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Wind Turbine Performance with Permanent Magnet Generator and Active Control

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ABSTRACT- Electricity's discovery and subsequent expansion over the previous few hundred years have firmly cemented its use and enhanced our dependency on it. This is since it is the most basic and cost-effective technique of carrying energy across large distances, and it is easy to convert into other forms such as mechanical motion or heat. As energy use rises and individuals who previously had access to electricity become increasingly prepared to engage in the energy market, certain challenges arise. New infrastructure cannot be built in a place that is too remote from existing infrastructure and has a small population. In this situation, renewable energy sources such as micro-hydro (if available), solar, and wind are the next best options. As the globe attempts to attain a carbon-neutral goal to minimize future damage caused by the use of fossil fuels, renewable energy sources are gaining in favor. This study provides a plausible idea for a tiny wind-powered microgrid for a small population in windy environments including mountainous regions and natural wind paths like valleys and mountain passes, large plains, and ocean locations, among others.

KEYWORDS- Microgrid, Domestic Wind Turbine, Fossil Fuels.

I. INTRODUCTION

Wind as a source of energy has been explored for decades, with uses ranging from grain mills to pumping water, yet it is still largely obscure [1].

Since the first electric turbine was introduced in 1888, its use, power generation, and presence have grown during the last century. They have shown to be a clean alternative fuel, but they are confined to regions that are typically windy, or specifically where the wind speed and volume are suitable for energy conversion [2].

Windmill design is another area of study, with the wind turbine itself being a research topic. As a result, a variety of wind turbine designs have emerged, which may be split into two types.

Wind turbines with a vertical axis (VAWT) and horizontal axis are examples of this (HAWT). See the figure 1 [3] for more information.

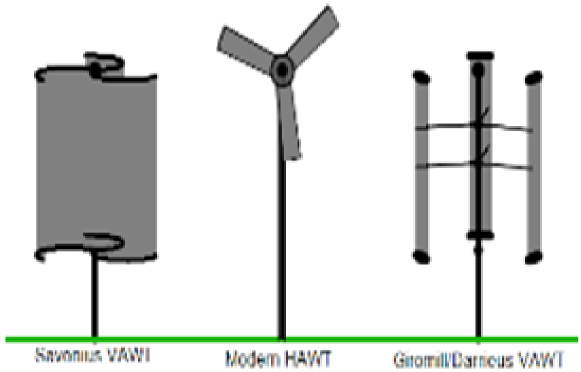


Figure 1: Savonius, Modern and Giro mill vawt

The horizontal axis wind turbine, or HAWT, is the most popular kind in real-world applications. Smaller versions can be found at wind farms in rural areas or near cities. Because the wind over oceans is strong and so carries more energy, they are currently being installed at ocean areas as well.

This project is a simulation of a very basic wind turbine microgrid design, in which a single wind turbine provides power to a small village. (A little load is one with a capacity of less than 1MW.) It should be noted, however, that it is not necessarily the only source. Auxiliary sources will be utilized to support it, such as diesel generators or solar PV. In the case that wind turbine production falls below a certain level, this design also contains a storage medium (battery) to provide an uninterrupted energy supply.

A. Methodology

The simulation of the system is done in MATLAB Simulink. The PMSG wind turbine is modeled using the core design premise of PMSG systems. An inverter is used to create an AC voltage waveform since the loads are AC. This is because the frequency and voltage of wind speed, and hence the power generated by a turbine, fluctuate. As a result, this is accomplished via a DC link.

II. LITERATURE REVIEW

Wind power as part of a modern electric grid is an excellent concept. It is clean because it has a little global environmental impact. This is a popular renewable energy source. Turbines for large installations have a tower with a nacelle on top that houses the generator and gearbox, then

the turbine and blades. When compared to HAWT, VAWT is more efficient [4]. As a result, this project likewise employs the HAWT design.
Wind turbines are commonly employed in large farms, however lone turbines are uncommon. The importance of design concerns and improvements in the industry has increased as wind turbines have grown in prominence, particularly in applications such as microgrids. For medium microgrid applications like those explored in this paper, wind turbines are typically paired with solar, using a concentrated parabolic solar dish Stirling engine (CPSD-SE) connected with a wind turbine.
A storage device is typically utilized to provide a consistent supply of power when wind energy sources are employed in microgrids or in combination with traditional grids. Because it combines energy density and compactness, lithium-based batteries are becoming more attractive for energy storage. [6]
This also increases the design's applicability in the case of islanded microgrids. This design may then be combined with a diesel generator to provide electricity. [7]
Wind turbines commonly employ induction devices as part of their equipment. PMSGs, on the other hand, are used in stand-alone and tiny systems since they don't require any further excitation. [8]. Turbines in combination with diesel generators, battery storage, and solar power are realistic and practical options for future microgrid designs. This research, on the other hand, focuses on a microgrid based on islanded wind turbines with only battery storage. [9-10]

III. WIND TURBINES AND PMSG

This section will provide an overview of wind turbines, their designs, and the theory behind them. After that, the PMSG (Permanent Magnet Synchronous Generator) is discussed, as well as its application in wind turbines. Finally, a fundamental overview of microgrids is provided, as well as the concepts for building one.
Wind turbines are power generating machines that include an induction or PMSG type generator, as well as a gearbox that regulates the shaft speed and torque of the generator. This includes the braking system, which guarantees that the generator shaft does not Overspeed and the turbine wind blade rotors do not rotate faster than the speed limit, since this might result in a mechanical failure. A blade pitch control system is also included in the turbine, which regulates the amount of energy collected from the wind as well as the turbine speed. In the case of HAWT, the turbine and generator assembly are housed in a nacelle on top of a tower. Turbine yaw motors control the rotation of the nacelle, which aligns the blades with the wind's direction to increase energy output. The top limit for energy recovery for wind turbines is defined by Betz's limit, which suggests that only 59.3 percent of energy may be recovered from the wind. For the turbine to work, there must be a pressure or velocity gradient in the wind before and after the turbine blades. An anemometer, which measures wind speed and direction and is mounted on the outside of the nacelle, is also required. This information is then used to manage the braking and yaw systems.
The formula for describing the energy in the wind is as follows:

$$P = 0.5 \times \rho \times A \times C_p \times V^3 \times Ng \times Nb$$

Were,
P = Power output, kilowatts
A = Rotor swept area in m^2
Cp = performance coefficient, ranging from 0.25 to 0.45 in reality, (theoretical maximum = 0.59 | Betz' limit)
ρ = the air density
Ng = generator conversion efficiency
Nb = gear box efficiency
V = wind velocity in m/s
A wind speed of 8 m/s can be used as an illustration of this. The turbine has an area of 80 m^2, a Cp of 0.4, an air density of 1.02 kg, and an 83 and 88 percent generator and transmission efficiency, respectively. The power output in this example is 6103 kilowatts. Figure 2 shows the part of HAWT

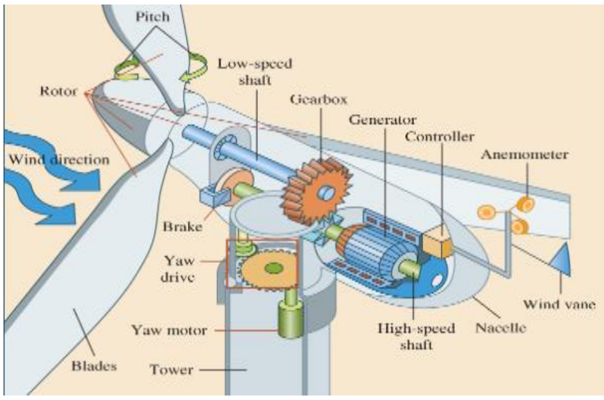


Figure 2: Parts of a HAWT

A permanent magnet generator is made up of a rotor and stator. To enhance the polar magnetic flux, the magnets are positioned in a Hall-Bach configuration on one side of the magnet array, on the rotor. The windings are inserted in the stator. Brushes are no longer required, and any related losses or wear are avoided. The generator winding is also three-phase since the power output is three-phase. In this situation, permanent magnets made of rare earth elements, such as neodymium magnets, are used to generate a strong magnetic field. These magnets have the advantage of not requiring external stimulation to begin generating power. Figure 3 shows part of PMSG.

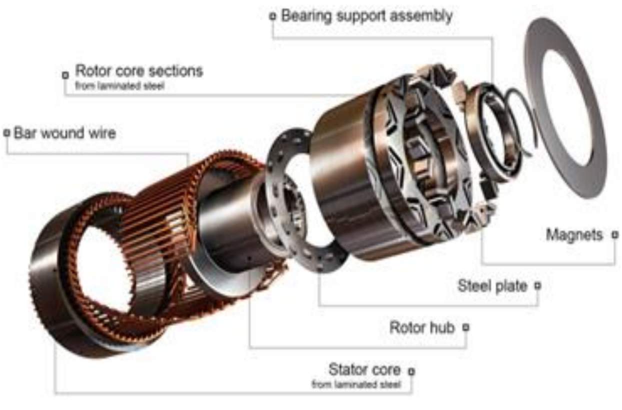


Figure 3: Parts of a PMSG

Synchronous machines do not require external stimulation. External DC excitation sources, such as capacitor banks, aren't used in this case. This reduces the complexity of the machine. It also allows for small-footprint power production. However, because the system is unable to increase the magnet flux and hence output power, this is a design defect.

