Project Report

Of

Asynchronous and Synchronous Machines

On

Applications & Simulations of Permanent Magnet Synchronous Machines

submitted towards the partial fulfilment of

the requirement for the award of the degree of

Bachelor of Technology

In

Electrical Engineering

Submitted by

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CANDIDATE'S DECLARATION

We, **Ritul (2K20/EE/221)** and **Saarthak Vijay Singh (2K20/EE/229)** students of B. Tech. hereby declare that the project titled '**Applications & Simulations of Permanent Magnet Synchronous Machines**' which is submitted by us to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Bachelor of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the project titled '**Applications & Simulations of Permanent Magnet Synchronous Machines**' which is submitted by, **Ritul (2K20/EE/221)** and **Saarthak Vijay Singh (2K20/EE/229**) of Delhi Technological University, Delhi in complete fulfillment of the requirement for the award of the degree of the Bachelor of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi

Prof. Krishna Dutt
SUPERVISOR

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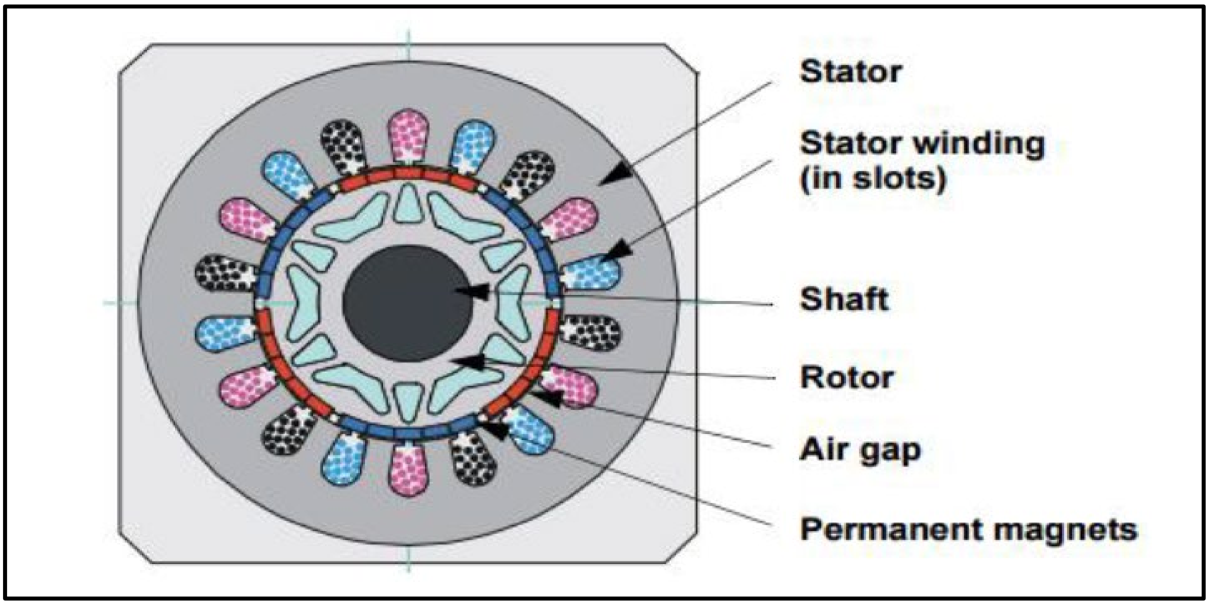
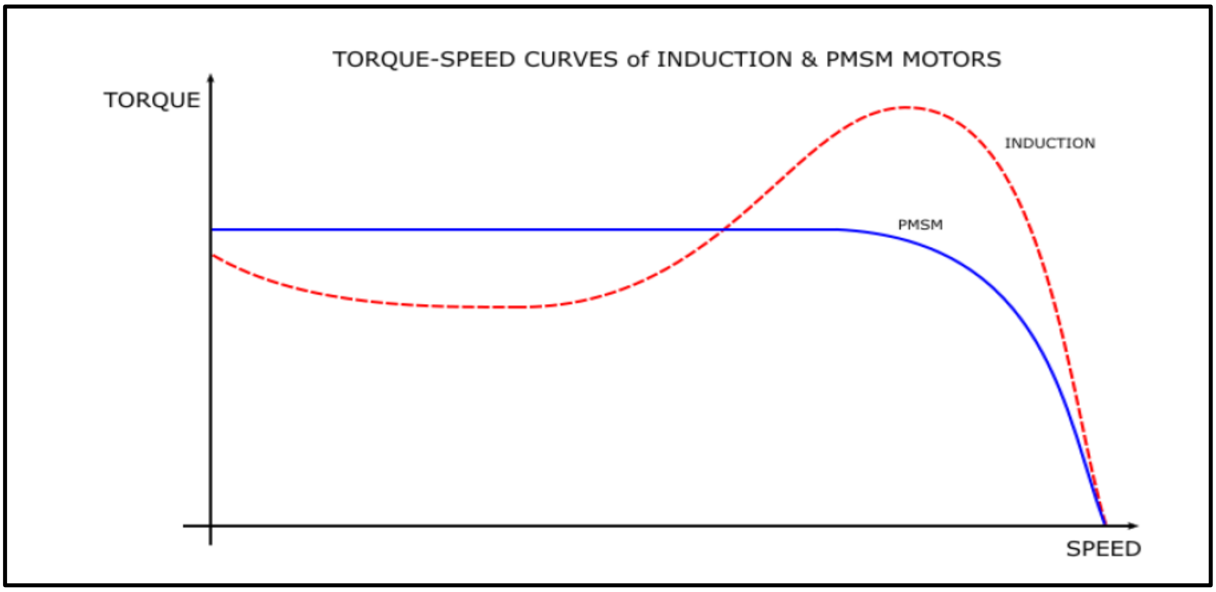
INTRODUCTION

Permanent Magnet Synchronous Motor

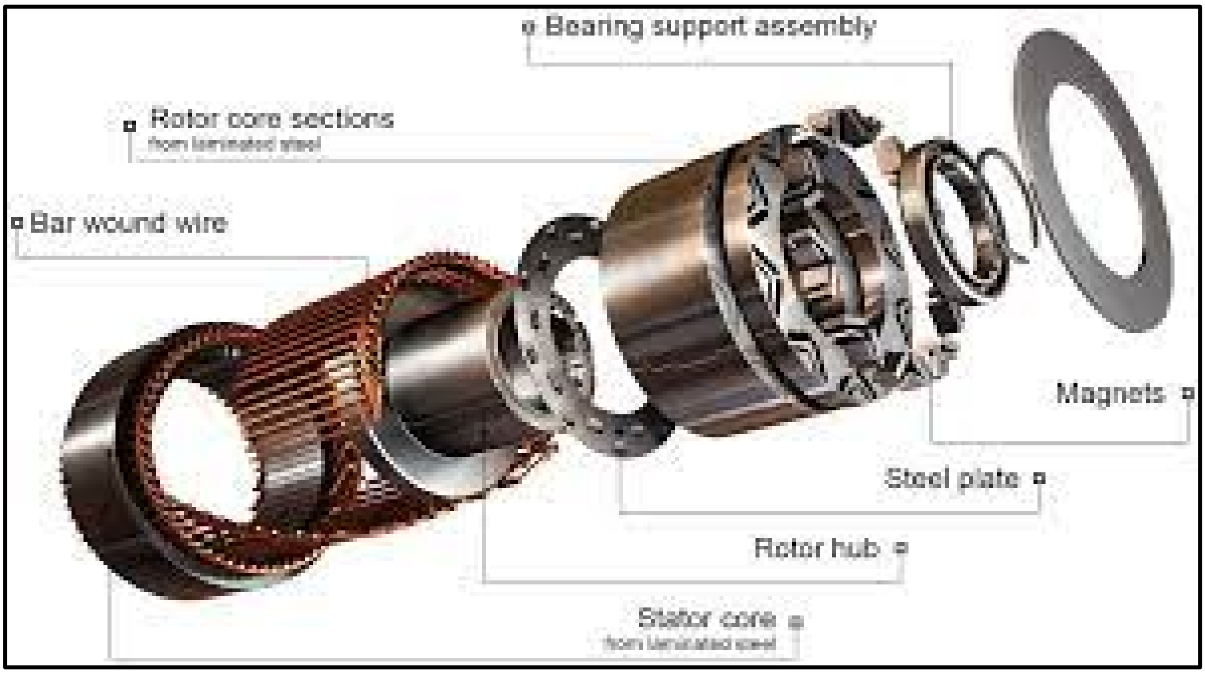
Permanent-magnet synchronous motors (PMSM) refer to the group of motors that rotate at the same speed as the supply frequency and have permanent magnets embedded in their rotor. Due to its permanent magnet rotor, it also has a high torque with a small frame size and no rotor current. Instead of using winding for the rotor, permanent magnets are mounted to create a rotating magnetic field. The magnets on the rotor produce a constant magnetic flux in the air gap between the rotor and stator. The performance output of a PMSM motor is limited by the counter electromotive force (back EMF) that is generated in the stator windings when the motor rotates. The back EMF has a polarity that opposes the voltage supplied to the motor windings.



