BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY

BUET

Department of Electrical and Electronic Engineering

Course No.: EEE 206 | **Group No:2**

Course Title: Energy Conversion Laboratory | **Section:B1**

PROJECT TITLE: *FIELD ORIENTED CONTROL OF THE PERMANENT MAGNET SYNCHRONOUS MOTOR(PMSM)*

Student Id of group members :

1706072

1706073

1706074

1706075

1706076

1706077

PROJECT SUPERVISERS:

1.Dr. Md. Nasim Ahmed Dewan

Professor

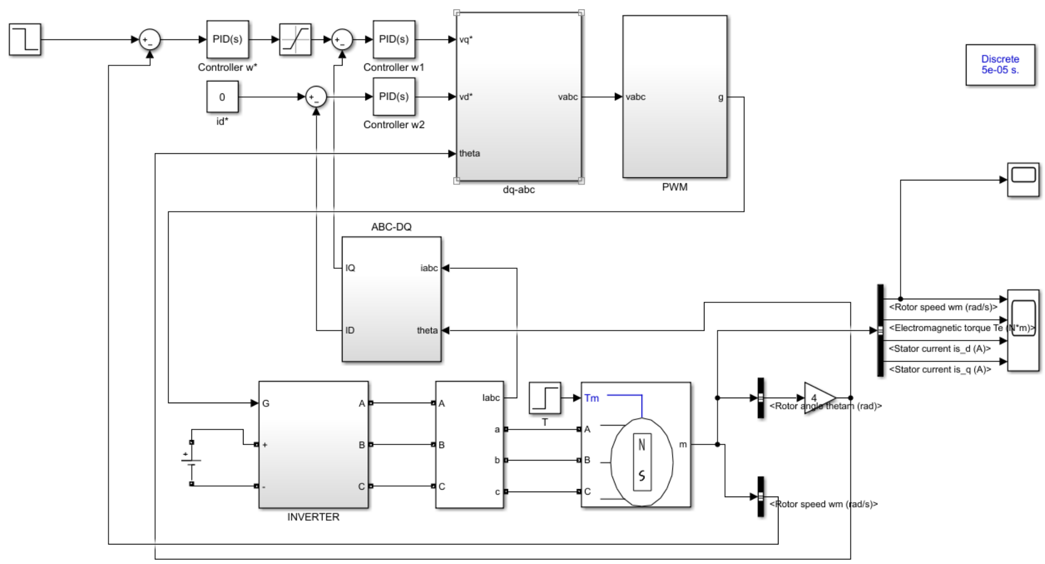
Dept. of EEE, BUET

2.Md. Hadiur Rahman Khan

Assistant Professor

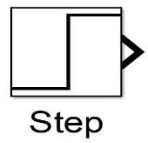
Dept. of EEE, BUET

Full Circuit Diagram:



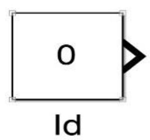
Step Block:

Step block provides a step between two definable levels at a specified time. If the simulation time is less than the step time parameter value, the block's output is the initial value parameter value. In the Simulink, we use step block to control the speed so that at a certain time one speed level is instantaneously changed to another speed level. From step block it goes through the feedback block and then goes to the PID controller block.



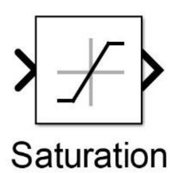
Constant Block:

Constant block is used to input constant value. Here, in the Simulink model we use constant block to give input of Id which is the direct component of current. Id value actually indicates the flux linkage component. We know flux linkage component cannot effect the torque. So, we use the value of Id zero here.From constant block Id goes through the feedback block and then goes to PID controller block.

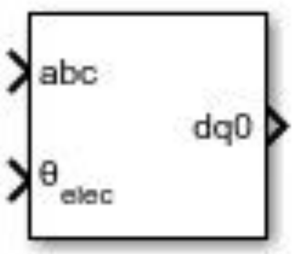


Saturation Block:

The output of PID controller goes through the saturation block in the Simulink model. The saturation block imposes upper and lower bounds on a signal. When the input signal is within the range specified by the lower and upper limit parameters, the input signal passes through unchanged. The input signal passes through without any kind of distortion or interference. Saturation also detects the zero crossing values and in the case of overshoot or undefined differentiation. Then the output of the saturation block goes through the feedback block.