Wind turbines frequently use induction devices, although they cannot generate power on their own. They require an external excitation source, which in this case is provided by an external capacitor bank. They won't start producing energy until they're rotating faster than the synchronous speed of the machine. As a result, they're impossible to use in small, isolated designs. Another form of generator that may be used in this type of small-scale application is a DC generator, which can be a permanent magnet or independently stimulated. Brushes, which connect the armature to the output terminal contacts, are wear-prone components that must be maintained on a regular basis. However, in this case, a rectifier is unnecessary, and the output can be directly regulated before being converted to AC through an inverter.

There is no need for a commutator because the magnets are situated on the rotor and the stator winding connections are easily accessible, resulting in reduced wear and less regular maintenance.

Even at lower rotor revolutions per minute (rpm), a three-phase synchronous generator has the advantage of intersecting more flux and therefore extracting more energy. This three-phase AC is converted to DC and then filtered, resulting in less ripple than the single-phase version. Depending on the circumstance, this enhanced DC waveform is then managed and converted to AC single-phase or 3-phase for loads, or even utilized as DC.

The Figure 4 show the wear on brushes and commutators in DC machines, as well as the capacitor banks used in wind turbines.

Figure 4: Commutator wear

The above graphic depicts commutator wear. The black carbon print on the commutator is caused by graphite from brushes embedding themselves on the copper commutator. Sparking and poor contact result, resulting in increased contact resistance and I2R losses.

Carbon brush pieces shatter and fly into components all the time, causing electrical shorts or becoming caught in bearings.

This is one of the disadvantages of a DC machine system. In the case of a separately excited system, a battery power source is also required to deliver initial starting excitation to the generator.

Figure 5: Capacitor banks for a wind farm

The Figure 5 above shows capacitor banks for a wind farm. The capacitors are contained in rectangular constructions, which are not suitable for a small placement due to their size. This setup must also include protection systems and switchgear in order to function smoothly and properly.

Microgrids are electrical links between sources and generators that are decentralized. Both the sources and the loads are important. The difficulty of long-distance transmission is reduced since supplies are closer to loads. This concept is used in renewable energy applications and their integration with existing grid infrastructure. Microgrids can also refer to a restricted interconnection of sources and loads in a small area that is isolated from the larger electric network, referred to as an island-type microgrid.

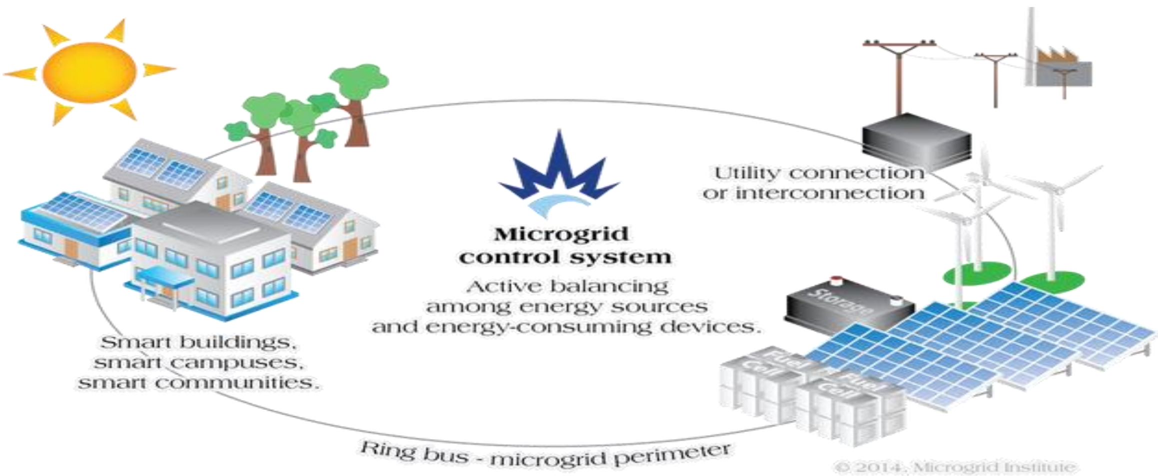


Figure 6: Renewable sources are connected with loads and the conventional transmission network (source: Image via MicrogridInstitute.org)

Several renewable energy sources, as well as loads and the traditional transmission network, are depicted in the figure 6. As people become increasingly reliant on power and renewable energy sources are integrated into the regular system, microgrids are becoming more common. This is because renewable energy sources, unlike traditional energy sources like rivers, are spread out across a broader region. An excellent example is the use of sunlight in solar-power systems. When the space would otherwise be unoccupied, this might be done on the rooftops of buildings.

Roof-top solar energy may be sufficient to power a modest home, but it may only be sufficient to illuminate a few levels in a large structure. The rest of the energy must come from the grid. This position poses the question of merging the two power sources so that solar energy may be injected into the grid and used, among other things, to balance energy costs. As a result of this topology, consumers become prosumers, a term that aims to include the idea of a consumer both being a producer and selling a resource rather than merely consuming it. The figure 7 shows the presumer . Figure 8 shows the rooftop solar provide an overview of roof-top solar and prosumer economics.

Figure 7: basic concept of a prosumer

Figure 8: Rooftop solar was implemented on a public building

Figure 9: Kyocera Headquarters in Tokyo Japan with BIPV

There are BIPV (building-integrated solar photovoltaics) panels on the southern side of the Kyocera headquarters in Tokyo, Japan (left).

In the Figure 9 , the shading problem is solved and the placement is enhanced by inclining the panels. They're also positioned such that the top panels don't obscure the view of the lower ones. In a heavily populated area, such as a city centre, where buildings shadow one another, this would not be an ideal design.

IV. DESIGNING IN SIMULINK

This section discusses the simulation's design, as well as design considerations and simulation settings. Photographs of the model blocks are also included.

This system consists of a wind turbine with a synchronous generator (PMSM), rectifier, inverter (DC-AC, single or three-phase), electric loads (house loads (RL loads), and non-linear loads), transformer placement in ideal places, battery storage system, and wind profile modeling. These will be looked at further.

A. Wind Turbine and PMSG

It is the most significant part of the arrangement and the subject of research because it is the primary power source in this design. To replicate the mechanical architecture of the wind turbine, which comprises the blades, gearbox, brakes, and shaft, several functions must be employed. These components are then axially connected to a PMS generator, also known as a PMSG, which generates electricity.Figure 10 shows mechanical model of the turbine

