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Vector Speed Control of Induction Motor

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Abstract - *This paper presents the design and implementation of Closed loop Vector Speed control of Induction motor. Vector speed control method is the one of the best ways to control speed of induction motor over full range. Vector speed control method has so many advantages. Such as by using this method we can get full torque at zero speed and rate of acceleration and deacceleration is maximum. It is cost effective and power consumption is very low and fast response. This method is a variable frequency drive method. In this method we can raise speed of the motor above its rated value by field weakening method and for below ranges we are using velocity controller. This paper contains a brief explanation to various speed control techniques, introduction to vector speed control methods, and its advantages and its implementation using MATLAB Simulink and output wave forms.*

1. INTRODUCTION

Induction motors are widely used in domestic, industrial and residential appliances. Induction motors are rotating at asynchronous speed that's why it is called asynchronous motors. Asynchronous speed is generally lower than synchronous speed. Induction motors are very cheap and its maintenance is low and efficiency is more compare to another methods. Like all other DC motors, this induction motor also has both stator and rotor. But unlike all other DC motors, here in this induction motor we are giving supply for only stator windings. Due to electromagnetic induction (due to transformer action) the rotor windings excited. Due to this reason induction motor also called Rotating Transformer.

Speed of Induction motor:

Speed of induction motor mainly depends upon frequency and number of poles available. Synchronous speed is directly proportional to the frequency. As the frequency increases the speed of the motor will be increases. If we decrease frequency then speed also decreases. And also, synchronous speed is inversely proportional to the number of poles. As the number of poles increases the speed will be decreases. And if we decrease number of poles the speed will be increases.

$$\text{Synchronous speed} = \frac{120f}{P}$$

Where f represents frequency ….., P represents number of poles.:

Various speed control methods

We have many types of speed control methods to control the speed of the induction motor. Speed of the induction motor depends upon various parameters such as frequency, number of poles, supply voltage, rotor resistance, flux and etc., This are the some of speed control methods of induction motors

1) Pole Changing method
2) Variable supply frequency control method
3) Variable supply voltage method
4) Rotor resistance method
5) Constant V/f method
6) Rotor side excitation control method
7) Vector speed control method

1)Pole Changing Method We know that, speed of the induction motor is u=inversely proportional to the number of poles. As the number of poles increases, speed decreases vice versa. But changing the number of poles is difficult. We can change number of poles by three ways, those are

1)Multi Stator Winding
2)Consequent pole method
3)Pulse Amplitude Modulation

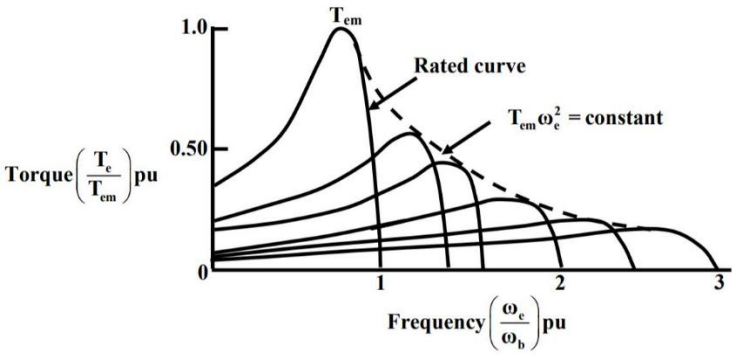
1)Multi Stator Winding: - In this method, we have two stator windings with different number of poles. According to speed requirement we are giving supply to one of the stator windings. For explaining this concept, here I am providing example for easy understanding. Consider a induction motor having two stator windings one with 2 poles and another with 4 poles. Here we are giving supply to stator windings according to speed requirements. For speed around 1500rpm we will give supply to 4poles stator winding. For speed around 3000rpm we are giving supply to 2pole stator winding.

2)Consequent pole method: - In this method we are dividing stator windings into various parts. According to the speed requirement we are giving supply to some groups of winding. Whenever we require low speed then we are giving supply to more number of divided windings. And for higher speeds we are giving supply to some windings only. Here, in this method divided windings acts as poles whenever we gave supply to them.

3)Pulse Amplitude Modulation: - In this method speed will be varies according to the pulse amplitude. Higher the amplitude higher will be speed and vice-versa.

2)Variable Supply frequency control

As we know that speed of the induction motor is directly proportional to supply frequency. As the frequency increases speed will be increases and vice-versa. If we decrease the frequency beyond its limits then reactance will be decreased so the stator currents are increased then copper losses will be increased thus motor leads damage. If we increase frequency beyond its limits then the maximum torque of the motor falls. Because of these reasons this method not widely used.
Below picture represents the relation between torque and speed.



Variable supply frequency control characteristics

By observing above graph, we got conclusion that the maximum torque will be decreases while increasing frequency beyond its limits.

3) Variable supply voltage method

Consider induction motor with a constant rotor resistance and it is rotating nearer to synchronous speed then slip is minimum and square of the slip is negligible. Then motor torque is directly proportional to the square of the rotor voltage. Rotor voltage is almost equal to supply voltage.

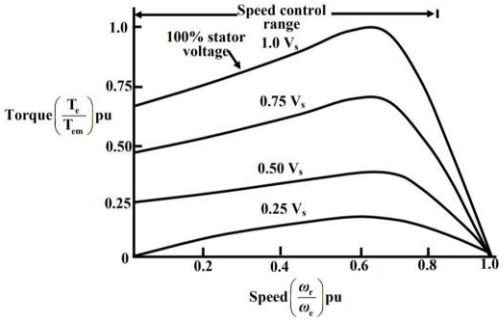
Here, we have Torque = $\frac{sV^2_r}{(R^2_r + (sX_r)^2)}$

Where s------ represents slip of the motor

Vr------ represents rotor emf
Rr------ represents rotor resistance
Xr----- represents rotor inductance

From above explanation, torque is directly proportional to the square of the induction motor. As we increasing supply voltage the torque of the motor will be increases initially. To maintain constant load torque, we need to increase the slip of the motor thus rotor speed will be decreases.