ABC to DQ TRANSFORMATION:



The abc to dq0 block uses a Park transformation to transform a three-phase (abc) signal to a dq0 rotating reference frame. The Park Transform block converts the time-domain components of a three-phase system in an abc reference frame to direct, quadrature, and zero components in a rotating reference frame. The block can preserve the active and reactive powers with the powers of the system in the abc reference frame by implementing an invariant version of the Park transform. For a balanced system, the zero component is equal to zero.

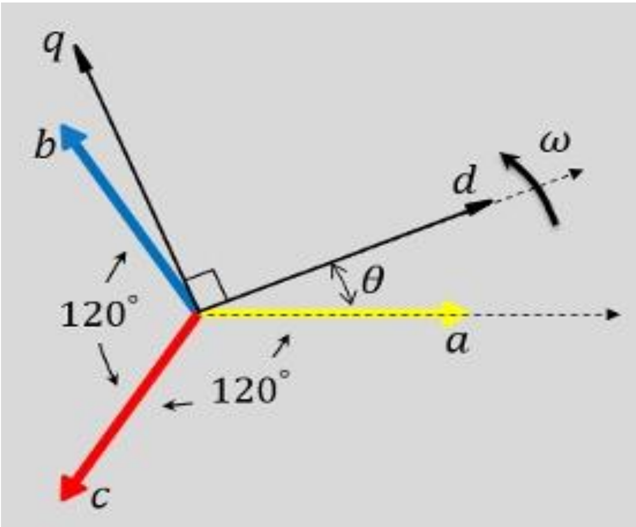


Fig: The a-axis and the d-axis alignment

Equation used for park transformation:

$Vd=(2/3)(V_a Sin(\omega t)+V_b sin(\omega t-2\pi/3)+V_c sin(\omega t+2\pi/3))$

$Vq=(2/3)(VaCos(\omega t)+V_b Cos(\omega t-2\pi/3)+VcCos(\omega t+2\pi/3))$

$V0=(1/3)(V_a+V_b+V_c)$

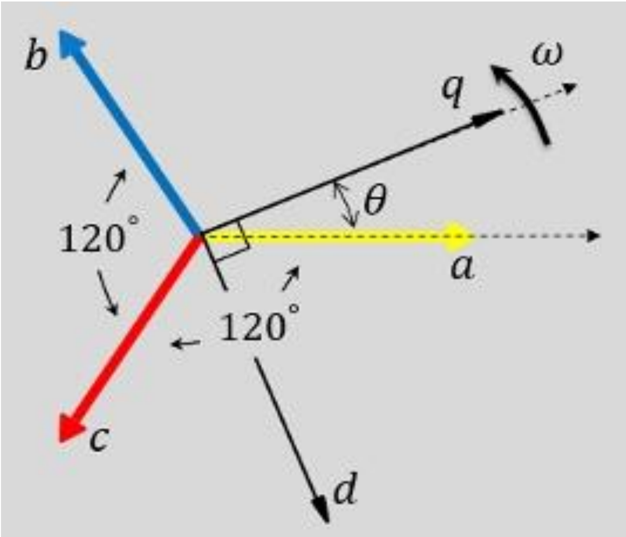


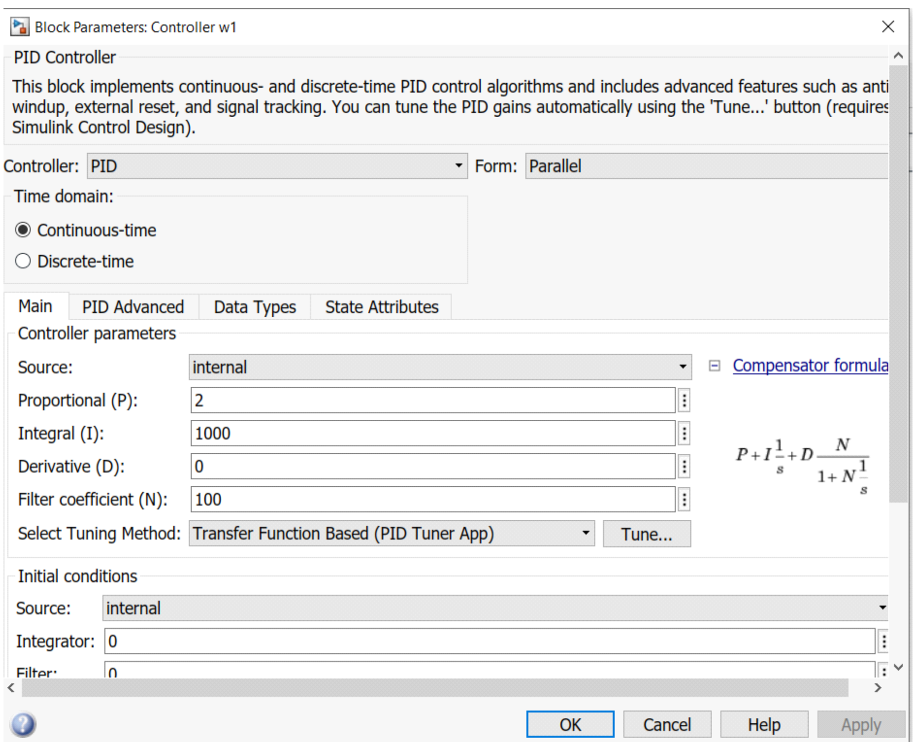
Fig: The a-axis and the q-axis alignment

