Midsem Project Report

On

Modeling and Simulation of Multi-Level Power Converters for Wind Turbine Systems using Matlab-Simulink

BY

Group 7

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Abstract

In India, the renewable energy capacity has doubled in the past eight years. As of January 2023, it has the fourth-largest installed wind power capacity globally, clocking in at just under 42 Gigawatts (GW). This shows the potential and the need for renewable resources and the scope of execution. Diversifying energy supply towards sources like wind, hydropower, solar energy, etc., is necessary to decrease dependence on fossil fuels. Wind farms are growing worldwide, and with the emergence of modern grid systems, wind energy systems are making a significant impact in penetrating the current energy market. Even though challenges persist, wind energy is a versatile source with a direct connection with power transmission with high scalability. In order to synchronize a wind turbine with the grid, a power electronic converter is used. This allows us to efficiently convert a variable frequency output of an induction generator, driven by a variable speed wind turbine, to one with a fixed frequency suitable for the grid.

In this research, we will simulate various types of power converter models, including but not limited to a three-level neutral point clamped converter for wind turbines (3L-NPC/ANPC) and a modular multilevel converter. Various parameters, such as the turbine's frequency and output current, are analyzed to ensure that they are consistent with the frequency and phase of the grid voltage. The results obtained determine the efficiency and economic sustainability of the power electronics simulated, hence determining their future scope.

Keywords: Renewable sources, Power converter, Wind Turbine

Contents

Introduction

Wind energy is rapidly becoming one of the most promising and sustainable alternatives to conventional fossil fuels, due to its abundant availability and environmental friendliness. Multi-level power converters play a crucial role in the efficient and reliable integration of wind energy into the grid. These converters are able to handle the high voltage and power levels generated by wind turbines, and provide a smooth and stable output voltage to the grid. In recent years, multi-level power converters have gained attention due to their higher efficiency and reduced harmonic distortion compared to conventional two-level converters. Modeling and simulation play a vital role in designing, analyzing, and evaluating the performance of these converters for wind turbine systems. To this end, the use of Matlab-Simulink for power electronics modeling and simulation has become increasingly popular due to its versatility, user-friendliness, and extensive library of models. This paper provides a comprehensive review of the modeling and simulation of multi-level power converters for wind turbine systems using Matlab-Simulink, aiming to provide researchers and engineers with an in-depth understanding of the various aspects of this topic, and highlighting the challenges and opportunities for future research. The paper emphasizes the critical role that multi-level power converters play in wind turbine systems and their application, which is increasingly important in the renewable energy sector.

Theory and Working of an IGBT Diode

The Insulated Gate Bipolar Transistor is a versatile switching device that evolved from the characteristics of BJTs and MOSFETs. The insulated gate refers to the high input impedance, which contributes to a near-zero input current and complete gate voltage dependence. This makes the IGBT a voltage-controlled device.

Advantages of IGBT

IGBTs have several advantages, including:

- They have a simple drive circuit and are easy to drive
- They have low on-resistance and switching losses, resulting in high efficiency
- They have a high voltage capacity and are suitable for high-power applications
- They have a fast switching speed, making them ideal for high-frequency applications
- They have a low gate drive requirement and high input impedance

- They require smaller snubber circuits compared to other power electronic devices
- They have superior current conduction capability due to their bipolar nature
- They have excellent forward and reverse blocking capabilities
- They have a higher switching frequency than BJTs
- They have enhanced conduction due to their bipolar nature
- They have a very low on-state voltage drop, resulting in reduced cost and smaller chip size.

Working Of IGBT

An IGBT has three terminals - collector (C), emitter (E), and gate (G) - with the collector and emitter terminals used for current conduction and the gate terminal used for control. The operation of the IGBT is influenced by the biasing between the gate-emitter and collector-emitter terminals. When the collector-emitter is connected to Vcc, the collector is positively charged compared to the emitter, resulting in forward biasing of junction j1 and reverse biasing of junction j2. As a result, the IGBT remains switched off, and no current flows between the collector and emitter in the absence of a gate voltage.
However, when a positive gate voltage (VG) is applied to the gate terminal, negative charges accumulate beneath the SiO2 layer due to capacitance. Increasing VG increases the number of charges, eventually forming a layer in the upper P-region when VG exceeds the threshold voltage. This layer creates an N-channel that short-circuits the N- drift region and N+ region.The electrons from the emitter flow from N+ region into N- drift region and the holes from the collector are injected from the P+ region into the N- drift region. The excess of both electrons and holes in the drift region enhances its conductivity and triggers the conduction of current, leading to the switching ON of the IGBT.