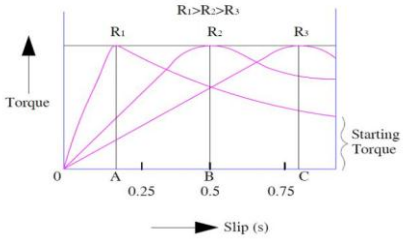
This method is the easiest way to control the speed of the motor but to vary small range of speeds we need to vary a large range of voltage values. Due to this reason this method is not widely used.



Variable supply voltage characteristics

From above the graph, As the voltage increases the torque will be increases and vice-versa.

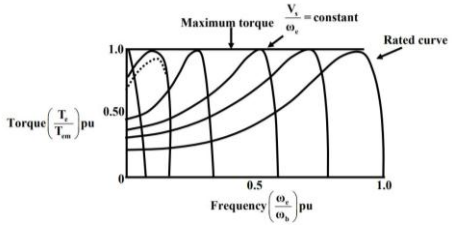
4) Rotor resistance method: - In this method, we are varying rotor resistance. This method is applicable for only slip ring motor. We cannot able to use this method for squirrel cage induction motor. In squirrel cage induction motor rotor windings are short circuited so we can not able to add external resistance. In slip ring induction motors, we are adding slip rings (rotor windings) to the external resistance. Initially we are adding large resistance to the slip rings then after we are decreasing external resistance.Initially, we are adding large resistance thus torque is maximum after then we are decreasing resistance the torque required to run motor at constant speed will be decreases. Finally, we are operating slip ring induction motor as squirrel cage induction motor. By using this method, we are getting low efficiency due to large copper losses in rotor windings due to this reason we are not using this method widely.



Rotor resistance characteristics

From the above graph, we got conclusion that as the external resistance increases, we can get maximum torque at lesser slip. As the rotor resistance decreases, we can get maximum torque at higher slip values.

5) Constant V/f method: -(variable voltage variable frequency method): - This is the one of the best method to control speed of the induction motor. By using this method we can constant torque by maintaining flux constant. In this method we are maintaining constant flux or V/f ratio as constant. If we decrease frequency beyond its limits by fixed rated voltage then air gap flux will be saturated. Due to this the stator currents will be increases and copper losses will increase and motor gets damage. So, in this method whenever we are increasing or decreasing frequency we need to increase or decrease supply voltage simultaneously. By maintain constant flux constant we can get constant torque. We can use this method for varying the speed of induction motor over a wide range.



Constant V/f control characteristics

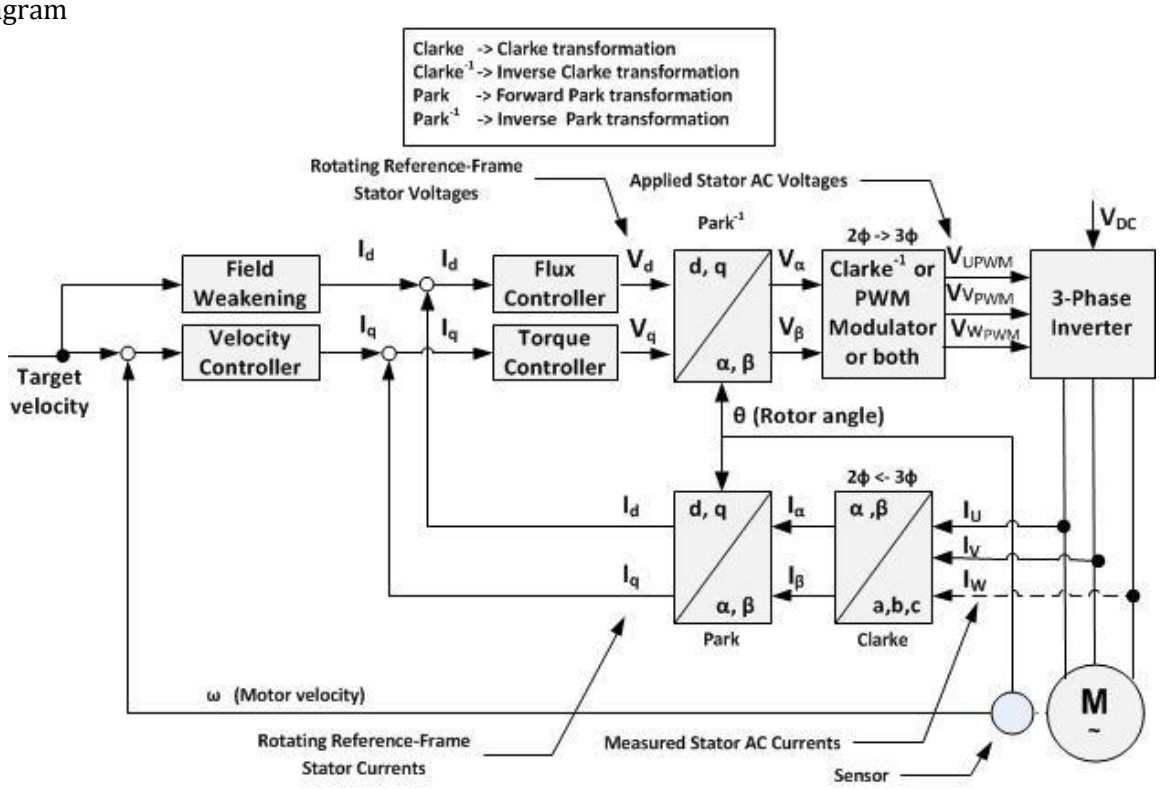
6) Rotor side excitation control method: - This is the one of the speed control method from rotor side control. In this method we are externally injecting emf on to the rotor emf in phase and out of phase to control the speed of the motor. Whenever we injecting the emf on to rotor emf in phase to it, then rotor resistance decreases then the torque will be decreases. And also if we inject the emf on to the rotor emf in opposite phase (anti phase) then rotor resistance increases thus the torque will be increases. By using this method, we control speed of the motor over a full range.