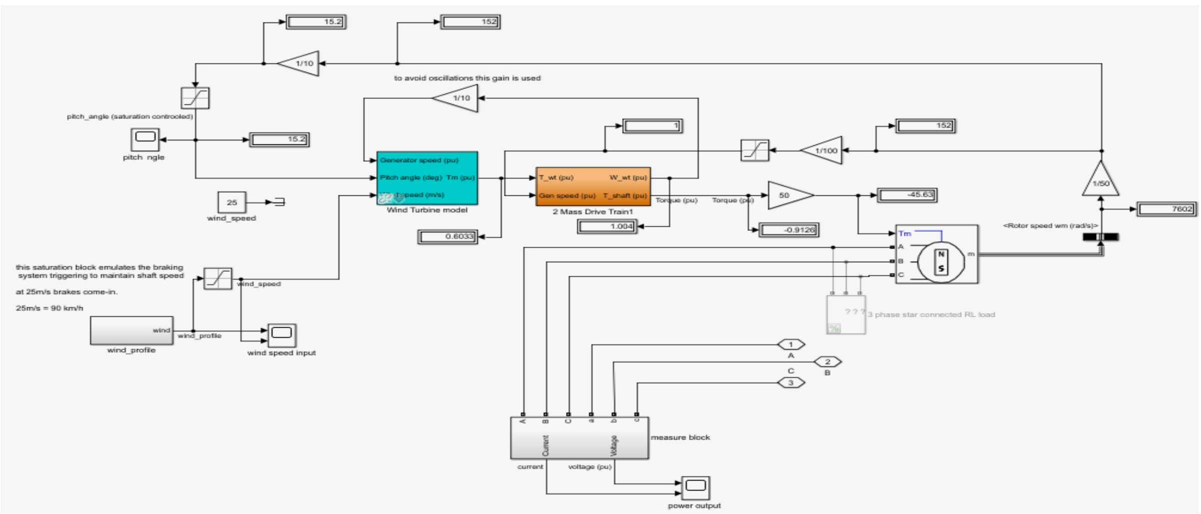


Figure 10: Model Diagram

Figure 11 shows the turbine mechanical model

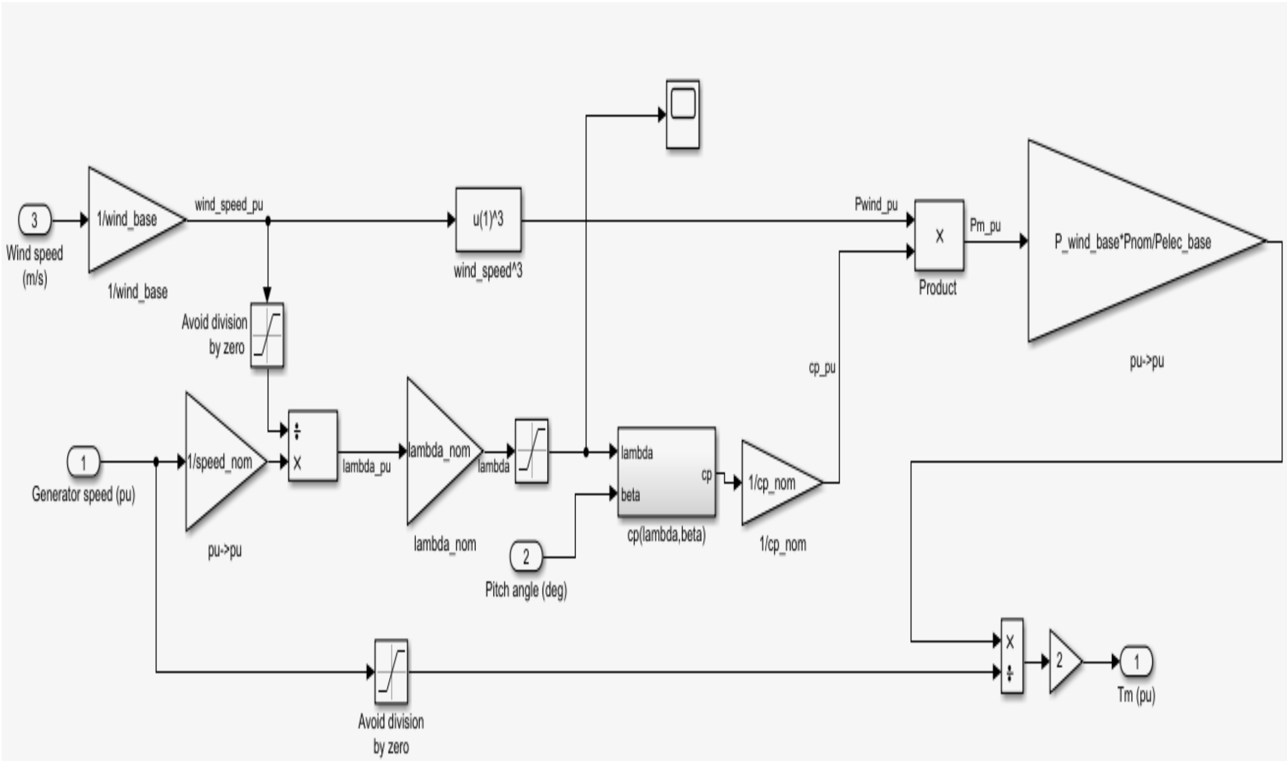
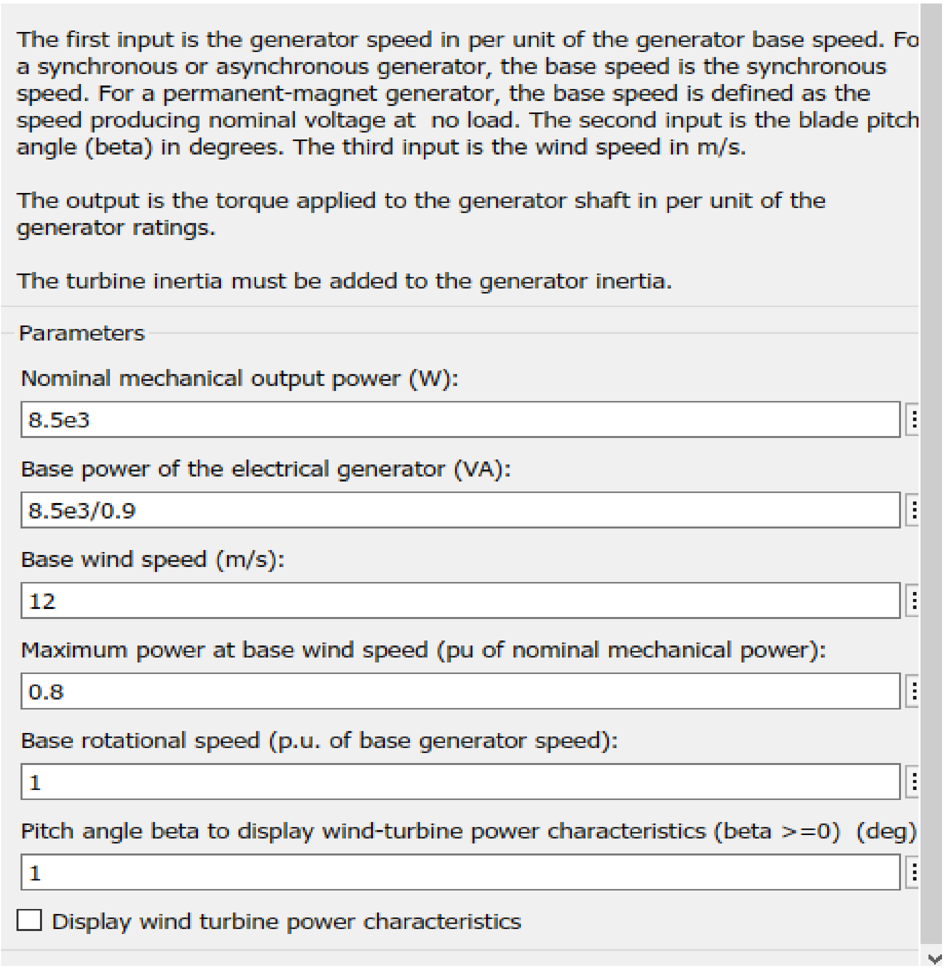


Figure 11: Turbines mechanical model (in green)



The first input is the generator speed in per unit of the generator base speed. Fo a synchronous or asynchronous generator, the base speed is the synchronous speed. For a permanent-magnet generator, the base speed is defined as the speed producing nominal voltage at no load. The second input is the blade pitch angle (beta) in degrees. The third input is the wind speed in m/s.

The output is the torque applied to the generator shaft in per unit of the generator ratings.

The turbine inertia must be added to the generator inertia.

Parameters

Nominal mechanical output power (W):
8.5e3

Base power of the electrical generator (VA):
8.5e3/0.9

Base wind speed (m/s):
12

Maximum power at base wind speed (pu of nominal mechanical power):
0.8

Base rotational speed (p.u. of base generator speed):
1

Pitch angle beta to display wind-turbine power characteristics (beta >=0) (deg)
1

☐ Display wind turbine power characteristics

Figure 12: Parameters used

The gearbox and shaft are represented as follows (orange block): mechanical inertia, damping, and stiffness of the shaft in response to torque forces are all included Parameters used can be seen in figure 12 . This is accomplished through the use of two machine models. Here, the inertia constant H is set at 2. This can be seen in figure 13.