Permanent-magnet synchronous motors are the most popular choice for electric vehicle manufacturers because of their greater power density and flatter torque profile. The torque output of an induction motor is non-linear, whilst a PMSM motor has a relatively flat torque output up until the knee-point, where the back EMF is large enough to limit motor current. In general, a PMSM motor outputs a greater torque at low speeds as the permanent magnets produce a constant magnetic field. The peak efficiency of PMSM motors is also greater than that of an induction motor as there are no magnetic losses in the rotor.



The permanent magnet synchronous motors, like any rotating electric motor, are consisted of a rotor and a stator. The permanent magnet synchronous motor construction is similar to the basic synchronous motor, but the only difference is with the rotor. In this type of motor, the permanent magnets are mounted on the rotor and the rotor doesn't have any field winding.



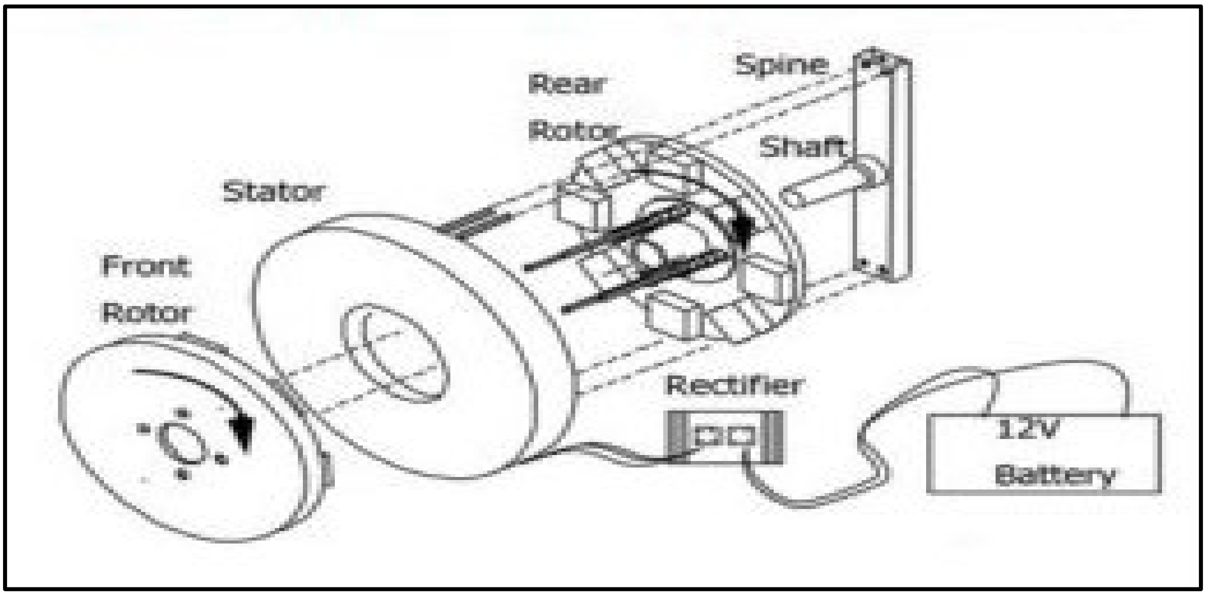
The permanent magnets are used to create field poles. The permanent magnets used in the motor are made up of samarium-cobalt and medium, iron, and boron because of their higher permeability. The most widely used permanent magnet is neodymium-boron-iron because of its effective cost and ease of availability.

	PMSM	INDUCTION
Torque Density	Permanent magnets increase magnetic field strength and application torque. Flatter torque-speed profile means torque can be applied consistently over motor's speed range.	Magnetic field must be induced in rotor and is hence weaker, reducing the applicable torque. Non-linear torque-speed profile means torque is reduced at lower motor speeds.
Power Density	PMSM motors can be implemented in more confined spaces, for example wheel hubs	A greater amount of steel laminations is required to match the power capabilities of a PMSM motor. This, in addition to endplates and stator back iron, increases motor mass and size, thus decreasing power density and power-to-weight ratio
Efficiency	Lack of rotor losses means PMSM motors are more efficient across a comparable speed range	High rotor losses due to induced magnetic field reduces overall efficiency.
Durability	Permanent magnets are vulnerable to high temperatures and high acceleration vibrations which cause them to demagnetise, thus reducing motor output torque and power.	Simplistic construction and lack of magnets means induction motors are more robust than PMSM motors
Cost	Rare-earth permanent magnets are at the influence of the global market. Their complex construction means PMSM motors are comparatively more expensive than induction motors.	Simplistic construction and use of standard ferromagnetic materials reduces manufacture costs significantly

Permanent Magnet Synchronous Generator

The permanent magnet synchronous generator is called so because in this synchronous generator excitation is provided with the permanent magnets instead of the external excitation source. Its rotor consists of permanent magnets that generates a field for excitation and replaces the external supply source for the generator.

In most of generation power plants like steam turbines, hydro turbines, and in gas turbines synchronous generator is used. Like other generators, the physical structure of this generator is the same it also consists of the rotor which also comprises of the permanent magnet with the shaft connected with it.