7) Vector speed control method: - Vector speed control method is also known as Field oriented control, the main reason to call like this is here we are controlling field parameters to vary speed of the motors. This method is used to control the speed of the synchronous and asynchronous motors. By using this method, we can get maximum torque at zero speed, and also its dynamic and steady state response is good. Its accelerating and deaccelerating rate is fast. We can control the speed of the motor very fast and power consumption is low because of minimum number of sensors used. And accuracy of torque and speed is very high and efficiency of control is high. Here, in this method performance of control is excellent because we are using PI controllers.

In this method there are mainly for transformations are present

1)Clarke transformation
2)Parks Transformation
3)Inverse Clarke transformation
4)Inverse Parks transformation

Block Diagram



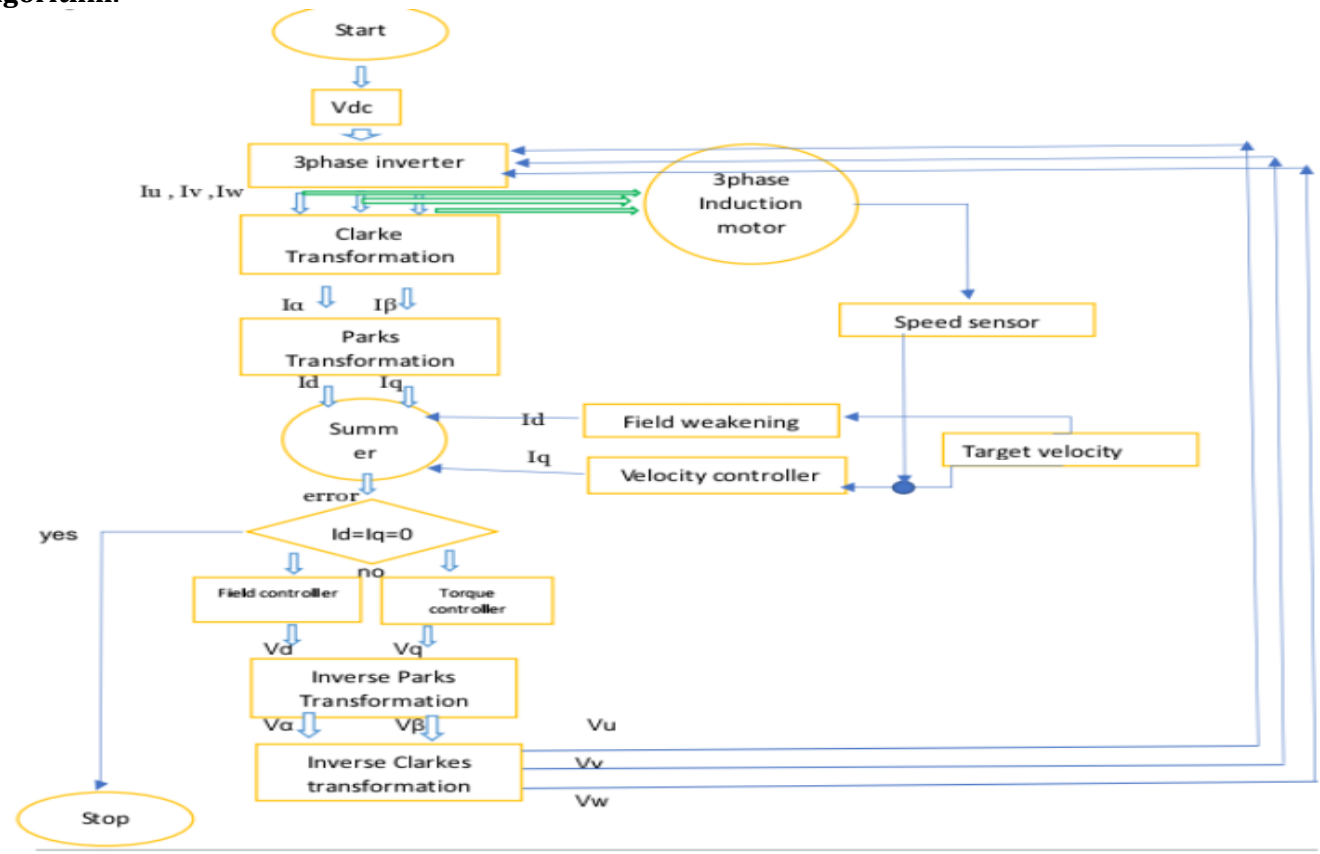
Working:

Here, in this speed control method, three phase stator currents (Iu, Iv, Iw) are identified as two phase balanced stationary orthogonal components (Iα , Iβ). In these two current components one represents flux and another represents torque of the induction motor. These two components are stationary in nature. This transformation is called Clarke transformation. Here, we are transforming 3ϕ current components into two phase balanced stationary components in order to make calculations easier. After, transforming two phase balanced stationary components then we are again transforming these components into two phase balanced rotating components (Id , Iq). This transformation is called Parks transformation. Here in, parks transformation we are converting linear differential equations into one time varying component and another one time invariant component. And here, while doing parks and inverse transformations we giving rotor angle as feedback.

Where Id----- represents rotating current component along direct axis
Iq----- represents rotating current component along quadrature axis

And also we are sensing motor speed by using sensor and then to get target speed we are controlling by using field weakening and velocity controller. In general, field weakening method is used to raise the speed of the induction motor more than rated speed but shaft torque is low. Velocity controller is used to control the speed below its rated speed but shaft torque is more. In field weakening method, we are raising the frequency double to its rated frequency then we get double rated speed and half torque. From the field weakening block we are getting reference Id, from velocity controller we are getting Iq reference. Then we are giving these references to summers. Here, at summer point we get errors, these errors are given to flux controller and torque controller. At this controller we are transforming rotating Current components into rotating voltage components. After, then we are transforming these two phase balanced rotating voltage components (Vd ,Vq) into two phase balanced stationary components (Vα ,Vβ). This transformation is called inverse parks transformation. Then after, we are again transforming these two phase balanced stationary components (Vα ,Vβ) into three phase stator voltage components (Vv,Vu,Vw). This transformation is called inverse Clarks transformation. Then these voltage components given to inverter. This process will be repeated until we get required target velocity and torque.