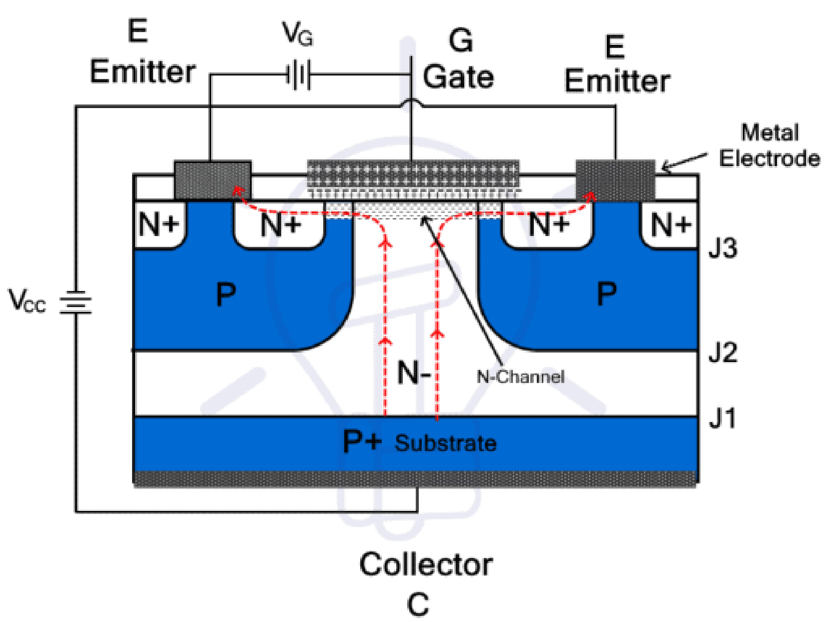


Figure 1: Working of IGBT

Practical working (based on our simulation)

Even though the use of IGBT lies in various field applications, it does have a few standalone disadvantages. The fundamental limitation of an IGBT switch is that it cannot conduct current in the reverse direction (i.e., it is a unidirectional device), unlike MOSFETs. Thus, a diode is also connected to the network to provide a current conduction path for the load, especially if the AC side load is of inductive nature. These diodes also prevent inductive spikes during reverse current flow.

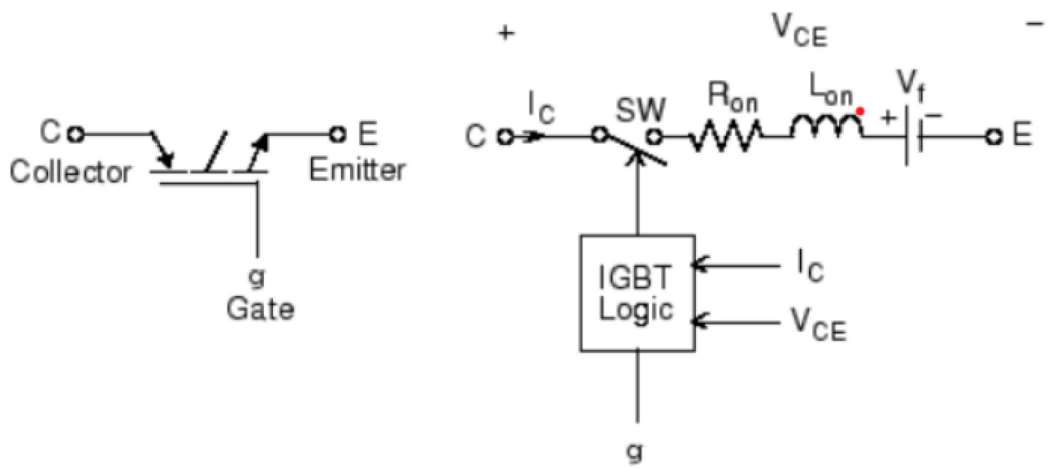


Figure 2

The nature of IGBT can be altered based on the internal inductance value; if L>0, then it acts as a current source, and if L = 0, it is termed as a variable topology circuit. (the same can be tested on Simulink). An IGBT cannot be connected in series with an inductor if snubbing is not present.