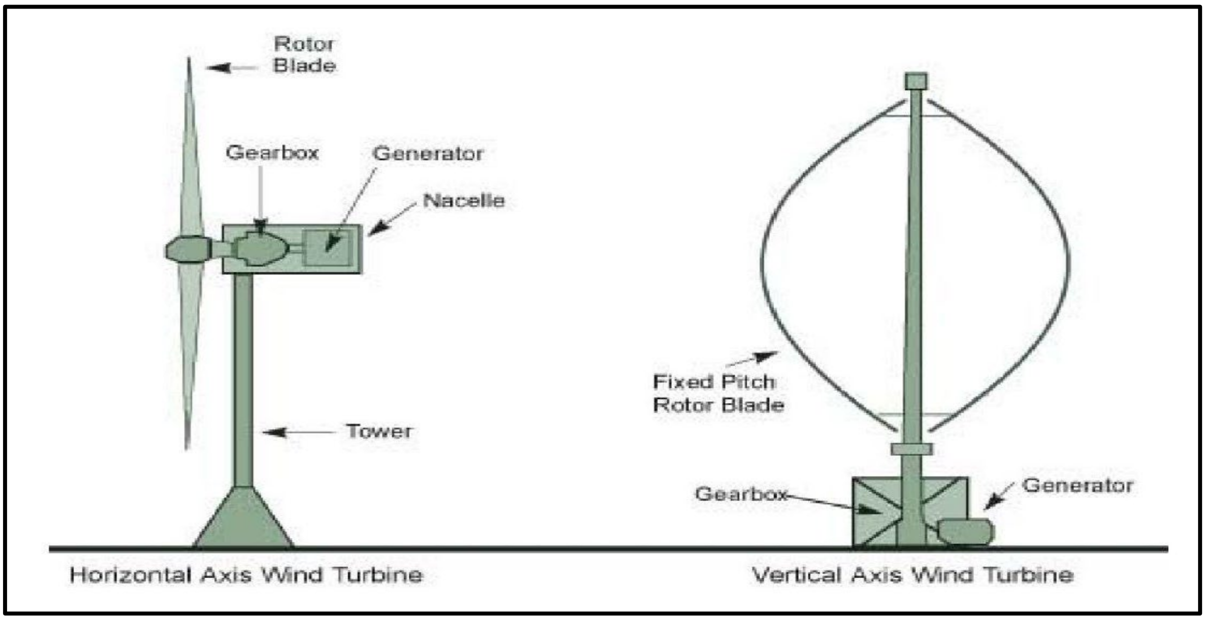
In permanent magnet synchronous generator, there is no need of the slip rings and carbon brushes, which make the machine less expensive, lightweight, and maintenance of the generator also decreases. But in high rating generators, large size generators are used that make machines somewhat expensive and increases the price. The generator attached with the power electronic conversion circuitry can work on the less speed and so there is no need of the gearbox. The presence of gearboxes increases the price, energy losses, and cost of repairing the generator but without the gearbox price and weight of circuitry deceases but it also the best option for the offshore applications.

APPLICATIONS

PMSG based WECS

Wind Energy Conversion System

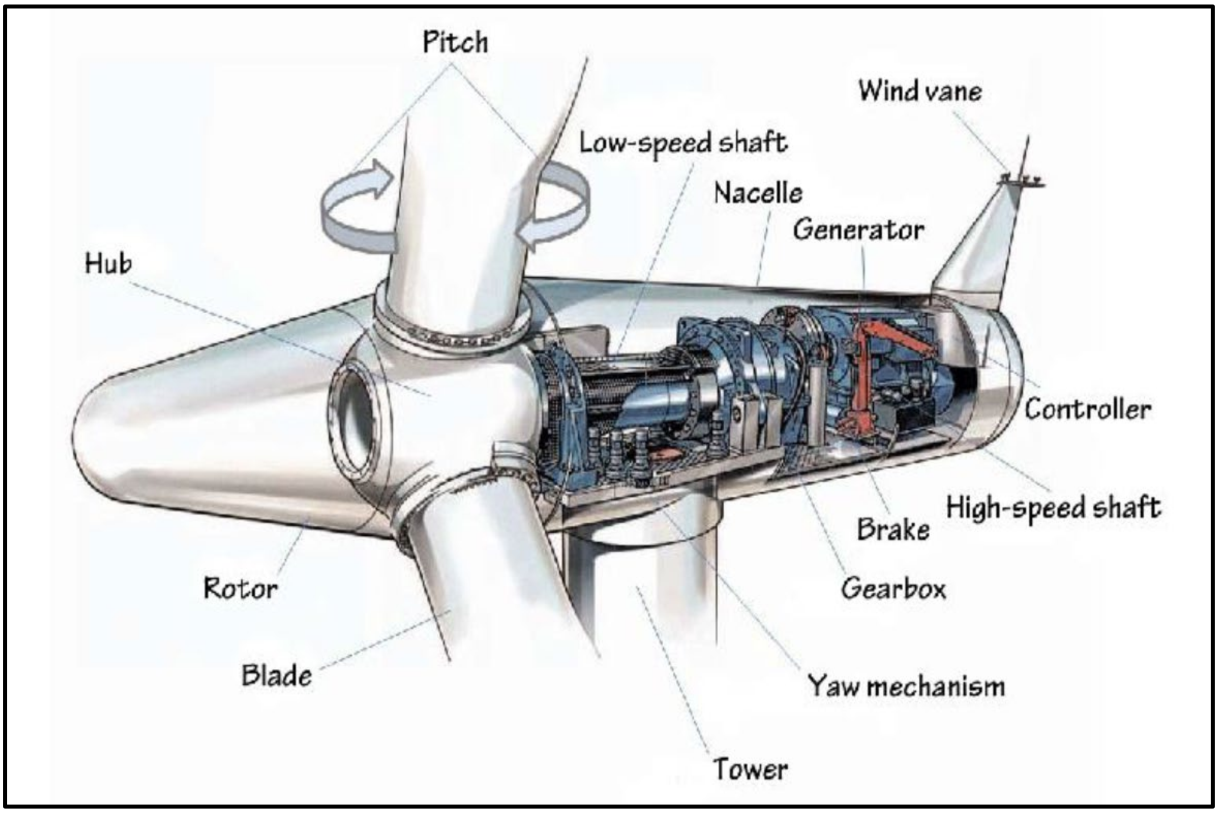
A WECS is a structure that transforms the kinetic energy of the incoming air stream into electrical energy. This conversion takes place in two steps, as follows. The extraction device, named wind turbine rotor turns under the wind stream action, thus harvesting a mechanical power. The rotor drives a rotating electrical machine, the generator, which outputs electrical power. Wind turbines are classified into two general types: horizontal axis and vertical axis. A horizontal axis machine has its blades rotating on an axis parallel to the ground. A vertical axis machine has its blades rotating on an axis perpendicular to the ground. Today, the vast majority of manufactured wind turbines are horizontal axis with two or three blades, operating either down-wind or up-wind.



A typical wind turbine consists of the following components:

- Blade- An important part of a wind turbine that extracts wind energy.
- Hub- Blades are fixed to a hub which is a central solid part of the turbine.
- Gear box- Two types of gear box used in wind turbine-
- Parallel shaft-It is used in small turbines, design is simple, maintenance is easy, high mass material and offset shaft.

- Planetary shaft- It is used in large turbines, complex design, low mass material and in line arrangements.
- Brakes-Two independent brakes sets or incorporated on the rotor low speed shaft and high-speed shaft. The low-speed shaft is Hydraulic operated. The high-speed shaft is self-adjusted and spring loaded.
- Nacelle- The nacelle houses the generator, the gearbox, the hydraulic system and yawing mechanism.
- Generator- The conversion of mechanical power of wind turbine into the electrical power can be accomplished by one of the following type of the electrical machine-
    - Synchronous machine
    - Induction machine
- Tower- Towers are made from tubular steel, concrete or steel lattice. Because wind speed is getting higher with the height, taller towers enable turbines to capture more energy and this way generates more electricity.