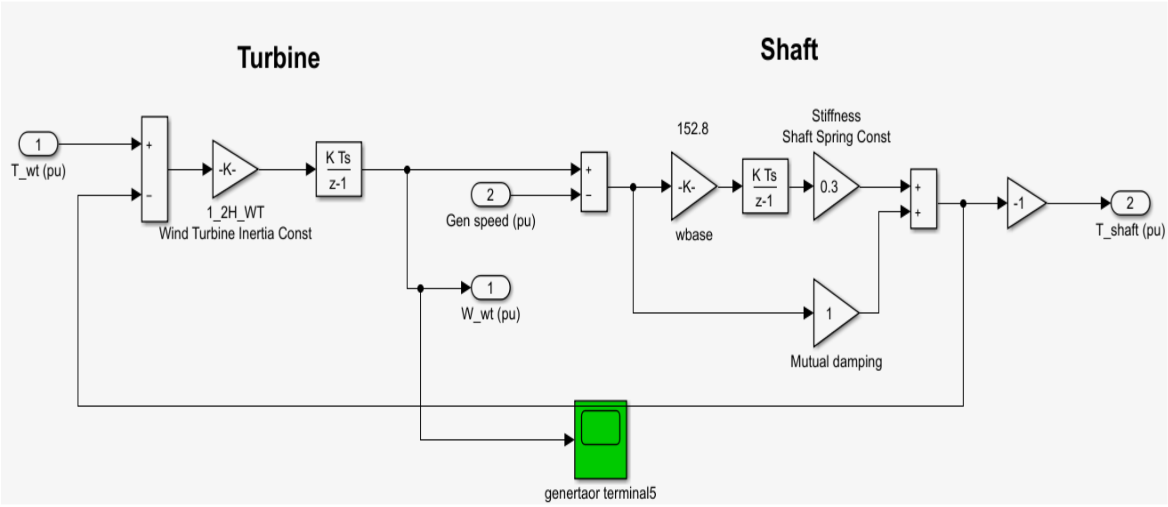


Figure 13: Model with Generator

B. *Rectifier*

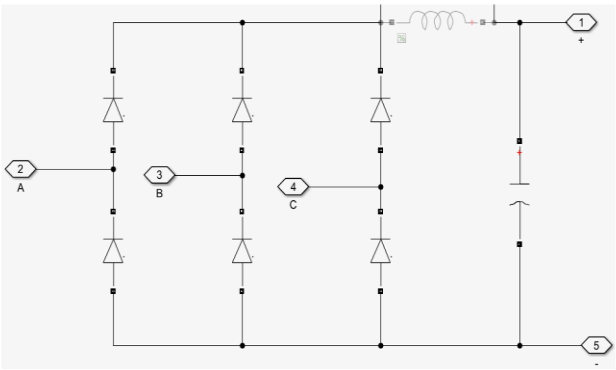


Figure 14: Rectifier

This is a straightforward three-phase diode rectifier with a capacitor to smooth the output voltage.. Rectifier can be seen in figure 14. A series inductor can also be employed to protect the turbine from being damaged by abrupt current spikes. However, because connecting a capacitor and inductor directly is forbidden in MATLAB, it is commented out and skipped in the simulation. This resonance issue might also arise in real life. As a result, caution should be exercised while designing such subsystems. The buck-boost regulator for DC buses is the next system as shown in figure 15. .

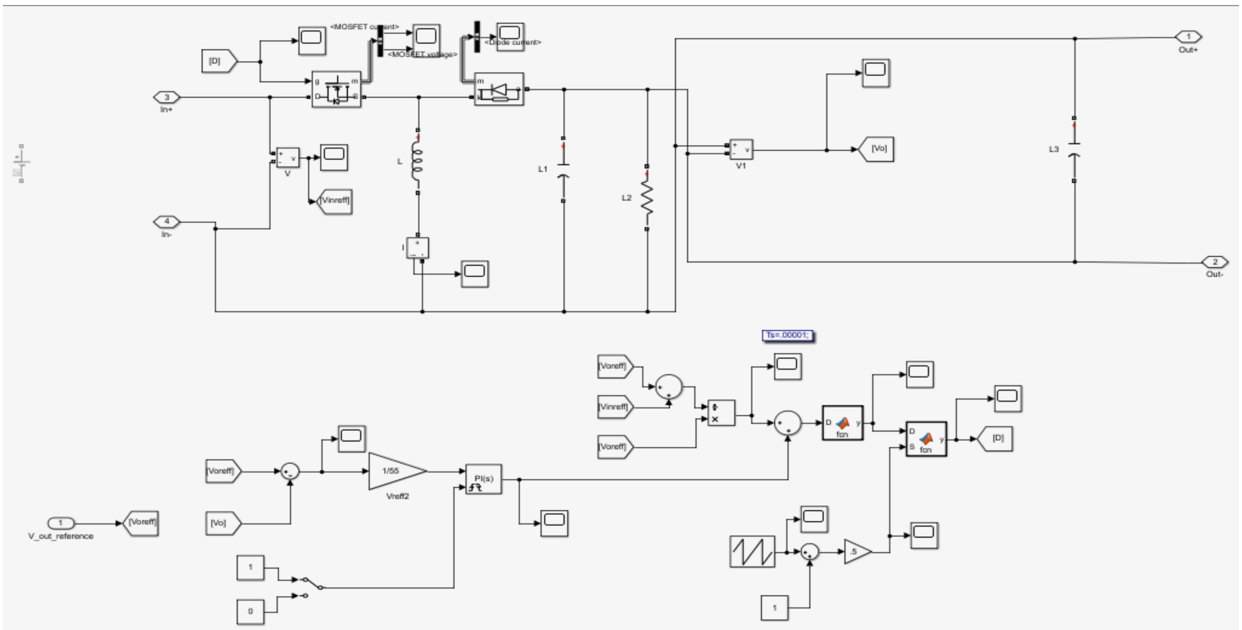


Figure 15: Buck-boost regulator for the DC bus

The buck-boost converter is used to manage the wind turbine's fluctuating and time-varying voltage. So that loads receive a consistent voltage waveform.
Integral control is used in the control loop to keep the voltage at 100 volts. This is done to avoid an issue with excessive voltage. Because the inverter creates three phases, the line voltages may be employed to obtain 200V at the necessary frequency, which is typical in most electrically powered goods.

C. Inverter

The inverter is a three-phase inverter with sinusoidal pulse width modulation (SPWM) control. The controls and blocks are shown in greater detail in figure 16 .
To avoid a direct short between the DC bus and the inverter leg, the phase shift for each signal is delivered using NOT logic for each inverter leg. Because the signal transition in real life is a finite length event, it is important to utilize a signal delay or dead time.

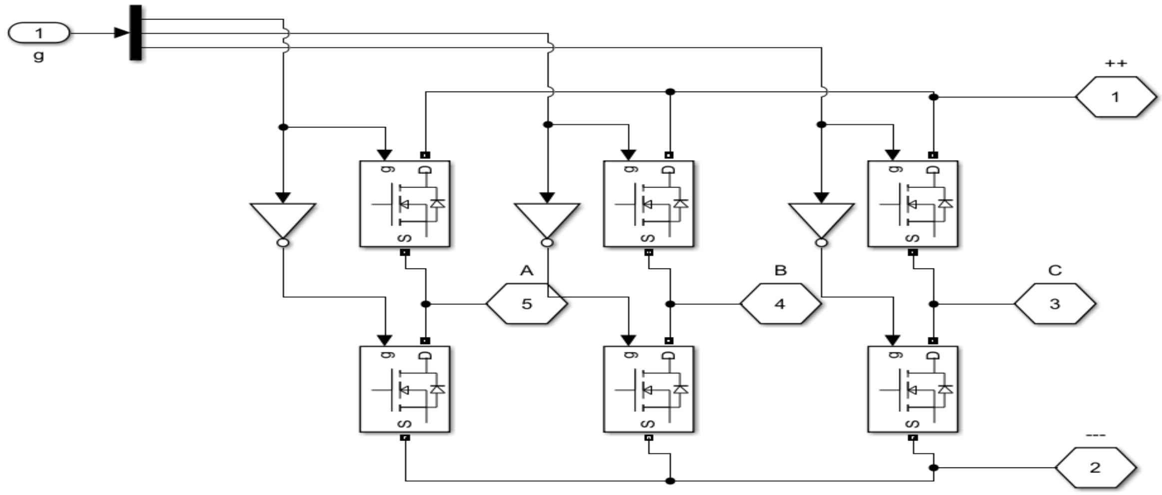


Figure 16: Inverter

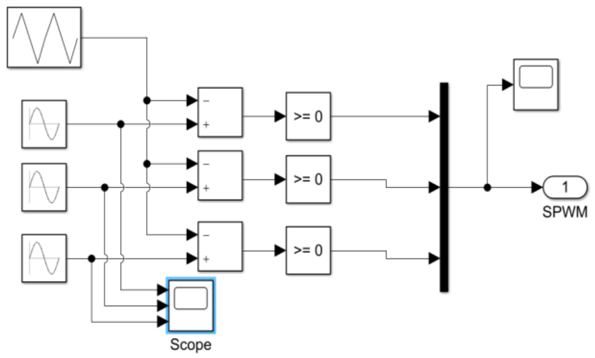


Figure 17: SPWM generation scheme

The SPWM generating scheme is as follows as shown in figure 17. About each other, each phase signal is 120 degrees out of phase. The carrier wave is a high-frequency rectangular wave with a frequency of 10 kHz in this case. Because the amplitude of the carrier wave is bigger than that of the modulating sine wave, the output sine wave is unmodulated. The SPWM signals may be seen in the waveform in figure 18

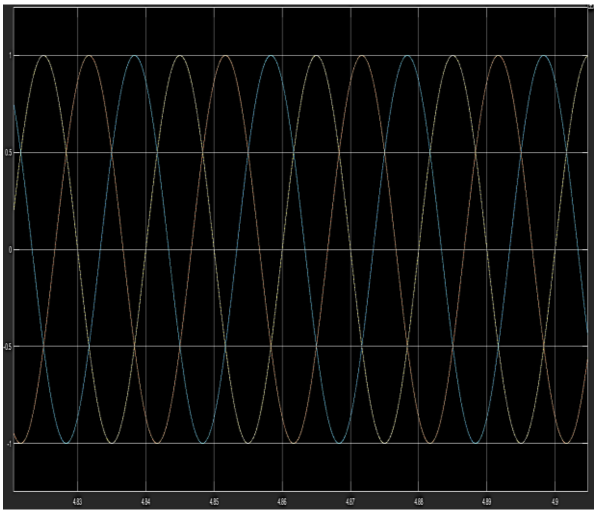


Figure 18: SPWM signals

The output PWM is presented next, followed by the reference waveforms that come from the comparison in figure 19

