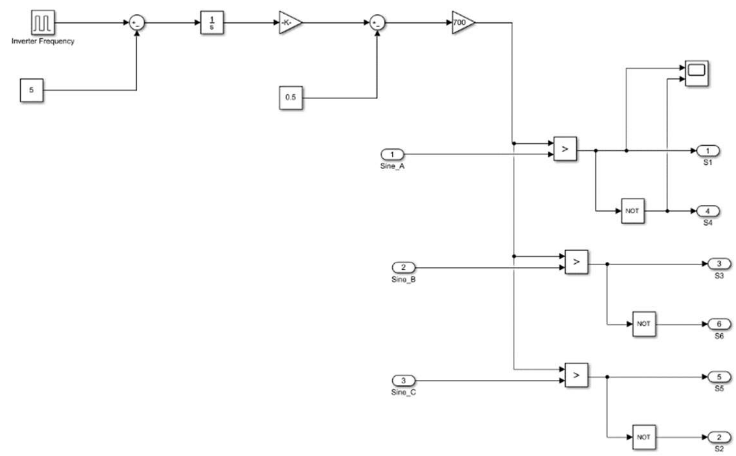
b. Variable Voltage



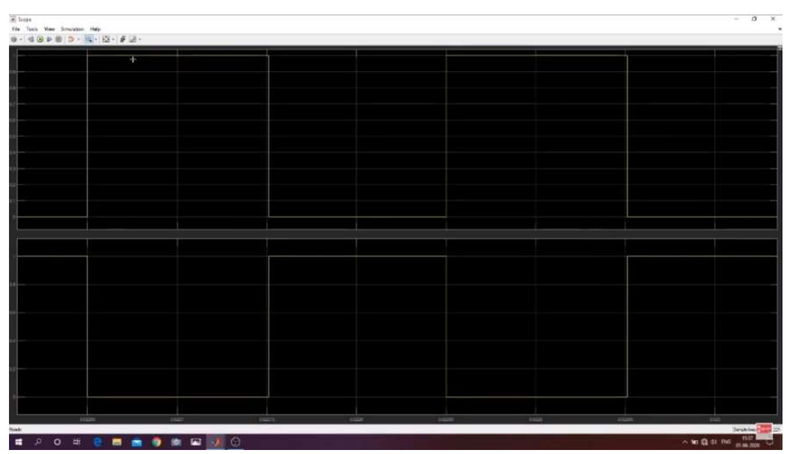
2. IGBT Inverter



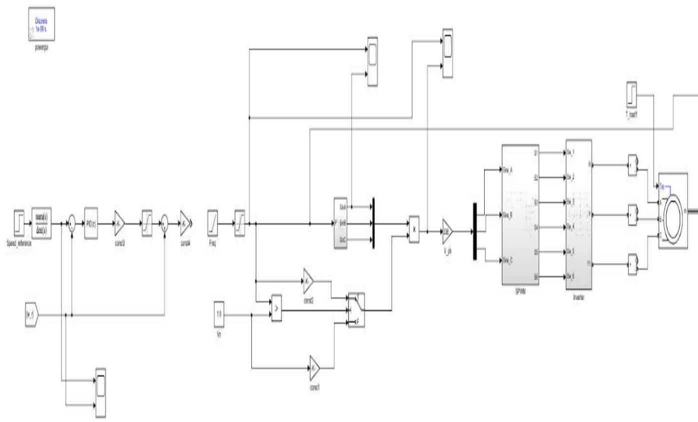
3. Sine Pulse with Modulator



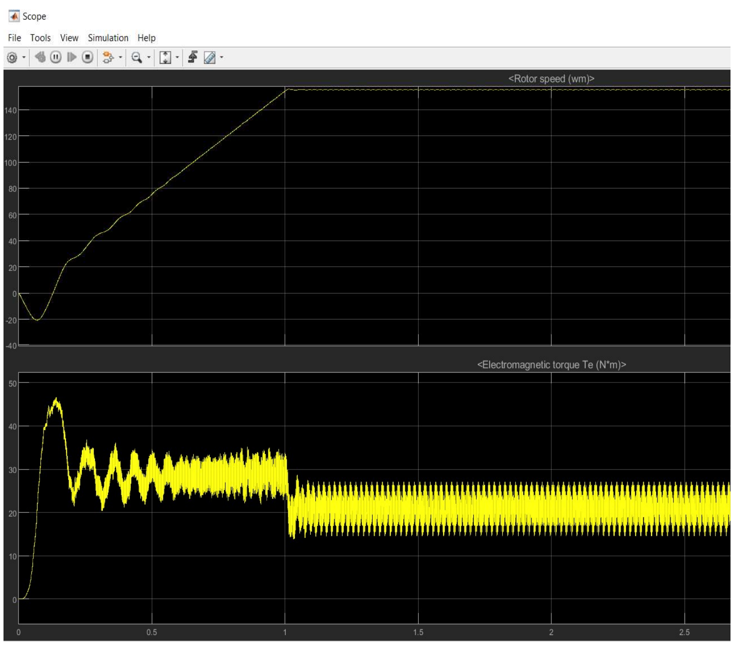
Output of subsystem



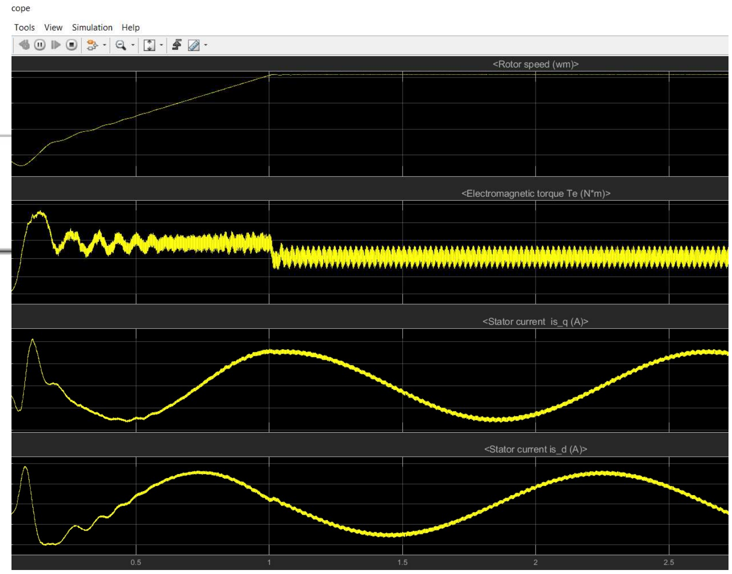
V. SIMULINK MODEL



OUTPUT



OUTPUT SHOWING THE VARIATION OF THE SPEED AND TORQUE RESPECTIVELY



output showing the current variation by varying the torque and speed'

CONCLUSION

- Through this model we can find the different torque variation by varying the frequency. where the maximum torque was remaining constant, starting torque goes increases as the frequency decreases
- V/f control method provide highest speed control range amongst all other speed control methods
- this method gives the maximum starting torque which is used to overcome all the friction and provide the acceleration to the machine hence this motor with this method was used in very heavy vehicles like electric trains or locomotive vehicles and traction load
- This type method has some drawbacks, which is insulation failure by increasing the voltage of the supply and magnetic saturation by increasing frequency only.
- It has very high copper loss in the starting due to high starting torque there is a high starting current in the winding as shown in the output.
- Starting $\propto$ (current)^2

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