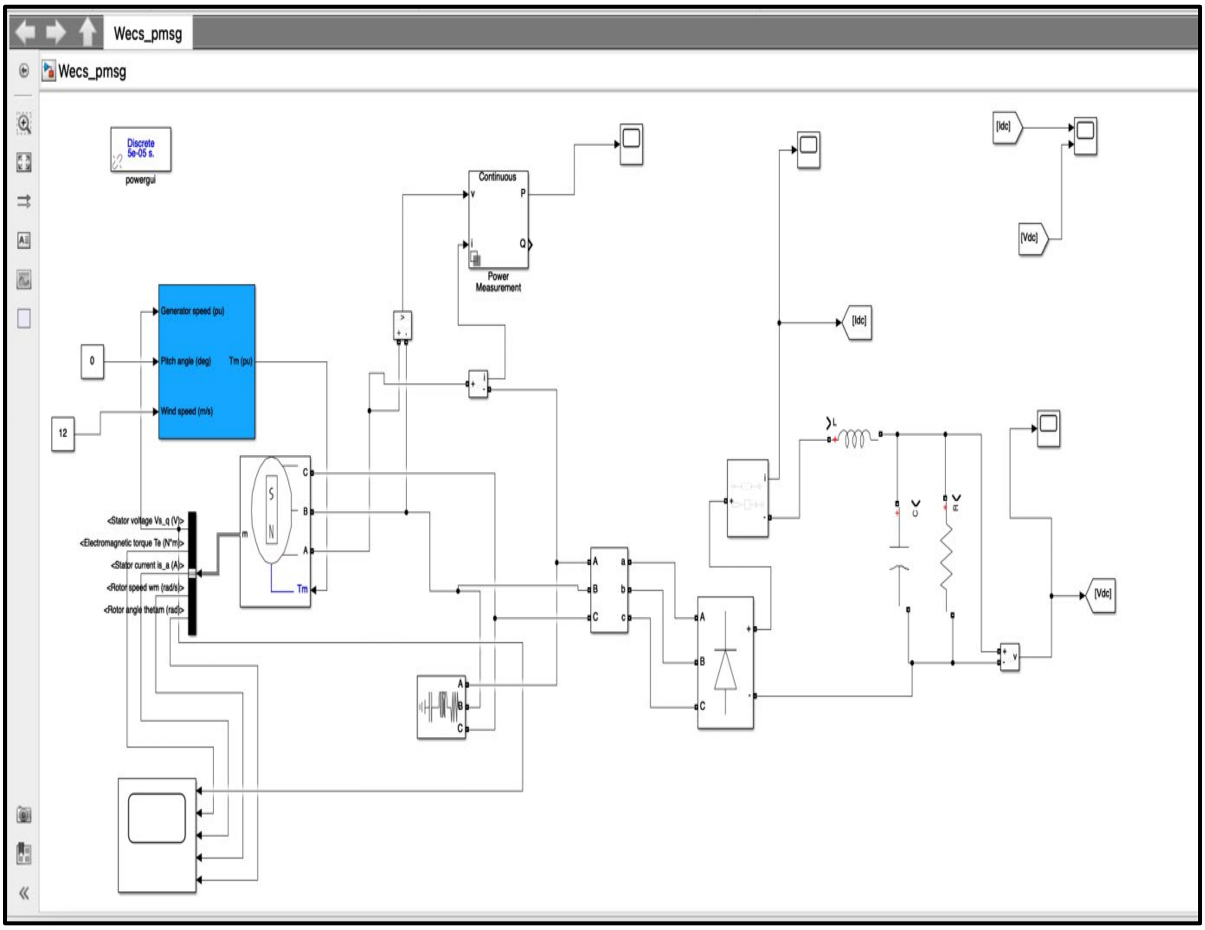
Working of the wind turbine is as follows-

- Wind blows toward the turbine's rotor blades.
- The rotors spin around, capturing some of the kinetic energy from the wind, and turning the central drive shaft that supports them.

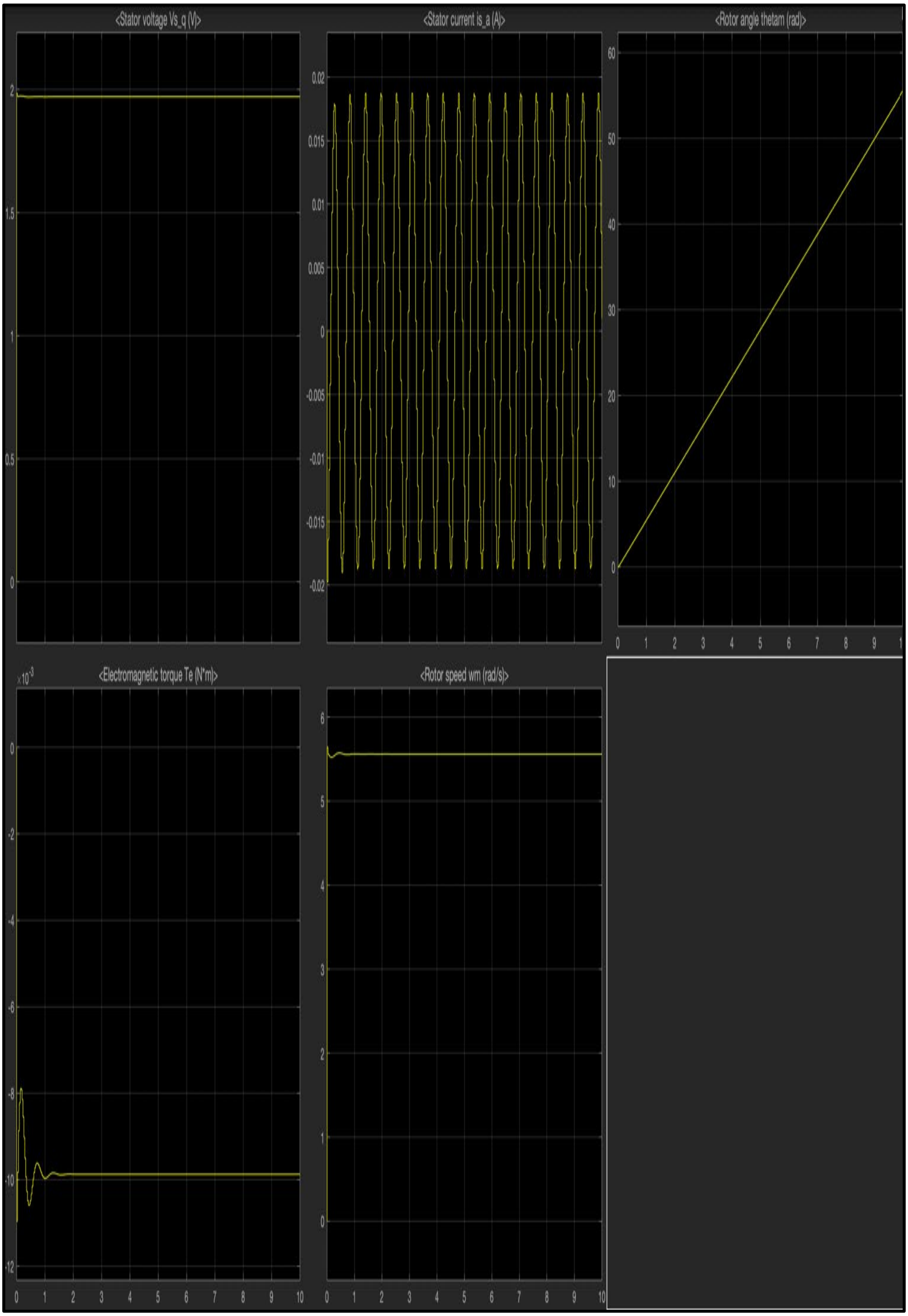
- In most large modern turbines, the rotor blades can swivel on the hub at the front so they meet the wind at the best angle for harvesting energy. This is called the pitch control mechanism.
- Inside the nacelle, the gearbox converts the low-speed rotation of the drive shaft into high-speed rotation fast enough to drive the generator efficiently.
- The entire top part of the turbine can be rotated by a yaw motor, mounted between the nacelle and the tower, so it faces directly into the oncoming wind and captures the maximum amount of energy.
- The electric current produced by the generator flows through a cable running down through the inside of the turbine tower.
- A step-up transformer converts the electricity to about 50 times higher voltage so it can be transmitted efficiently to the power grid. If the electricity is flowing to the grid, it's converted to an even higher voltage by a substation nearby, which services many turbines.