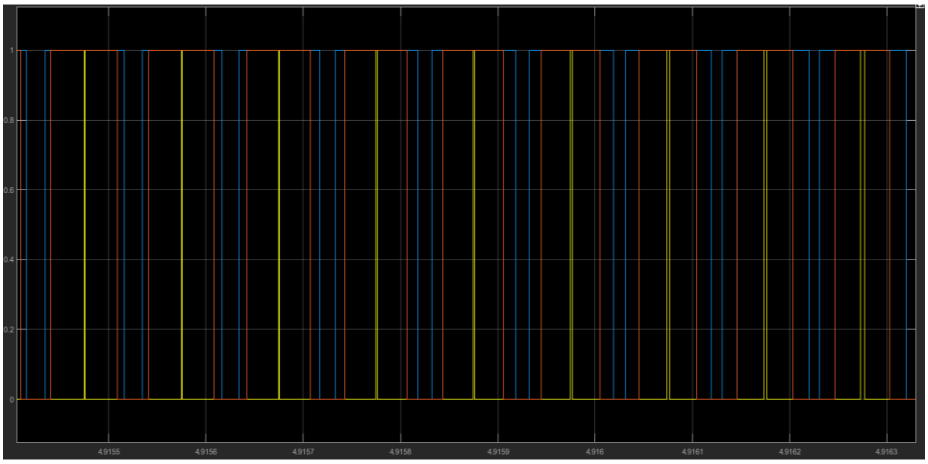


Figure 19: The resulting control PWM waveforms

D. Loads and Measurement

Three-phase and a non-linear rectifier load are employed in this example. As previously stated, the three-phase supply is 100Vpp since we can receive a 200V line to line from it.

A single-phase rectifier with an RL load is used as the non-linear load, simulating a phone charging circuit. To achieve 200Vpp, it is delivered via a line-to-line voltage. The block may be seen in figure 20

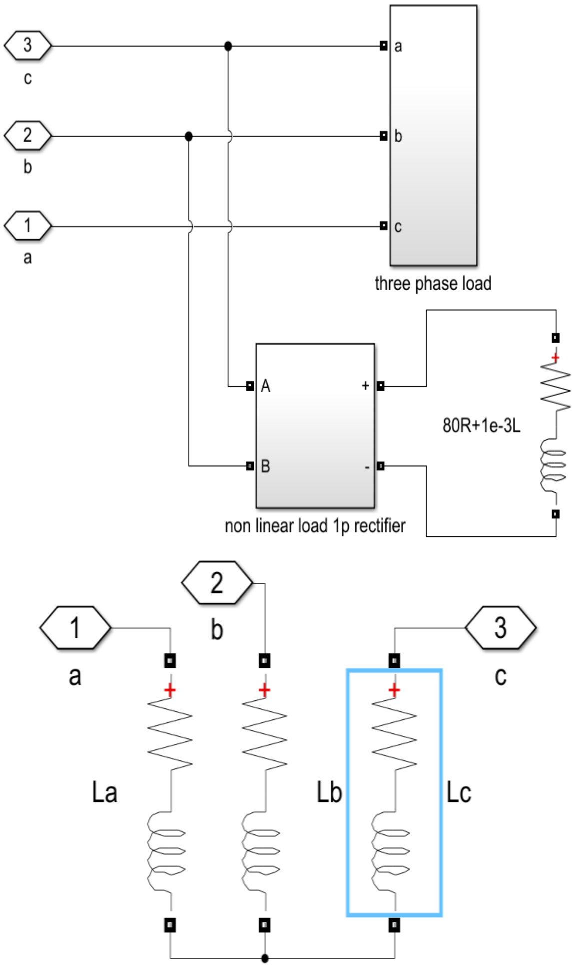


Figure 20: Three-phase load block

The measurements are done using a block that measures line currents and line-to-line voltages as shown in figure 21

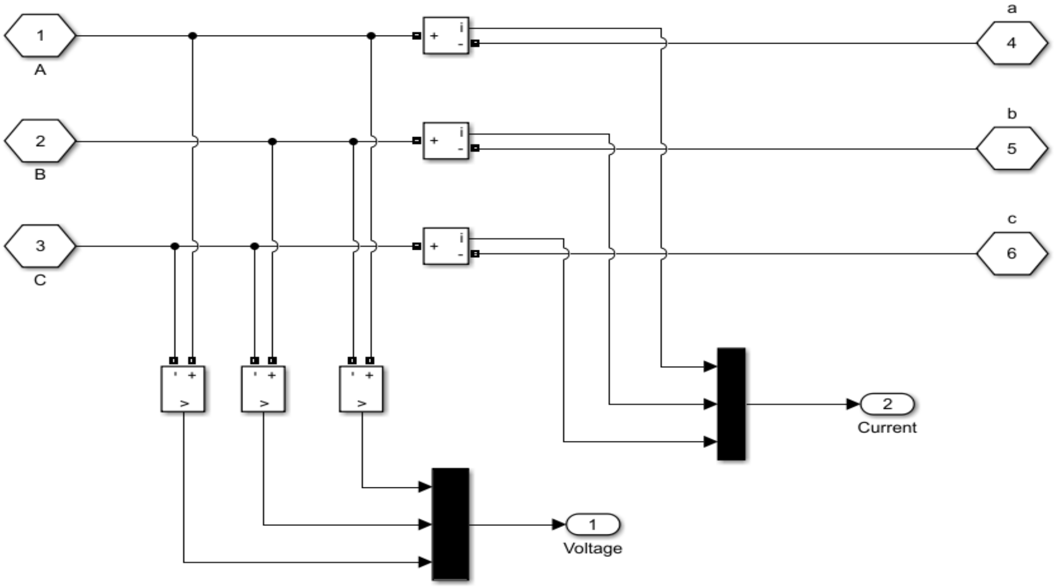


Figure 21: The line-to-line voltage

E. Battery Integration

Because the main simulation gets too heavy, the battery simulation is run independently. A battery is linked to a DC bus, and the voltage is varied to recreate comparable conditions in the second simulation. The following section depicts the current flow and voltage. The simulation diagram for the same is shown below. A 100V voltage source-DC is coupled in line with a 2Vpp AC regulated voltage source to emulate the DC bus, adding noise to the bus. To imitate the tiny change in voltage on the DC bus, the other regulated AC source provides a voltage swing of 6Vpp. A series RL circuit with R=40 ohms and L=6e-3 Henry is used as the load.

The battery utilized here is a lithium-ion battery, although a lead-acid battery might be used instead because it is more common and more durable. Because of its better energy density and less size and weight, the lithium-ion battery was chosen.Figure 22 hows the battery and figure 23 shows battery state and figure 24 shows the battery parameters.