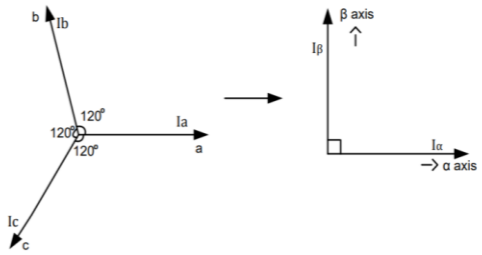
Algorithm: -



Transformations:-

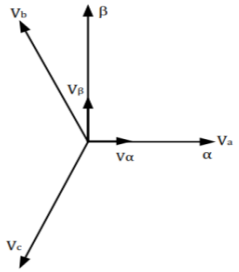
1**)Clarke Transformation**: - In this transformation we are transforming 3 phase components into balanced two phase stationary components. Here, following formulas are used to transformation

$$I\alpha = 2/3\ Ia - 1/3\ (Ib - Ic)$$
$$I\beta = 2/\sqrt{3}\ (Ib - Ic)$$



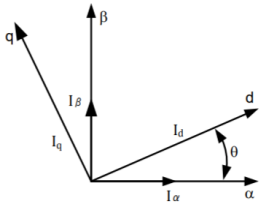
2**)Inverse Clarke Transformation**: - In this transformation we are transforming two phase balanced stationary components to three phase components.

$$Va = V\alpha$$
$$Vb = ((-V\alpha + \sqrt{3}*V\beta))/2$$
$$Vc = = ((-V\alpha - \sqrt{3}*V\beta))/2$$



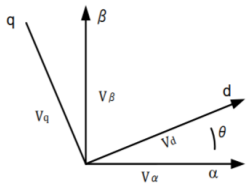
3)Park Transformation: - In this transformation we are transforming two phase balanced stationary components into two phase balanced rotating components.

$$Id = I\alpha * \cos(\theta) + I\beta * \sin(\theta)$$
$$Iq = I\beta * \cos(\theta) - I\alpha * \sin(\theta)$$



4)Inverse Park Transformation: - In this transformation we are transforming two phase balanced rotating components into two phase balanced stationary components.

$$V\alpha = Vd * \cos(\theta) - Vq * \sin(\theta)$$
$$V\beta = Vq * \cos(\theta) + Vd * \sin(\theta)$$

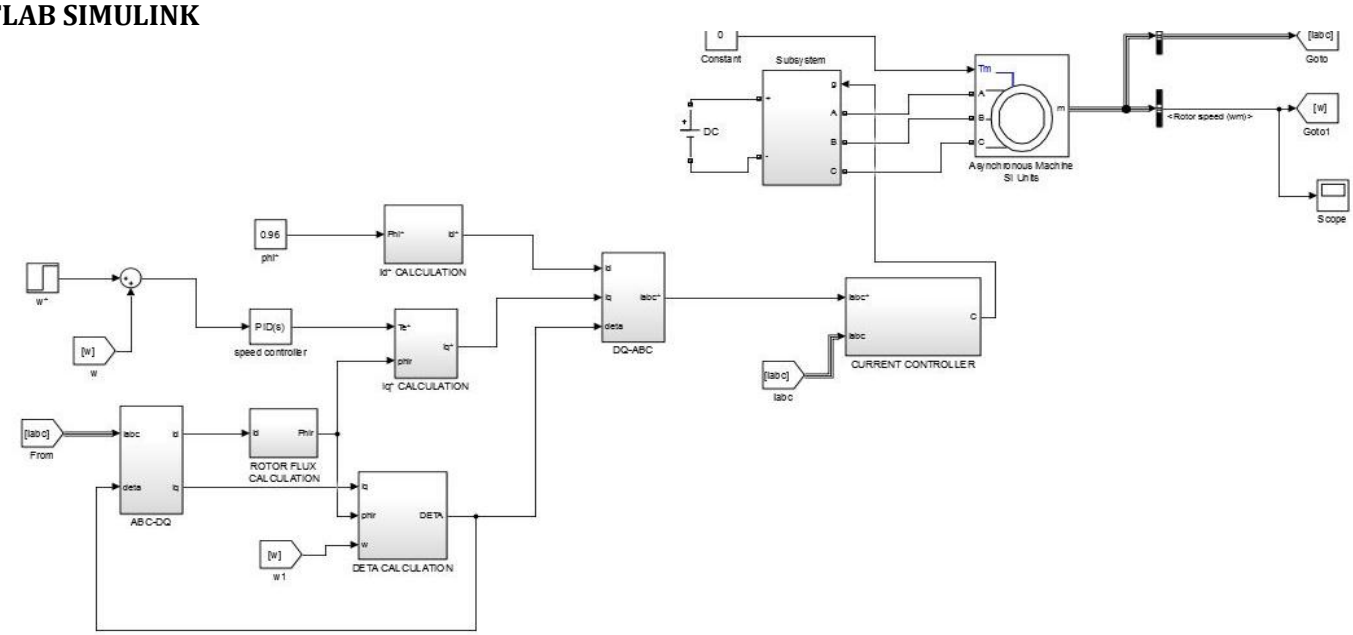


And also following formulas are used to direct transformation: -
V_(d)= 2/3 [Va cosθ+Vb cos(θ-2π/3)+Vc cos[θ+2π/3)]

V_(q)= -2/3 [Va sinθ+Vb sin(θ-2π/3)+Vc sin[θ+2π/3)]