Simulation

Simulink Schematic



Output

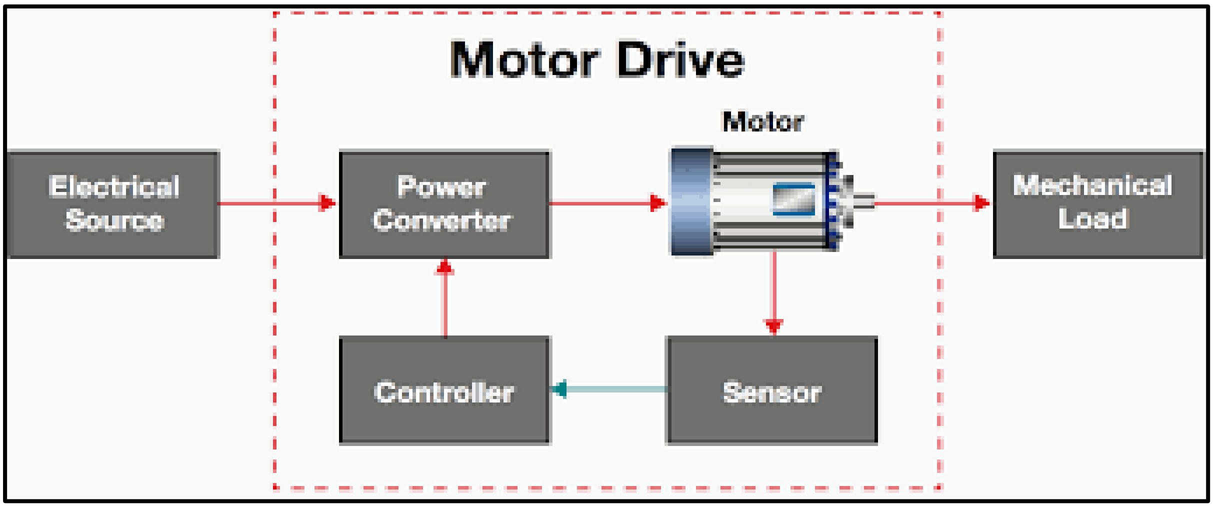

<Stator voltage Vs_q (V)>
<Stator current is_a (A)>
<Rotor angle thetam (rad)>
<Electromagnetic torque Te (N*m)>
<Rotor speed wm (rad/s)>

PMSM Drive Using 3 Phase Sine PWM Inverter

Motor Drive

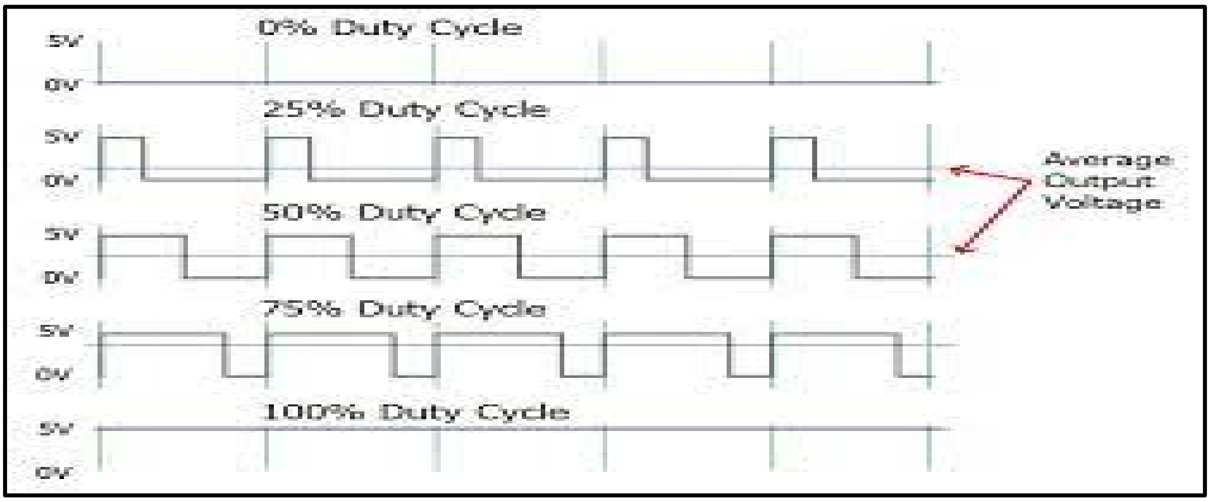
More generally, the term drive, describes equipment used to control the speed of machinery. A motor drive controls the speed, torque, direction, and resulting horsepower of a motor.

The number of poles and applied frequency determine speed. A drive provides many different frequency outputs. Any given frequency output of the drive produces a unique torque curve. The drive's control board signals control circuits to turn on the waveform positive or negative half of the power device. Alternating positive and negative switches recreates the three-phase output. The longer the power device remains on, the higher the output voltage. The longer it is off, the lower the output frequency. The drive output is not an exact replica of the ac input sine waveform. Instead, it provides constant magnitude voltage pulses.

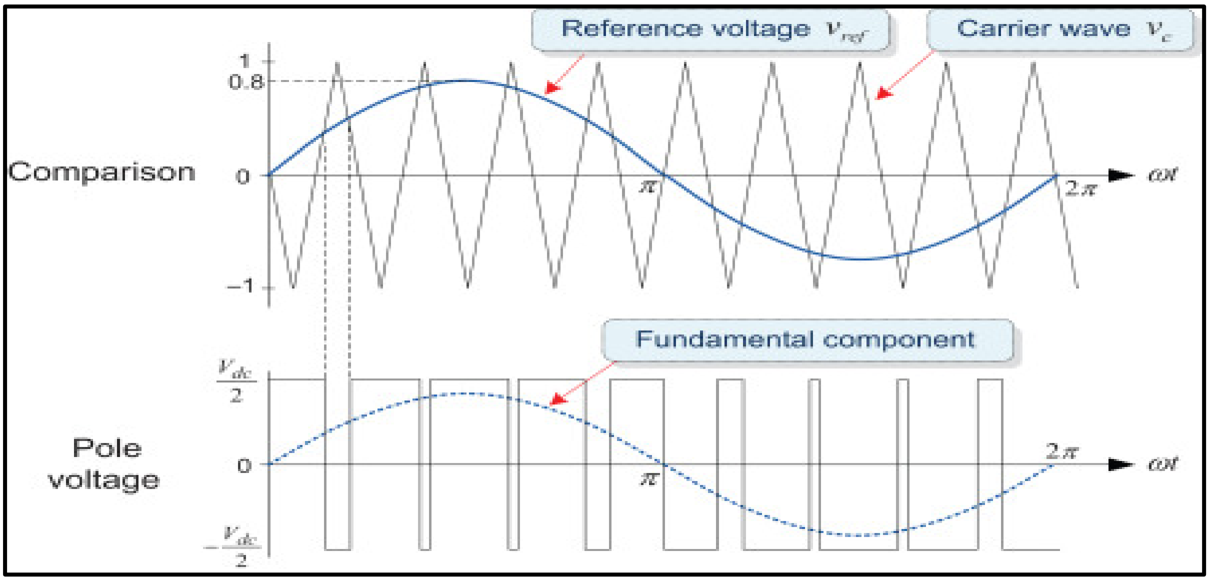


Pulse Width Modulation

In Pulse Width Modulation (PWM) technique, pulses of constant amplitude but different duty cycles are generated by modulating the time periods. This modulation is done by using one carrier and one reference signal. These two signals are fed to a comparator and the corresponding signals are generated based on the logic of the comparator. The reference wave is the desired signal output which may be a sine wave or a square wave. The carrier wave, on the other hand, is generally sawtooth or triangular wave having frequency significantly higher than that of the reference signal.