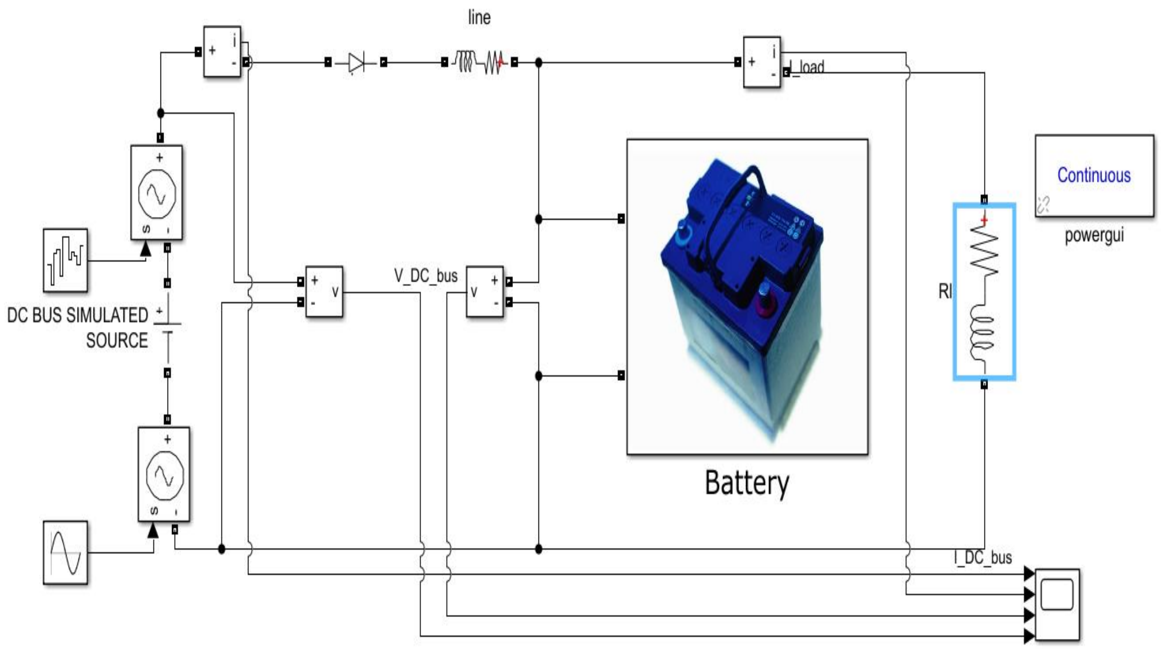


Figure 22: Battery

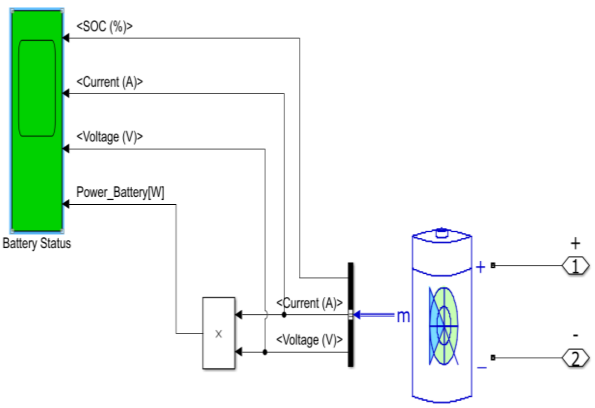


Figure 23: Battery State

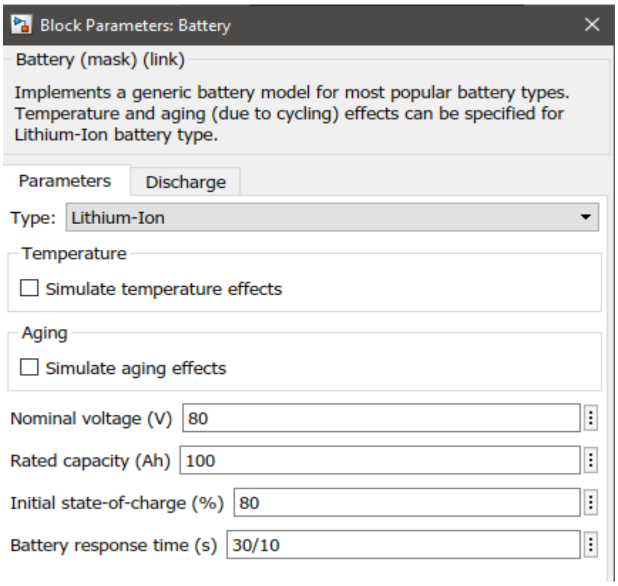


Figure 24: Battery parameters

F. Wind Profile

Several phases, frequency, and amplitude varying sinusoidal signals are combined to generate a general time-varying amplitude varying waveform to represent a progressive shift in wind speed for the wind turbine.Wind profile can be seen in figure 25

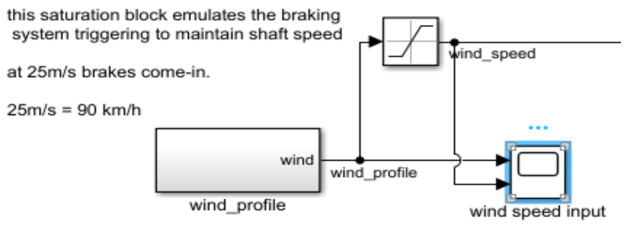


Figure 25: Wind Profile

The saturation block is used to simulate braking in the turbine to prevent Overspeed damage caused by high wind speeds This can be seen in figure 26

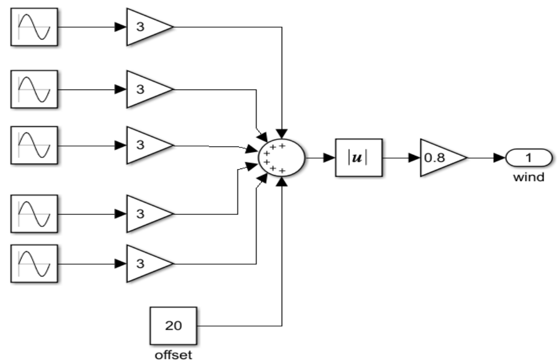


Figure 26: Saturation block

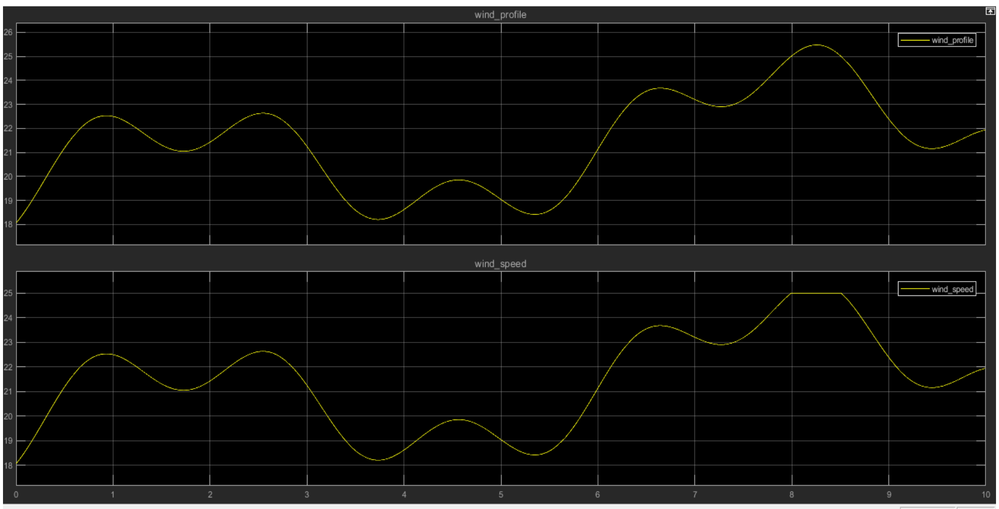


Figure 27: Generated Waveform

The wind profile is the first plot, while the wind speed is the second. The waveform snippets may be seen in the later section of the second plot. This is the braking mechanism that keeps the turbine's speed constant.

Because the simulation is large, it is divided into two portions, with battery integration being simulated independently. The primary simulation's final shape is shown here. The battery simulation is provided in this section's battery portion. Final simulation is illustrated in figure 28.

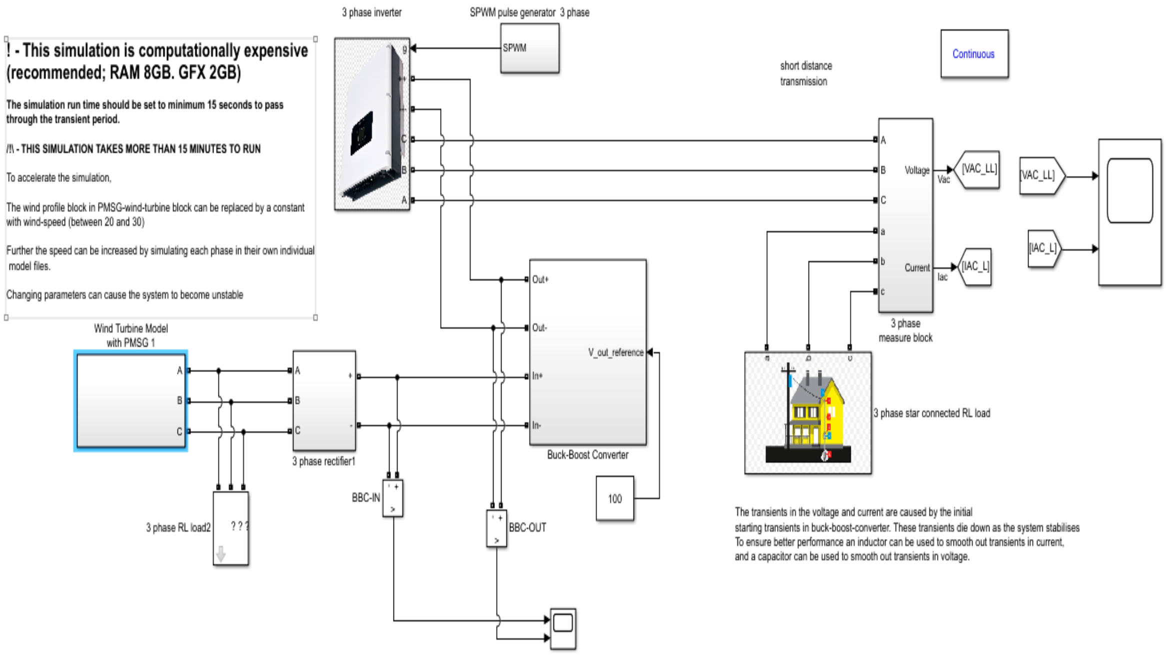


Figure 28: Final Simulation

V. SIMULATION AND RESULTS

The DC bus voltage following the buck-boost converter is now factored into the system's findings. The output signal of the inverter. The pitch angle of wind turbine blades also varies when wind speed changes.