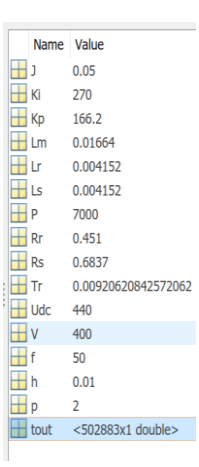
Va=Vd cosθ-Vq sinθ
Vb=Vd cos(θ-2π/3)-Vq sin(θ-2π/3)
Vc=Vd cos(θ+2π/3)-Vq sin(θ+2π/3)

MATLAB SIMULINK

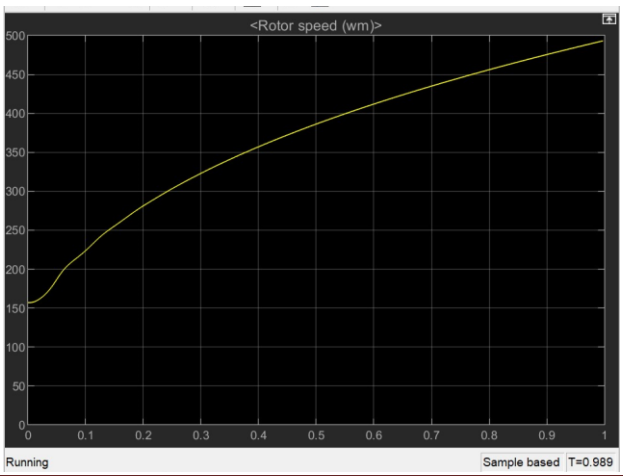


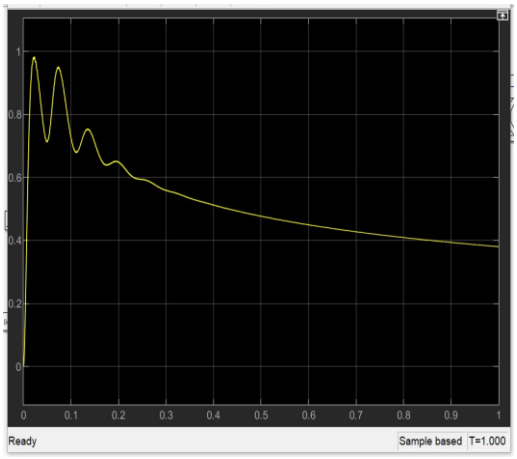
Analysis :- here in our project we are analyzing vector speed control of induction motor by various parameters. Here, We are varying following components voltage and rotor resistance and frequency.

Analysis of vector speed control by varying voltage: -



Name	Value
J	0.05
Ki	270
Kp	166.2
Lm	0.01664
Lr	0.004152
Ls	0.004152
P	7000
Rr	0.451
Rs	0.6837
Tr	0.00920620842572062
Udc	440
V	400
f	50
h	0.01
p	2
tout	<502883x1 double>





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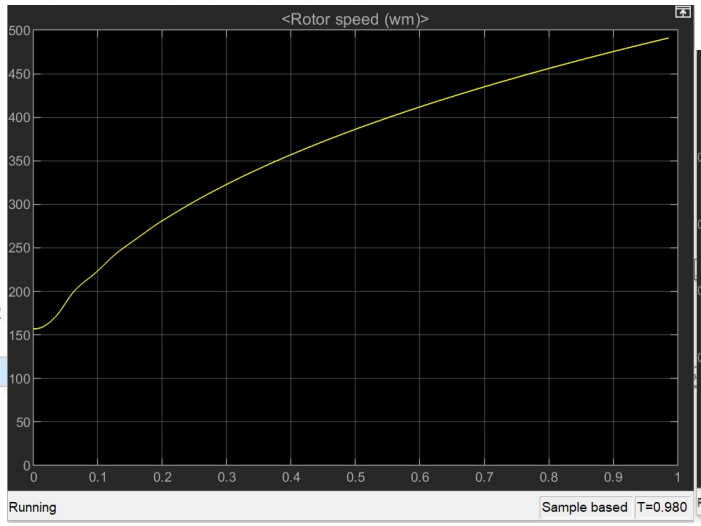

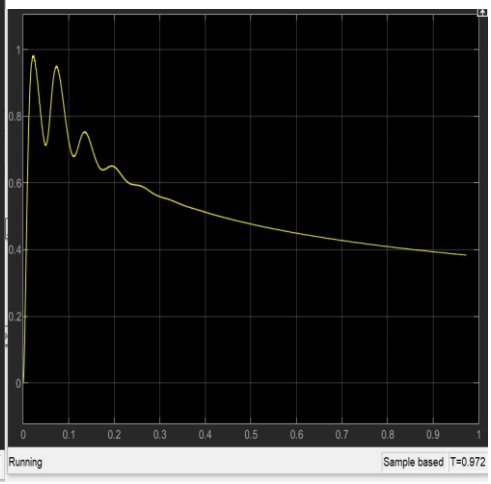

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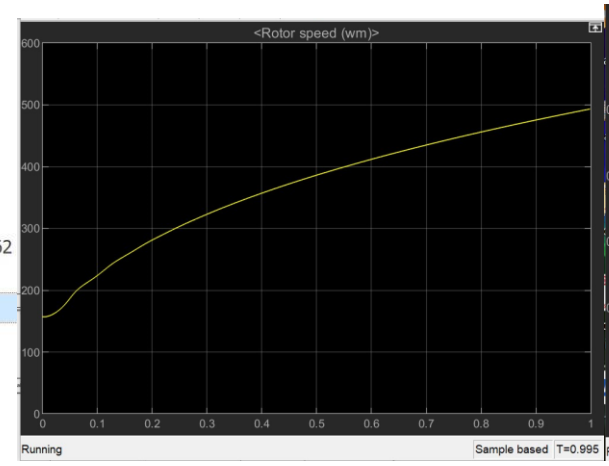