The reason of abc-dq transformation is to computational purpose.PID practically offers an effective and reliable control solution when the quantities are DC in nature. As the output of the block is fed into PID through negative feedback it is convenient to use dq reference frame rather than abc reference frame for the easier control over the system. We can easily control the flux and torque component of the current through 2 phase reference system.For these reason we use abc dq block to transfer Iabc to id(direct axis) and Iq(quadrature axis).

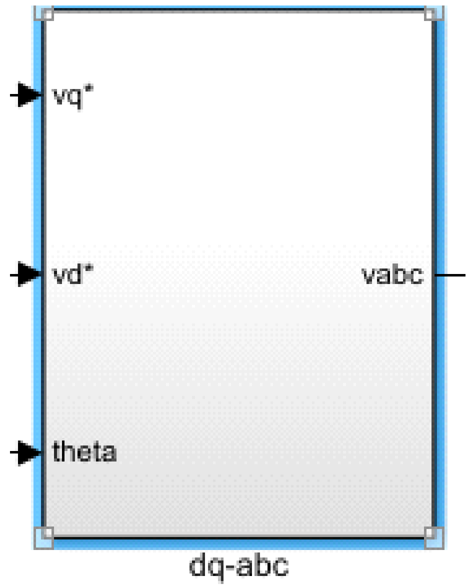
DQ to ABC TRANSFORMATION(REFERENCE VOLTAGE):

From the two-negative feedback, IQ and ID goes through the two PID controller for closed-loop control feedback to keep the actual output from a process as close to the target or setpoint output as possible.

Here, in PID blocks, time domain is continuous and in the controller parameters p refers proportionally parameter. Using proportional control alone will result in an error between the setpoint and the actual process value. I refers the history of previous errors and D refers the direction of errors.

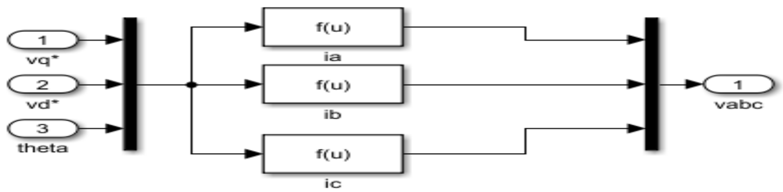


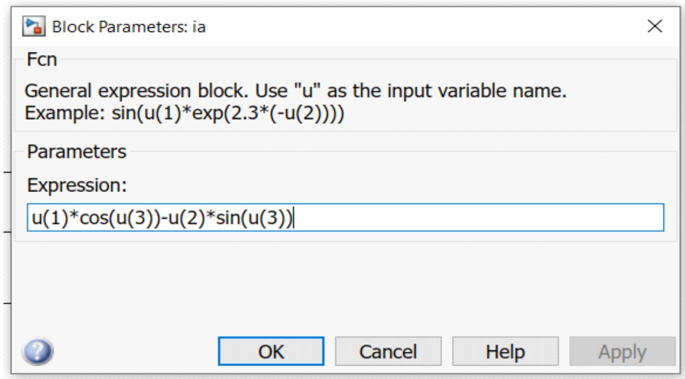
Now, the outputs of two PID controller go through the inverse park transformation block to transform the direct, quadrature and zero components in a rotating frame to the time domain components of a three-phase system in abc frame.



Inverse Park Transformation Block

And in the inverse park transformation block ,there is set of functions to transform the direct, quadrature and zero components in a rotating frame to the time domain components of a three-phase system in abc frame.