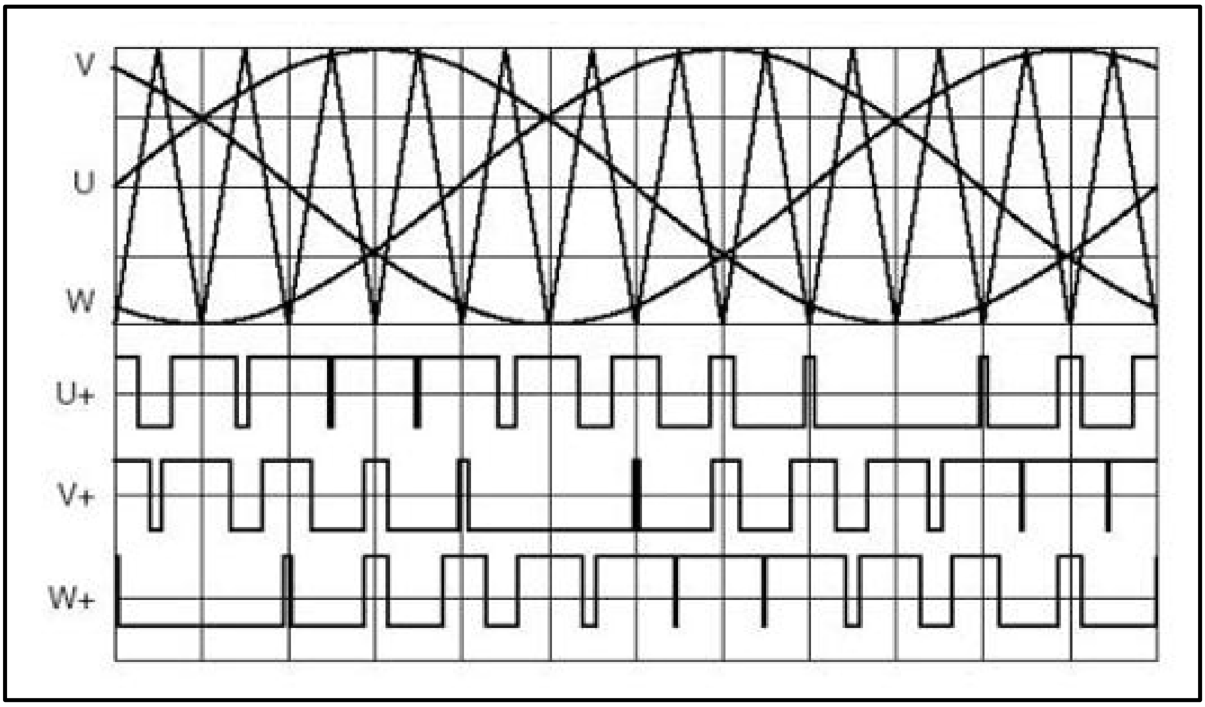


In Sinusoidal PWM, the width of each pulse is varied in proportion to the amplitude of the sine wave evaluated at the centre of the same pulse. The gating signals are generated by comparing a sinusoidal reference wave with a triangular carrier wave.

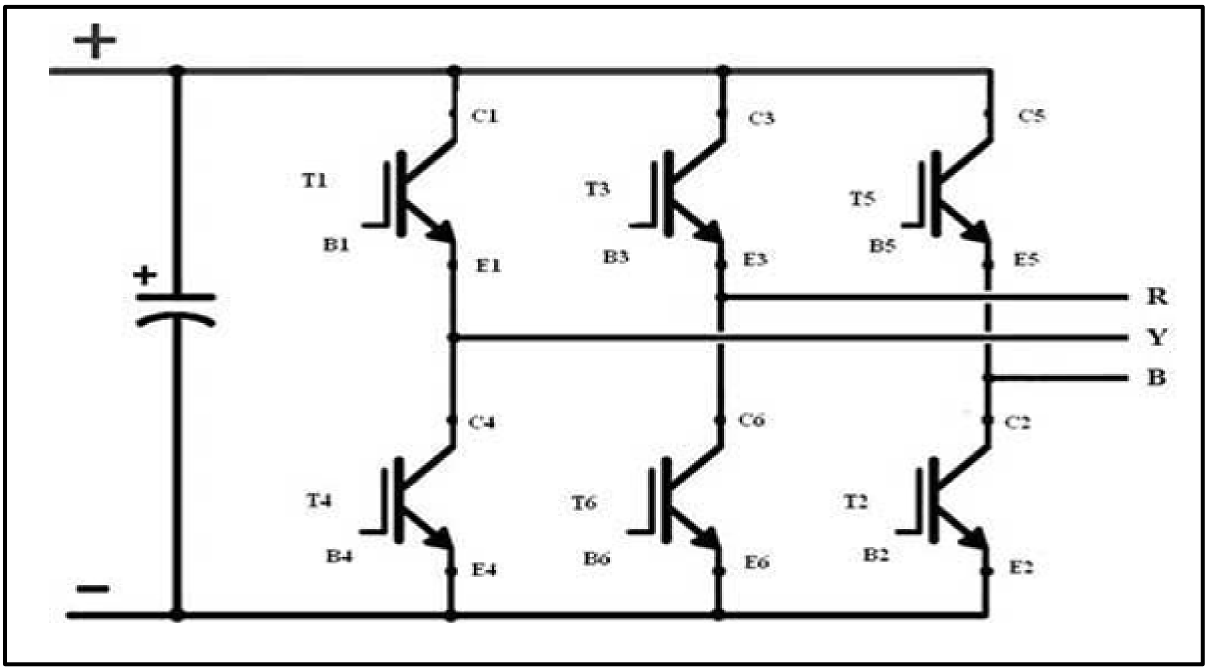


Three Phase Inverters

The three-phase inverter is used to provide variable frequency power for industrial applications. SPWM is used for the voltage control of three phase inverters and the corresponding gating signals are shown below. Here, triangular carrier wave is compared with three reference sinusoidal waves (U, V, W) which are displaced by 120 degrees.