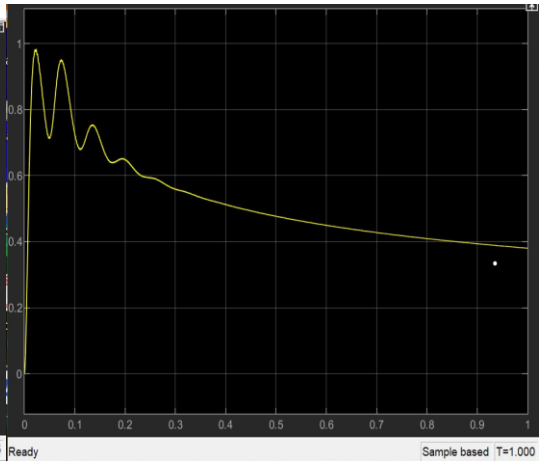

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Lm	0.01664
Lr	0.004152
Ls	0.004152
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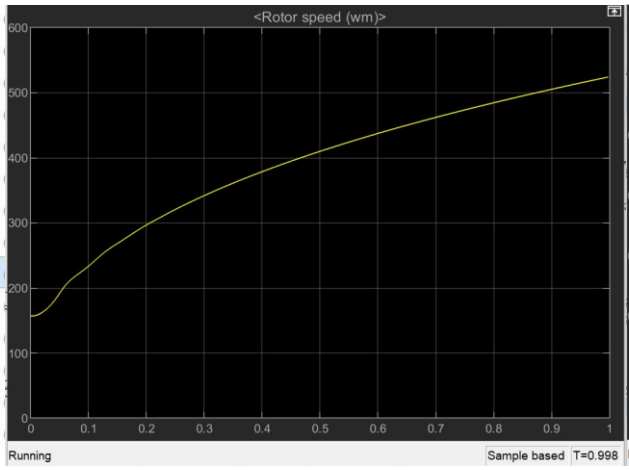
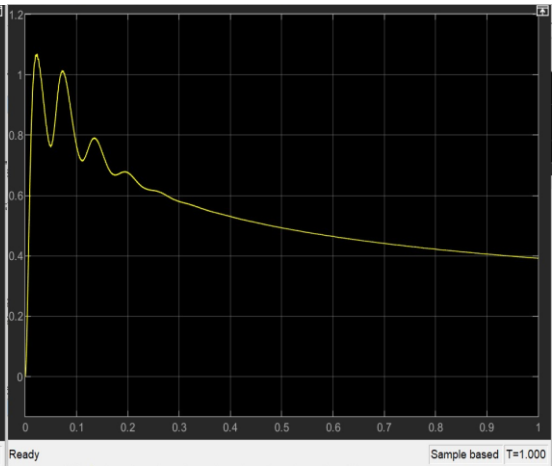
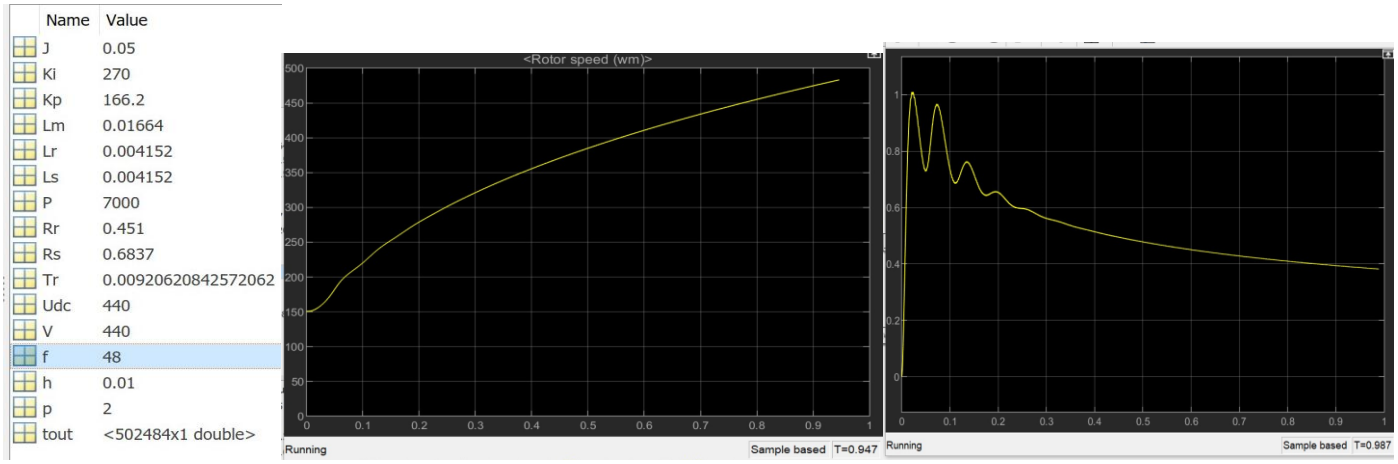
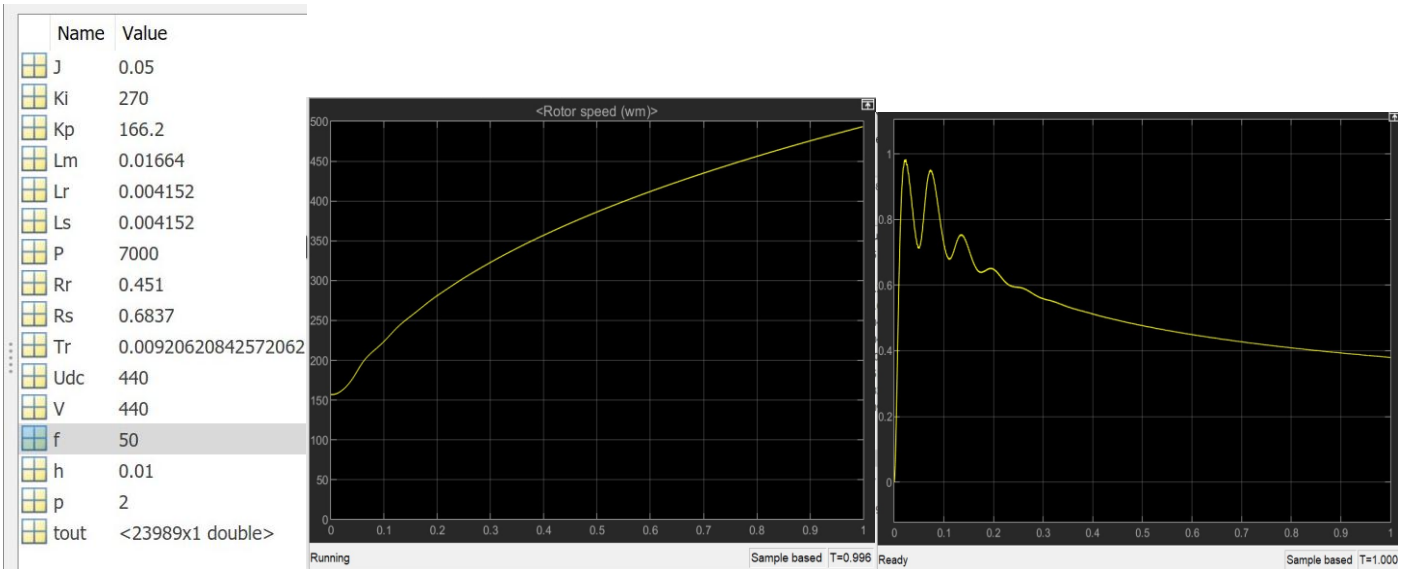