Defining Equations

The Inverse Park Transform block implements the transform for an a-phase to q-axis alignment as

$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \sin(\theta) & \cos(\theta) & 1 \\ \sin(\theta - \frac{2\pi}{3}) & \cos(\theta - \frac{2\pi}{3}) & 1 \\ \sin(\theta + \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} d \\ q \\ 0 \end{bmatrix},$$

where:

- d and q are the components of the two-axis system in the rotating reference frame.
- a, b, and c are the components of the three-phase system in the abc reference frame.
- 0 is the zero component of the two-axis system in the stationary reference frame.
- ϑ is the angle between the *a* and *q* axes for the *q*-axis alignment or the angle between the *a* and *d* axes for the *d*-axis alignment.

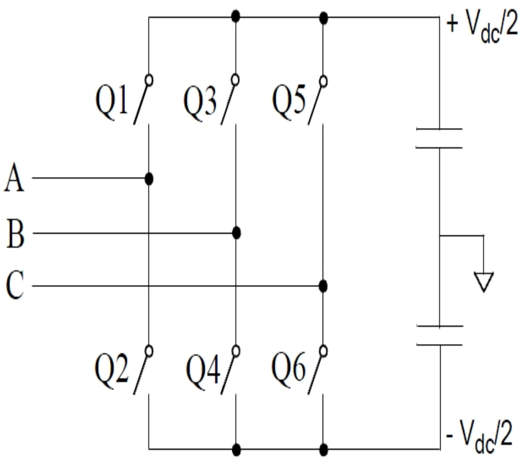
For an a-phase to d-axis alignment, the block implements the transform using this equation:

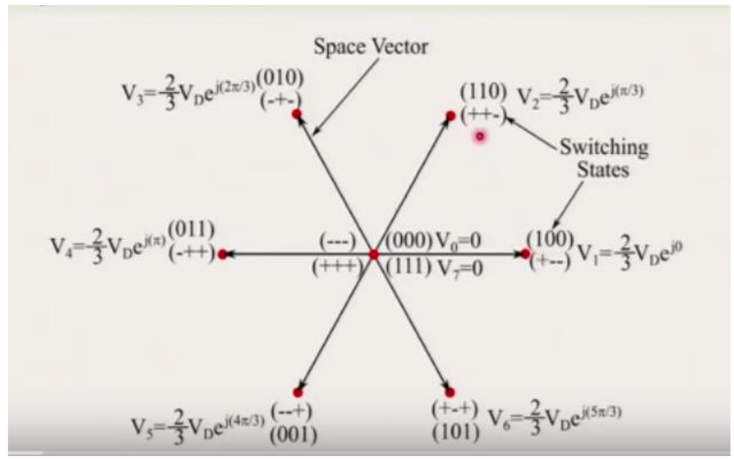
$$\begin{bmatrix} a \\ b \\ c \end{bmatrix} = \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 1 \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} d \\ q \\ 0 \end{bmatrix}.$$

SPACE VECTOR PULSE WIDTH MODULATION:

From the module of our project, we have performed a space vector pulse width modulation for our project. It involves a logical switching sequence and proper timing of the switching sequence to create a reference voltage. There are eight space vectors.

Switching sequence(logical) and Output voltage space of the two level inverter in dq coordinates:



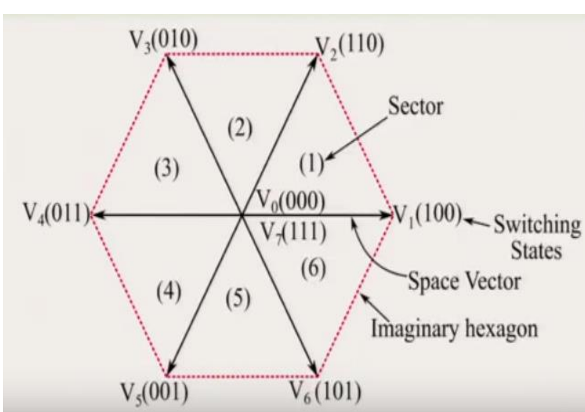


As shown in the following figure, the objective of the SVPWM technique is to approximate the reference voltage vector (V_{ref}) instantaneously by combining the switching states corresponding to the basic space vectors.

The eight space vectors are denoted by these red colored dots. There are six active vectors which are at the six corners of an imaginary hexagon and two inactive or zero vectors at the centre of the hexagon. As they are vectors, they are denoted by six arrow symbols. The magnitudes(2/3 of V_d) of these active vectors are same . That is why it is a regular hexagon.

We can now create boundary for the hexagon and then by making boundary we eventually have drawn up six sectors in the hexagon.