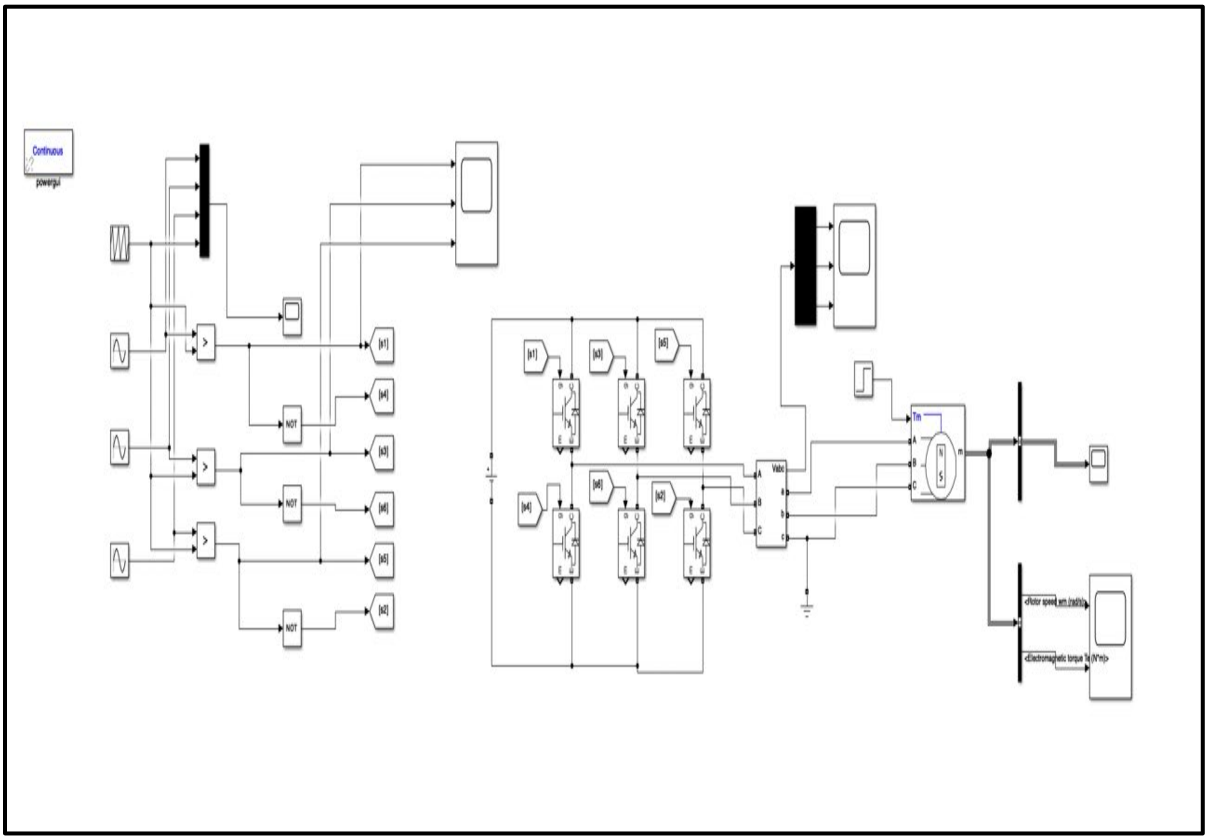


The basic circuit diagram of a three-phase inverter with 6 IGBTs is shown below-

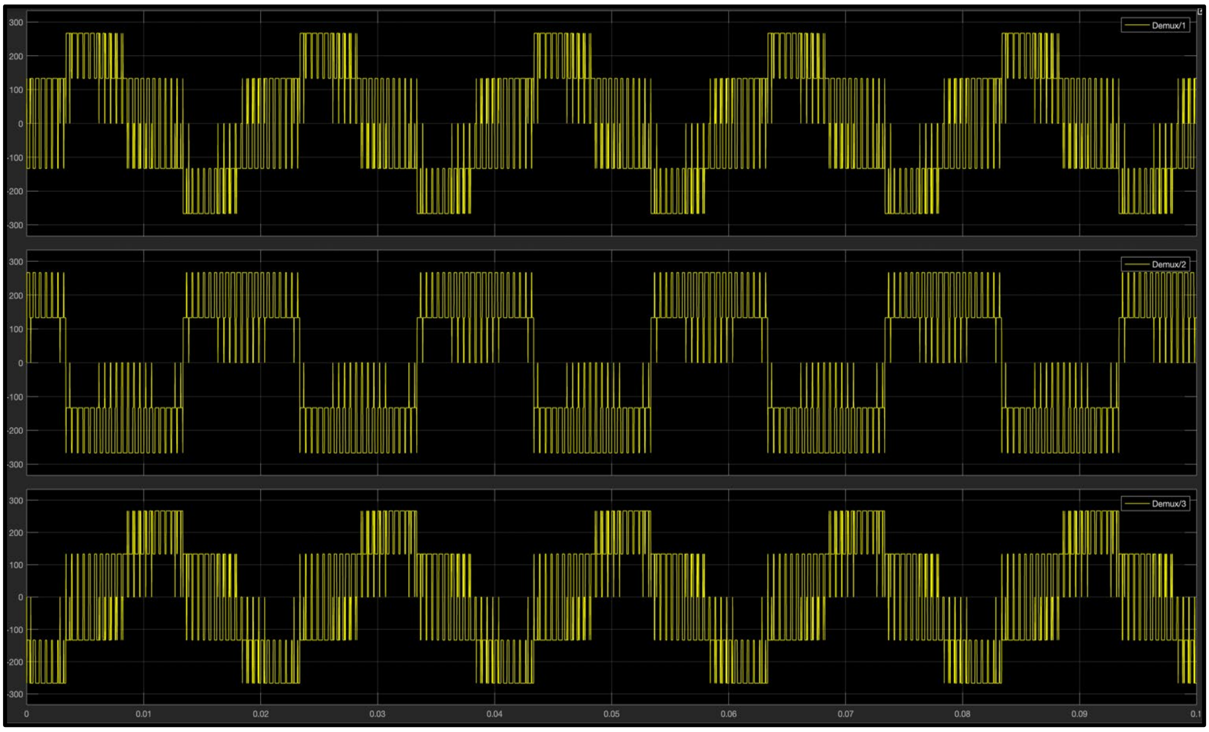


Simulations

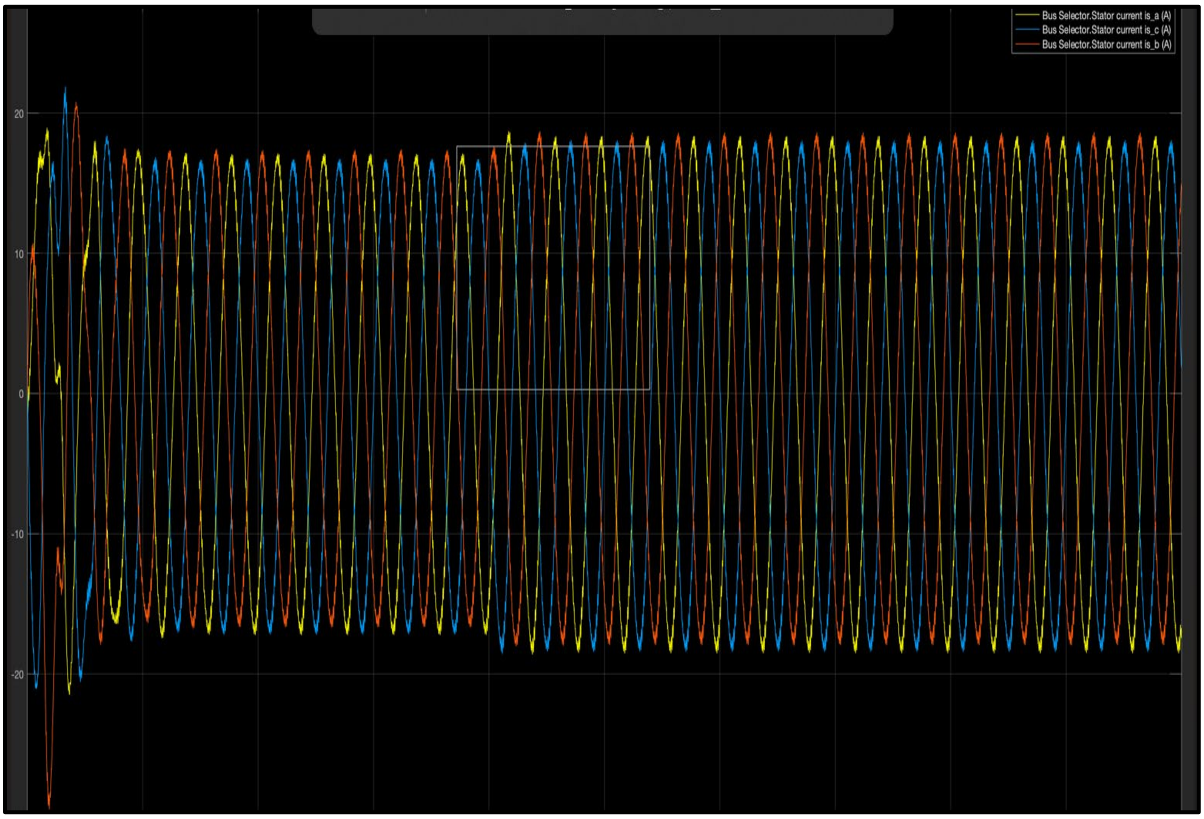