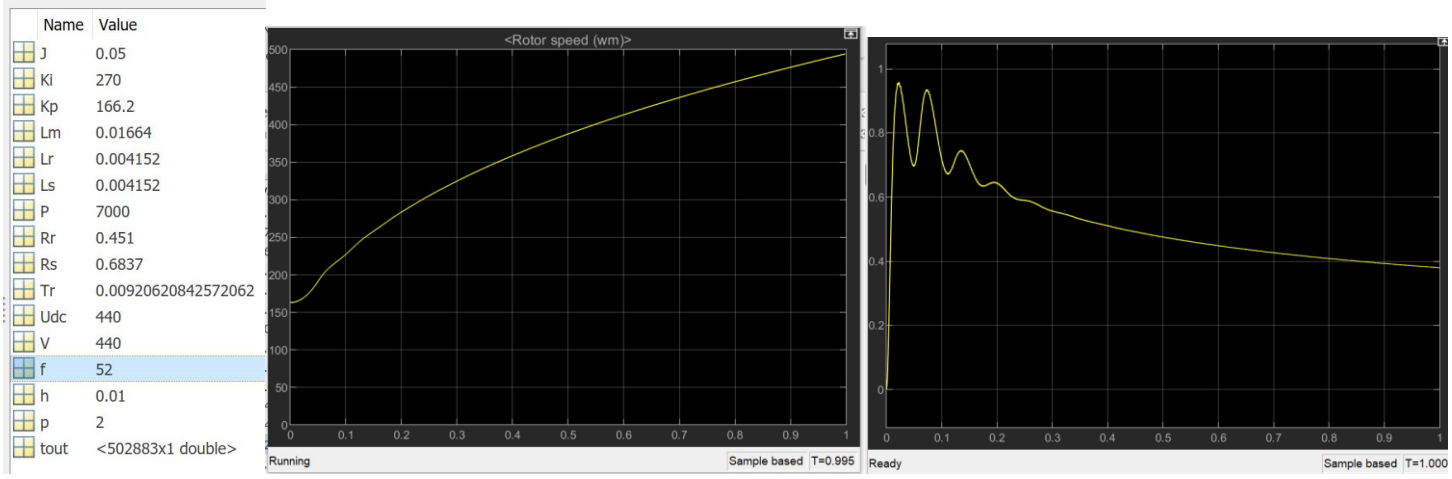


Analyzing results: - In vector speed control of induction motor whenever we are changing +10 or -10% Supply voltage then there will be no change in maximum speed and also there is no change rotor flux. But whenever we increase DC voltage then we can get a little bit of higher maximum speed and also rotor flux will be increases.