The overall voltage output of the inverter, as well as line currents. The inverter output can be seen in figure 29

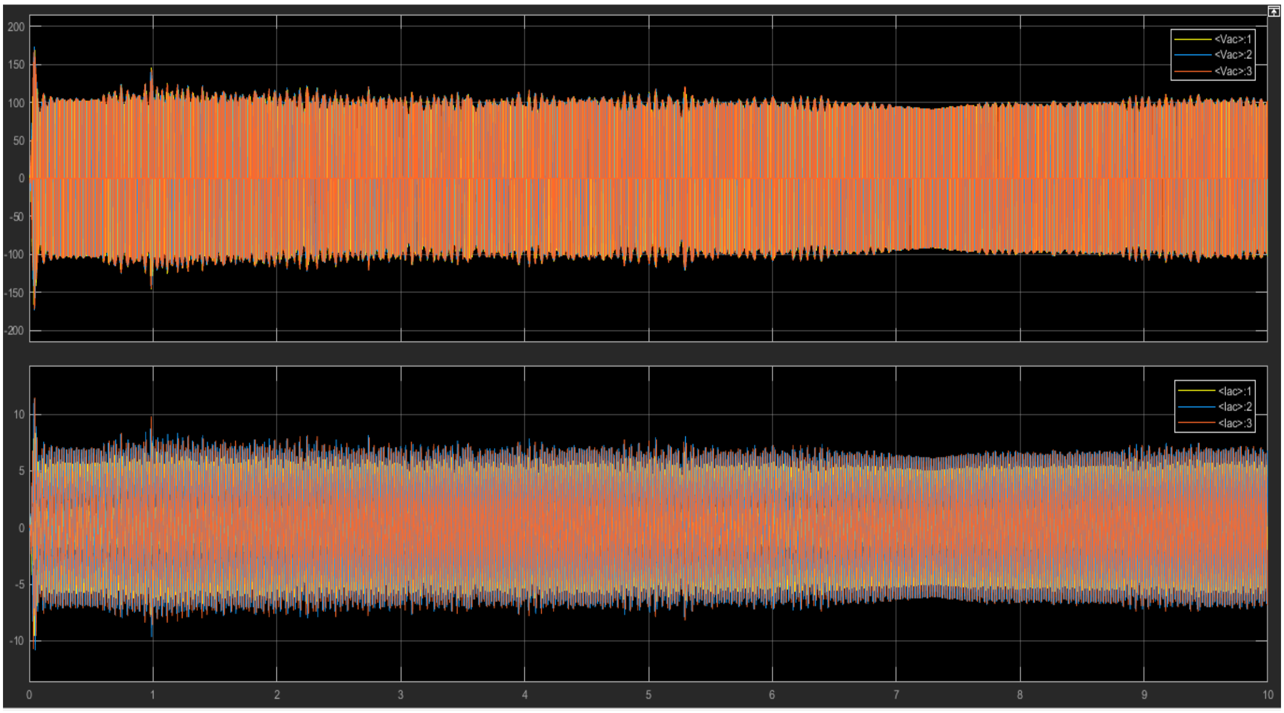


Figure 29: Inverter output

The image depicts the whole simulation run cycle, and hence only shows broad trends such as voltage sags and swells.

A zoomed-in view is shown in figure 30 . The non-linear load is to blame for the current aberrations.

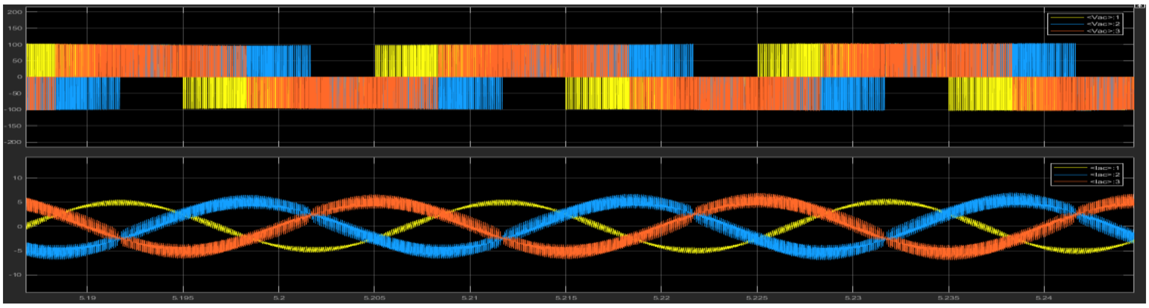


Figure 30: Voltage swags

The voltage and current of the three phases are represented by the first and second waveforms, respectivel as shown in figure 31

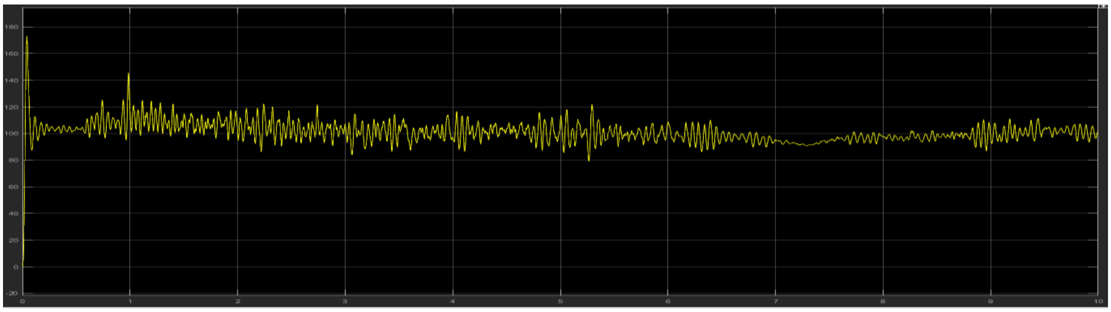


Figure 31: Voltage and Current of 3-Phase MXR

The voltage on the DC bus is shown in the figure 32 . The set point for voltage is 100 volts.

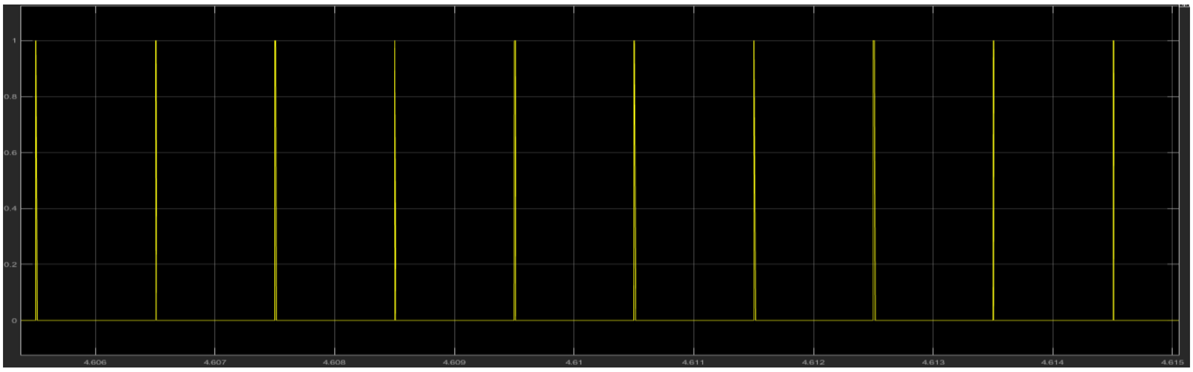


Figure 32: DC Bus Voltage

The PWM waveform for the buck-boost converter switch. Which is shown in figure 33 The duty cycle is quite low in this case, hence the converter is in buck mode.

The current loop's error waveform is shown in figure 34, followed by the PI controller output.