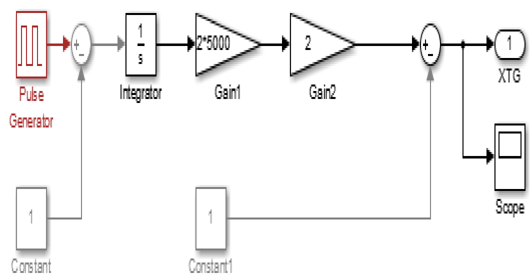
Sectors in Space Vector Diagram:



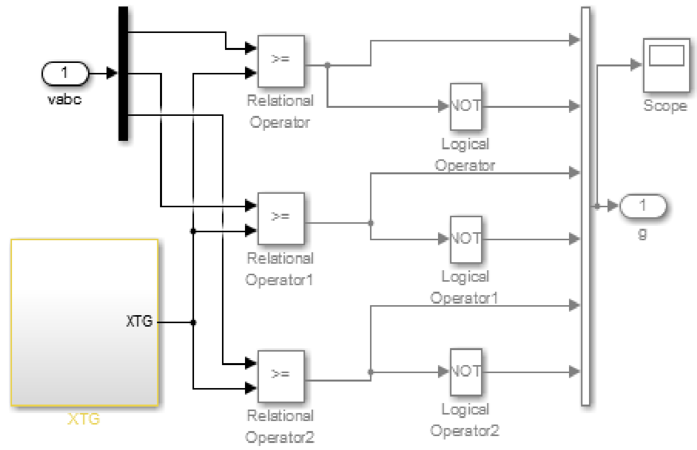
The reference vector at any point can be realized by the clever switching the nearest vectors in the same sector where the reference vector lies. The maximum voltage can be observed when the vector arrow touches the perimeter of the circle inscribed in the hexagon. $V_{R,max}$=(2/3)*cos(pi/6)V_D=.577 V_D. The harmonic performance of the PWM is much better.

Space vector PWM can be done by using the same carrier based approach like the sine PWM that does not require any complex timing and calculation.

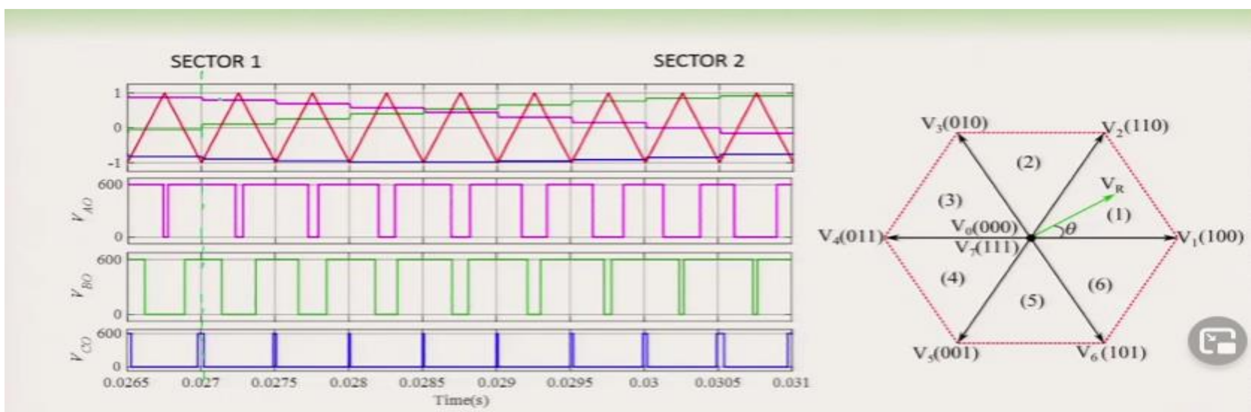
THE PULSE TRAIN PRODUCING MODULE:



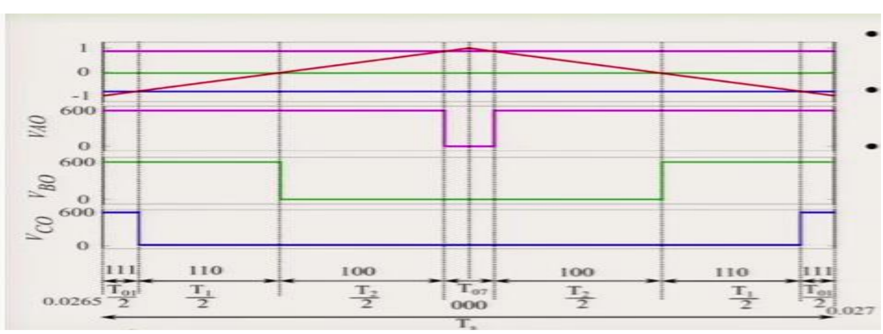
THE LOGIC COMPARATOR AND SWITCHING MODULE:



A ZOOMED VIEW OF THE PWM OPERATION:



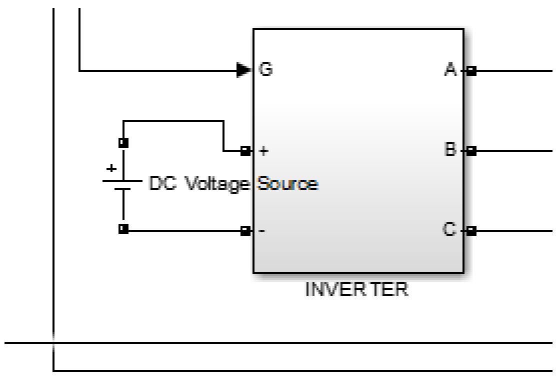
The pattern in the sector 1 can be characterized by 111-110-100-000-100-110-111 and so on.The pattern in the sector 2 can be characterized by 111-110-010-000-010-110-111 and so on.Now let us focus on only a small carrier:

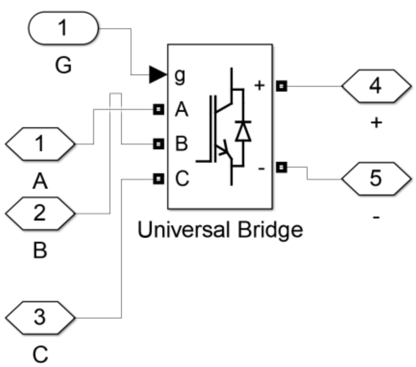


In SVPWM , the starting (000) and ending(111) vectors in switching cycle will always be equal.

Inverter:

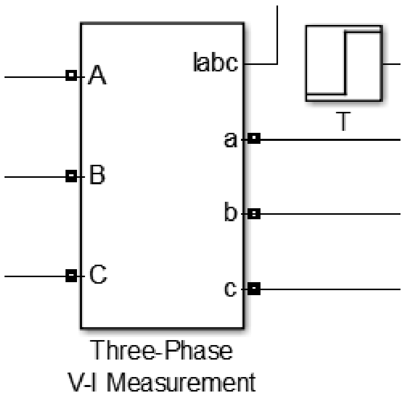
Now we need to convert the DC signal which is the output signal of the PWM blocks, to the AC signal through the inverter block where universal bridge is used.

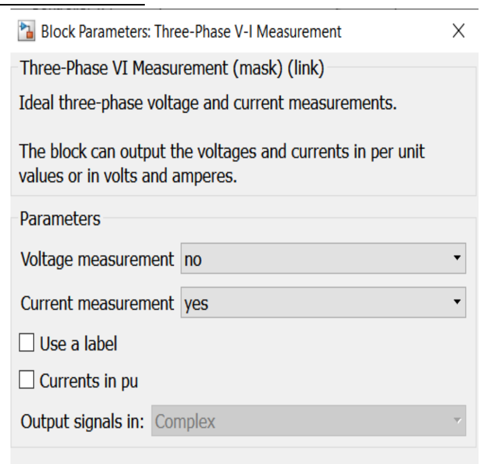




3 Phase VI Measurement Block:

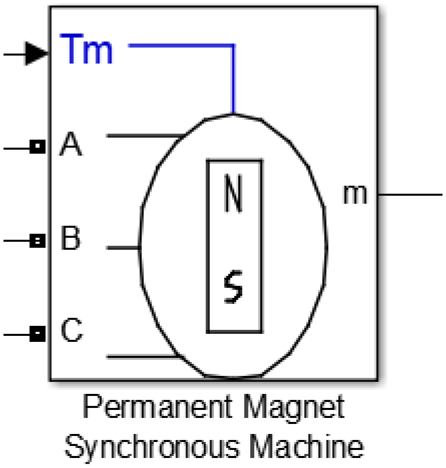
And the AC signal goes through the 3 phase VI measurement block from the inverter & there is current measurement parameter, not the voltage measurement parameter in the 3 phase VI measurement block.