Analysis of vector speed control by varying frequency: -

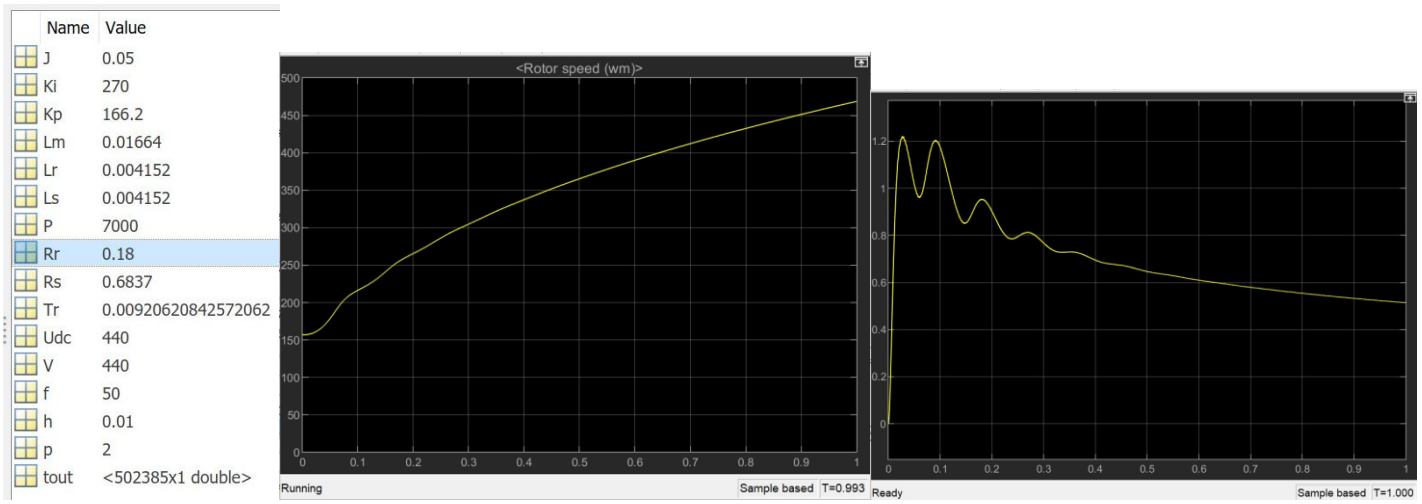


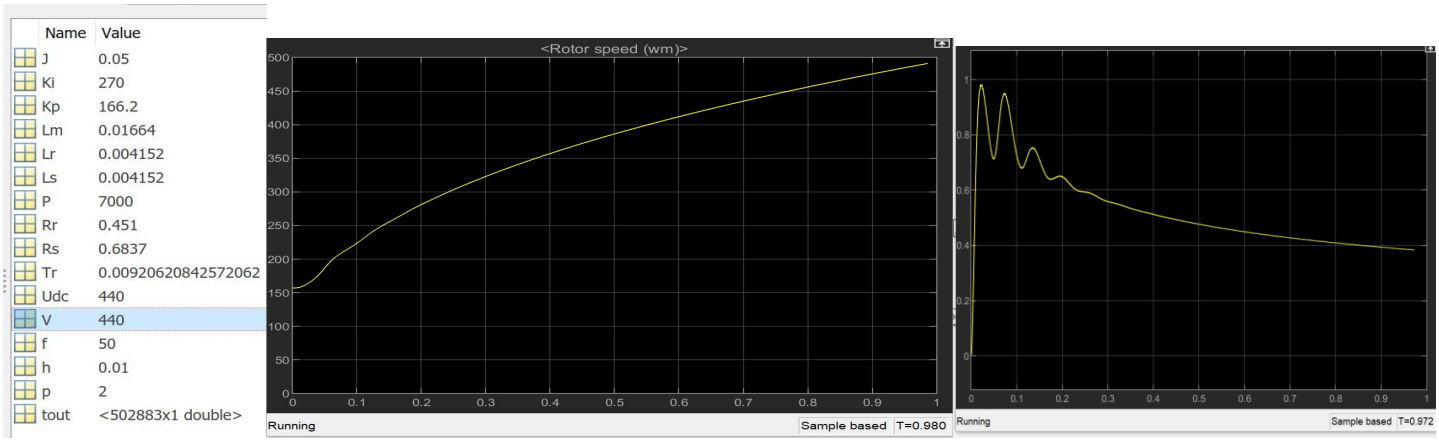


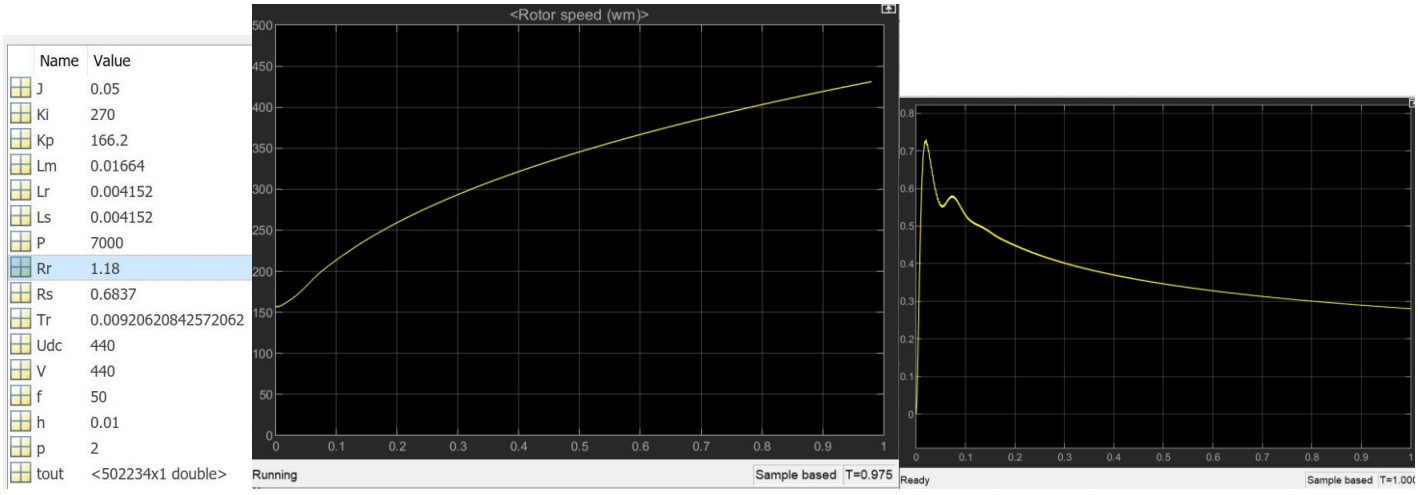


Analyzing results: - The change in frequency is not effecting on the maximum speed whenever changing 4% of frequency but there is a change in rotor flux. As the frequency decreases flux will increases and also whenever we increase frequency then rotor flux will decreases.

Analysis of vector speed control by varying rotor resistance: -







Analyzing results: - Whenever we are using lesser rotor resistance then maximum speed decreases and then while rotor resistance increases maximum speed increased .Beyond certain point of rotor resistance again maximum speed decreases. And also at lower rotor resistance values we will get higher rotor flux. And also whenever we are increasing rotor resistance then rotor flux decreases.

Advantages: -

Full torque at zero speed
Low power consumption
Controlling cost is low
Fast response
Speed of controlling rate is high
Acceleration and deacceleration rate is high

Conclusion

Vector speed control is the one of the best speed control method of induction motor to control over a full range. We can control over a full range of speed by using this method. By using this method, we can operate Induction motor just like as Dc motors. By using this method we can control induction motor very fast. And also, by using this we can get full torque at zero speed and fast control, dynamic performance of induction motor is good and power consumption is less. And also rate of acceleration and deacceleration is maximum and also accuracy of torque is high.

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