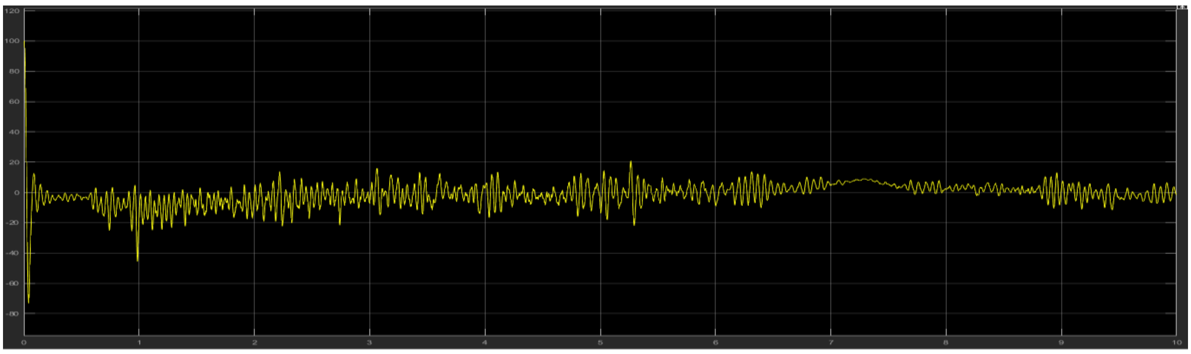


Figure 33: Buck-Boost Converter

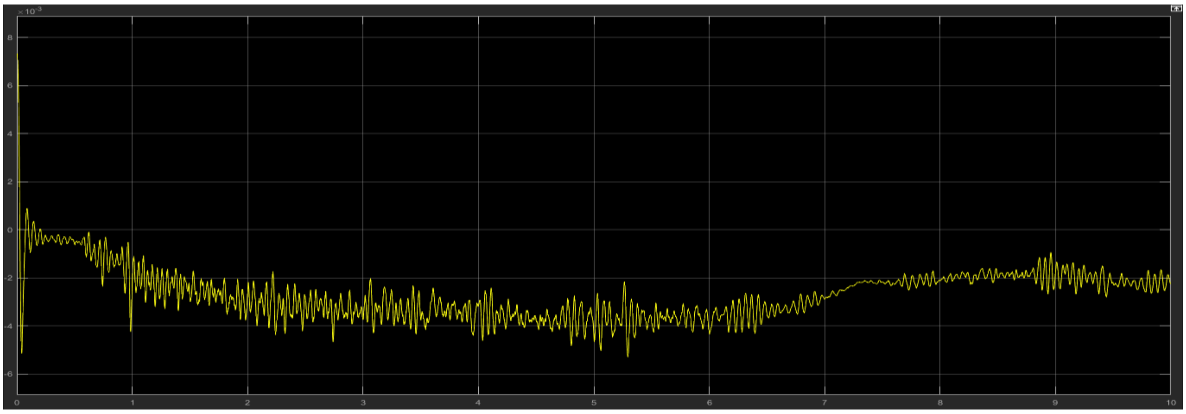


Figure 34: Current Loop Error

The I control, in contrast to the preceding curve, allows for static error and generates a gradual change rather than an abrupt one. The pitch angle fluctuation of wind turbine blades is now illustrated in the figure 35

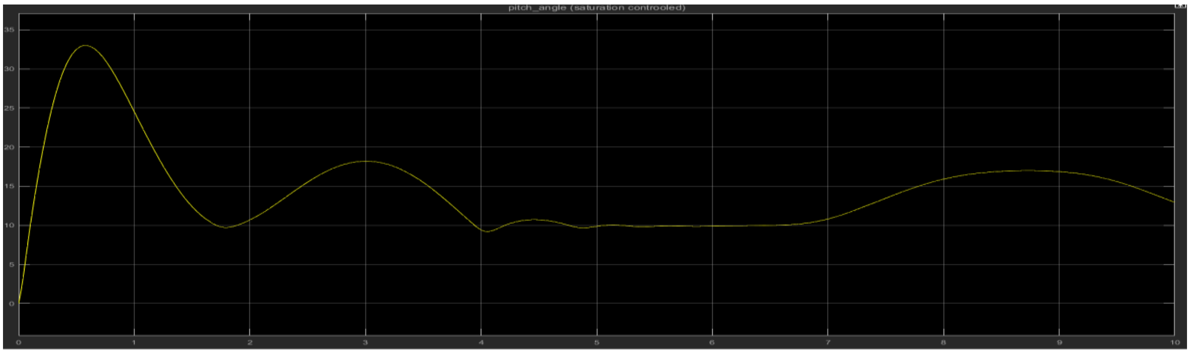


Figure 35: Pitch Angle of Wind Turbine Blade

There is no wind initially, as can be observed, hence the angle is zero. The turbine angle controller changes the angle to acquire rotation when the wind comes up. Because the wind speed diminishes as the intended speed is attained, the controller adjusts the angle to maintain the required speed. When the turbine's speed exceeds the established safety limits, the pitch is decreased to slow it down. This is the manner of operation for pitch control.

The following are the outcomes of the battery simulation. The present state of charge of the battery is referred to as the SOC.

As can be seen, the battery current follows the DC bus curve. Because the battery has an 80-volt rating. This will show charging in the simulation This can be seen in figure 36

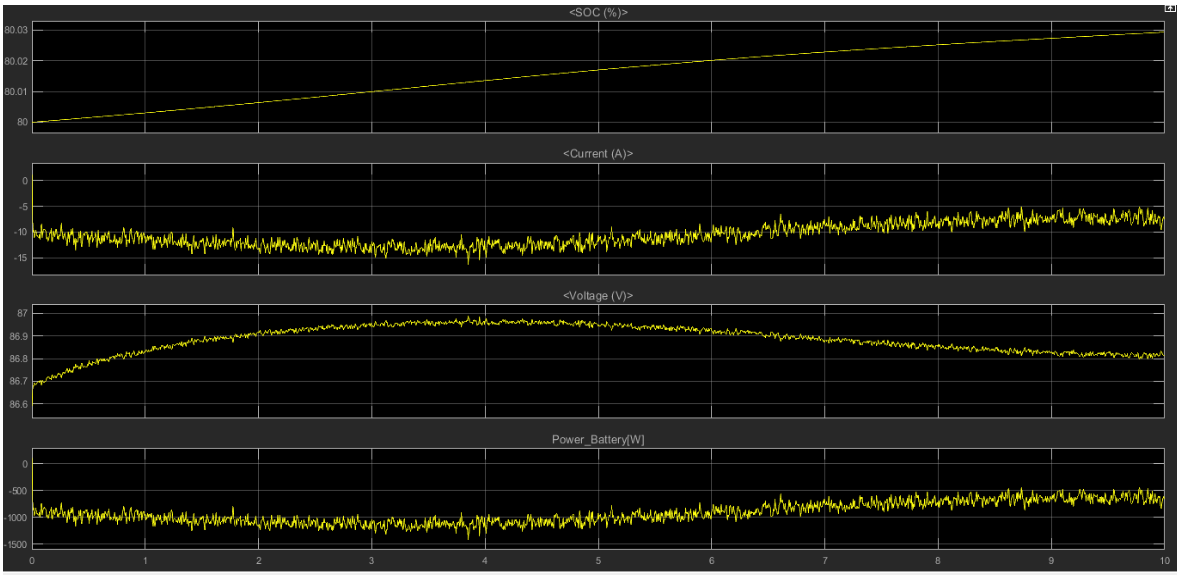


Figure 36: SOC

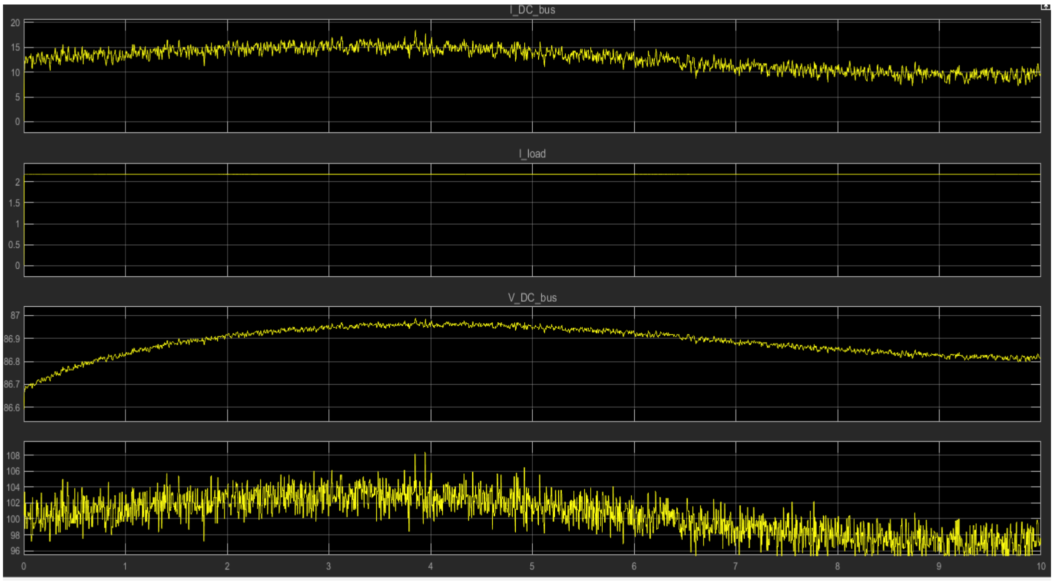


Figure 37: Simulated Bus Side Voltage

The bus, load currents, load side voltage, and simulated bus side voltage are shown in this sequence in the figure 37

The work's conclusion is presented in the next section.

VI. CONCLUSION

According to the simulation and results, employing a wind turbine as a stand-alone producing source in a breezy region is not difficult and might be explored further in applications like the one depicted here in the microgrids scenario. The wind turbine may be able to provide enough power to the loads while also satisfying current demand. Renewable energy has a bright future, and the utilization of microgrids and islanded microgrids shortly offers intriguing research opportunities.

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