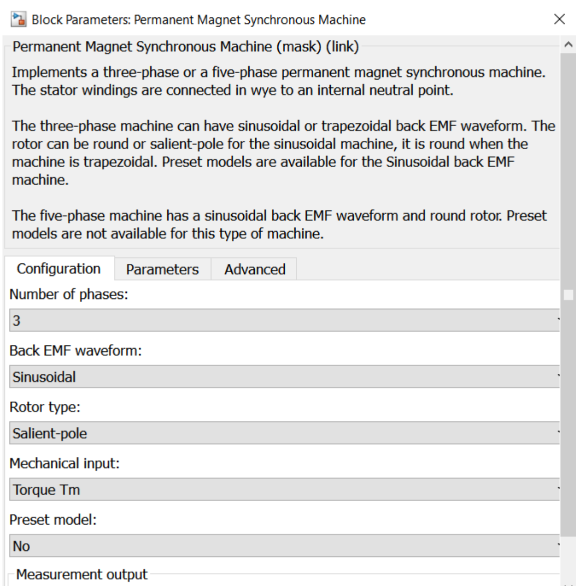




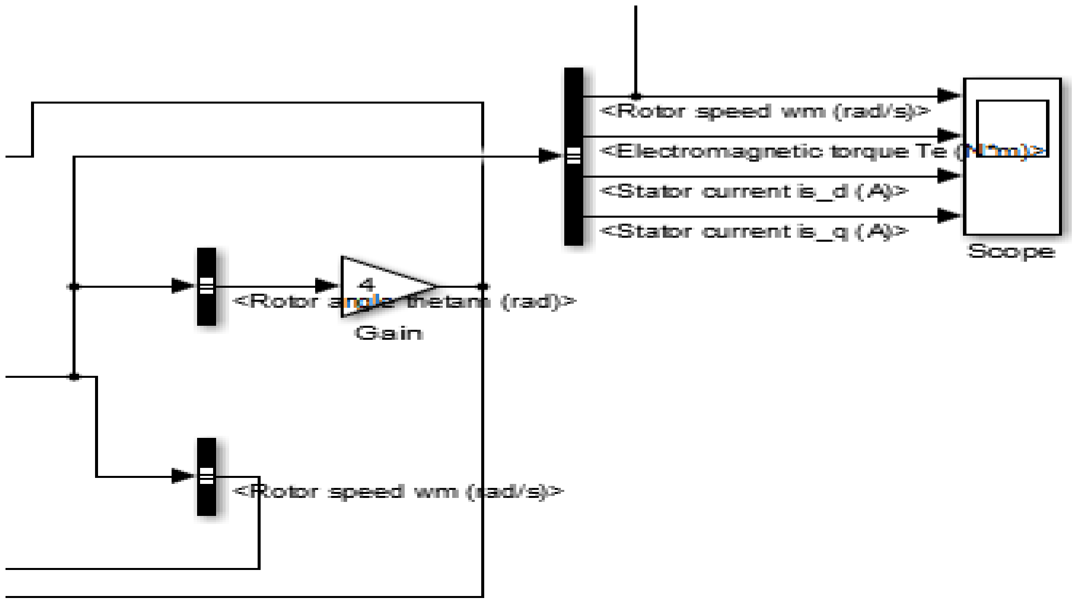
<u>Permanent Magnet Synchronous Machine:</u>

Then the output of 3 phase VI measurement block goes to the permanent magnet synchronous machine block which's configuration is shown here: here we can see the mechanical input of the block is Torque and the rotor type is Salient pole.





Then the output goes through two bus creator block that is actually a group of signals represented by a single line in a block diagram. And the output signal of permanent magnet synchronous machine goes through another bus that represents a four set of signals. They are: Rotor speed, Electromagnetic Torque, Stator Current in two phase reference frame of direct axis and quadratic axis. These four signals goes through the scope block in which we can see the graph of these signals with respect to the change of time.


<Rotor speed wm (rad/s)>
<Electromagnetic torque Te (N*m)>
<Stator current is_d (A)>
<Stator current is_q (A)>
Scope
4
<Rotor angle thetam (rad)>
Gain
<Rotor speed wm (rad/s)>

THE FINAL OUTPUT OF THE PROJECT:

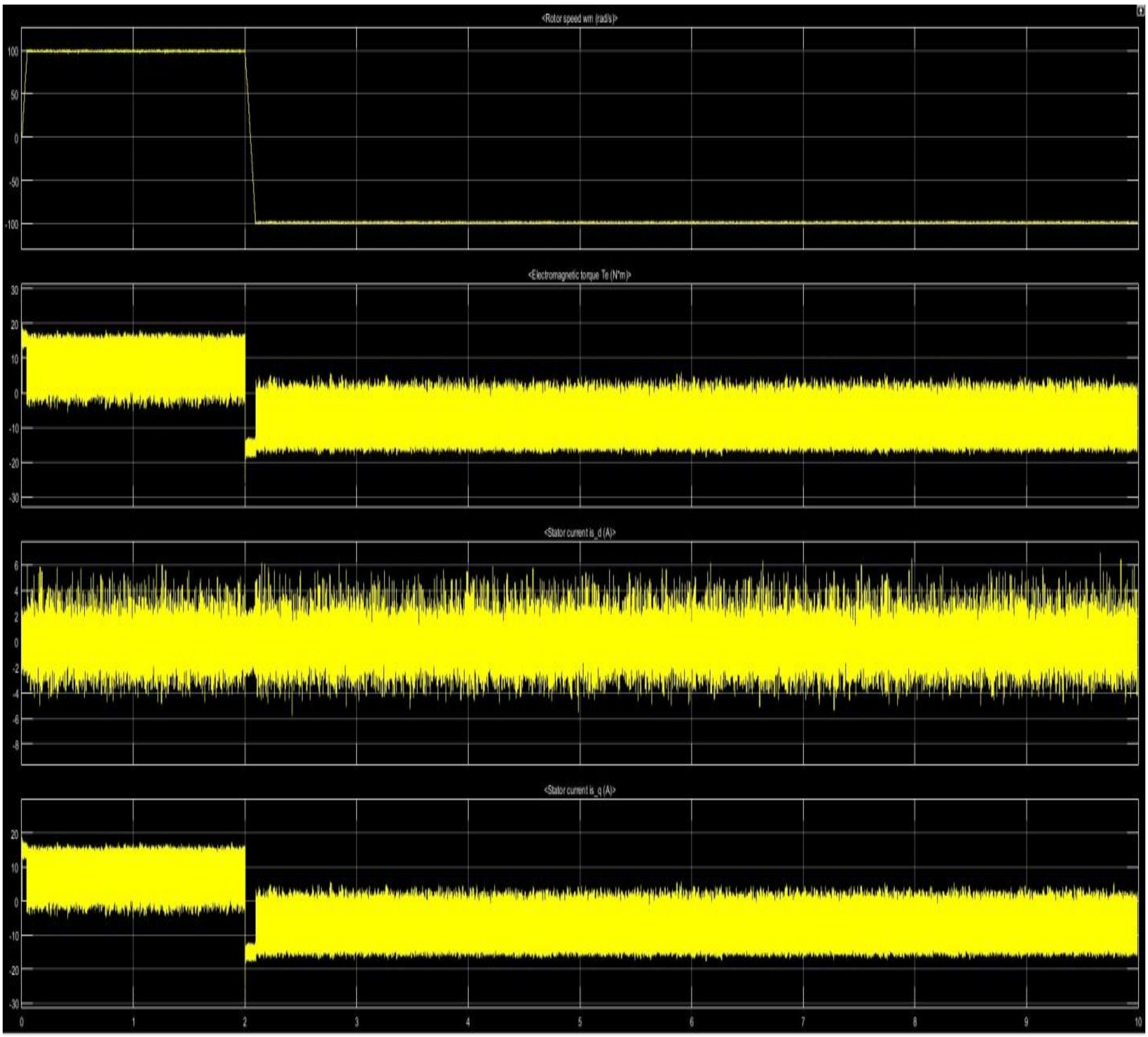
THE FOUR AREA OF INTERESTS ARE:

1.ROTOR SPEED,

2.ELECTROMAGNETIC TORQUE,

3. STATOR CURRENT (D-AXIS ELEMENT),

4.STATOR CURRENT (Q-AXIS ELEMENT)



In the following graph, we have set the reference speed of out motor at 100 rpm. We can see the speed of the machine changed from 0 to 100 rpm within 0.05s. The electromagnetic torque was about 20 Nm which satisfied the condition of maximum torque at starting. Then at 2 s, we changed our reference speed at -100 rpm, in other words, we reversed the direction of the motor. The change was quite instantaneous & subsequently the EM torque changed to -20 Nm.

On the other hand, the stator current is decomposed into two orthogonal components, Direct axis component & quadrature axis component. We can see that the direct current component doesn't contribute to the electromagnetic torque. The current is peak to peak 5 A with average current zero. At the same time, the stator current is 20 A with a subsequent drop to -20 A at 2s. Thus we have successfully controlled the speed regulation.