Simulink Schematic



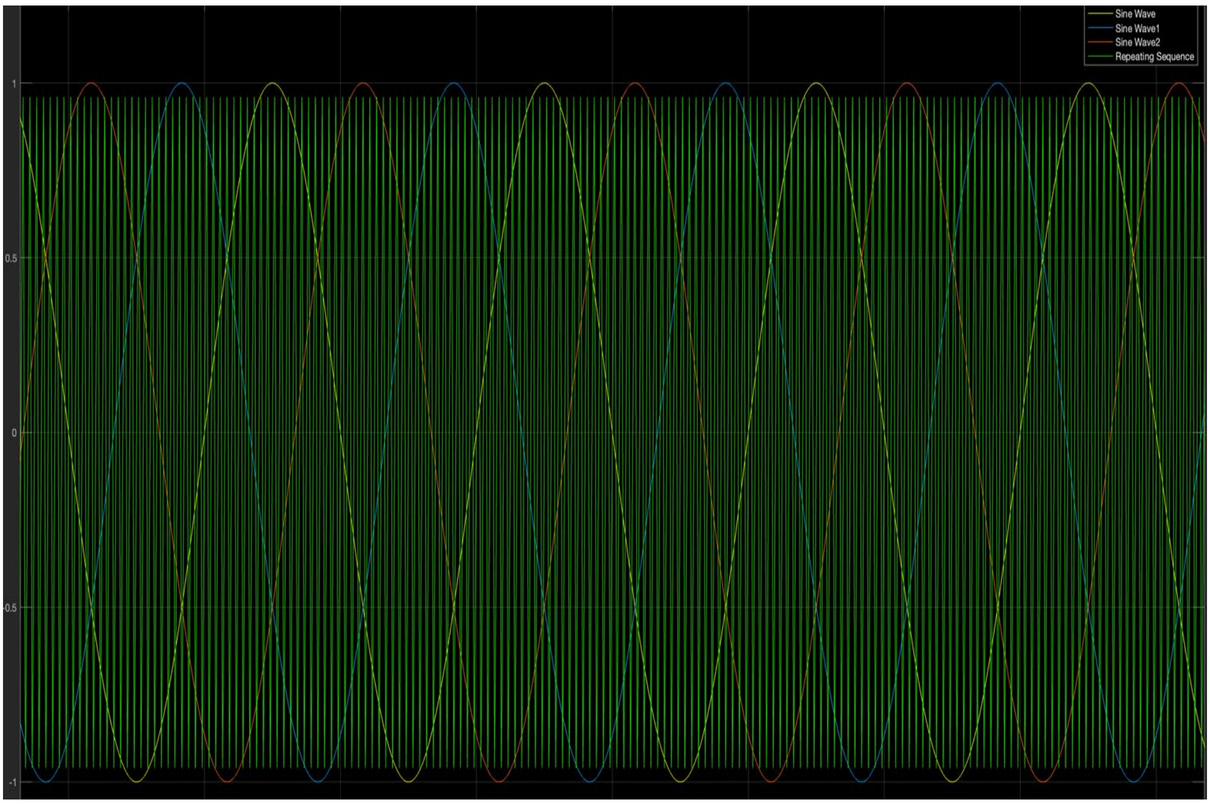
Demux Output



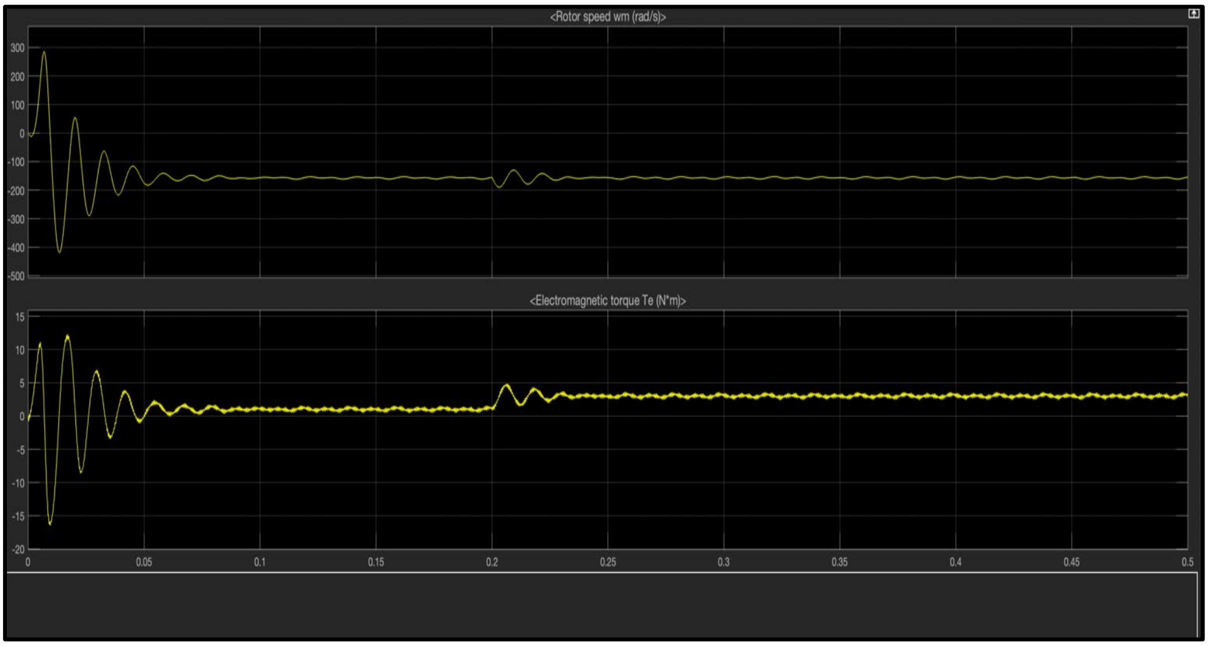
Stator Current



Sine wave



Rotor Speed & Electromagnetic Torque



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