Simulation using MATLAB Simulink

Circuit Diagram and Explanation

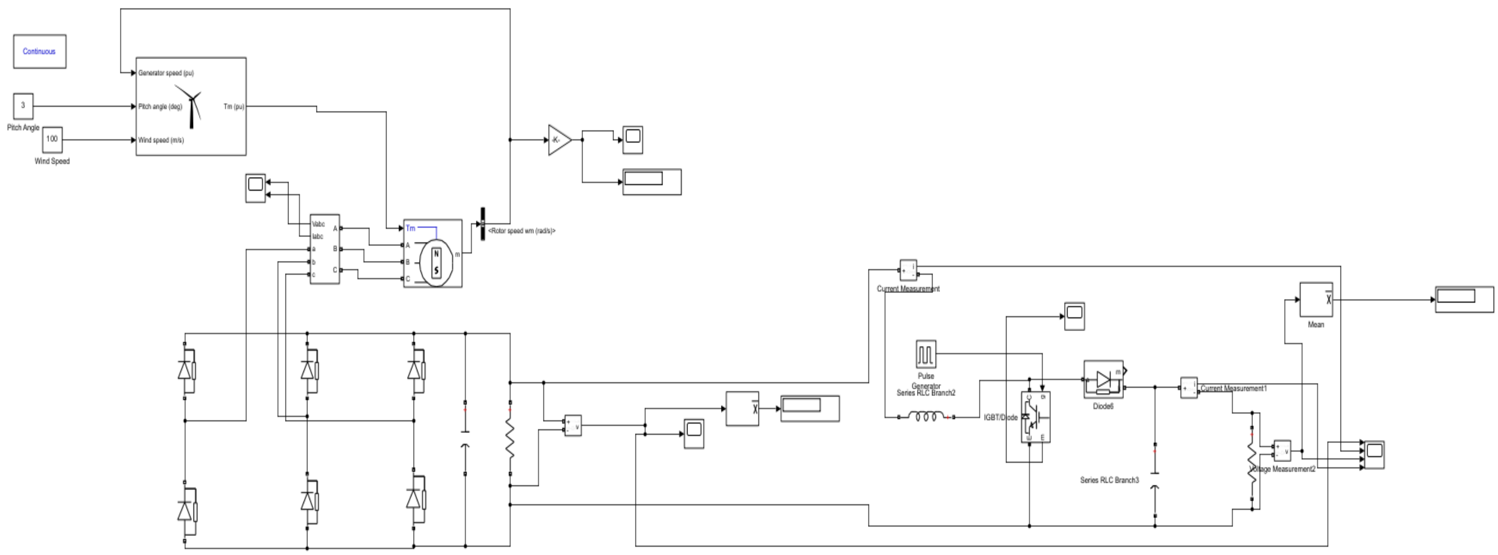


Figure 3

The main objective of the following circuit is to convert mechanical wind energy to electrical DC output. To achieve this, we make use of a 3-phase full-wave rectifier along with a boost converter.

- The mechanical energy obtained from the wind turbine is used to rotate a permanent magnet synchronous generator.
- The generator speed of the synchronous machine is in a feedback loop with the wind turbine.
- The output of the generator acts as a 3-phase AC supply to the 3-phase uncontrolled full-wave rectifier. Here, we assume that the output is a sinusoidal wave.
- The voltage across the 3-phase rectifier load acts as the input voltage to the boost converter. The graph of this input voltage can be found in Figure 3
- The boost converter is a DC-DC power converter that steps up voltage and steps-down current. It consists of 2 semiconductors, namely, an IGBT diode and a npn-transistor diode in series with an energy-storing element (like an inductor). Furthermore, we use a capacitor to smoothen out the ripples in the output voltage.
- The voltage across the RC filter is further provided to the substation for transmission

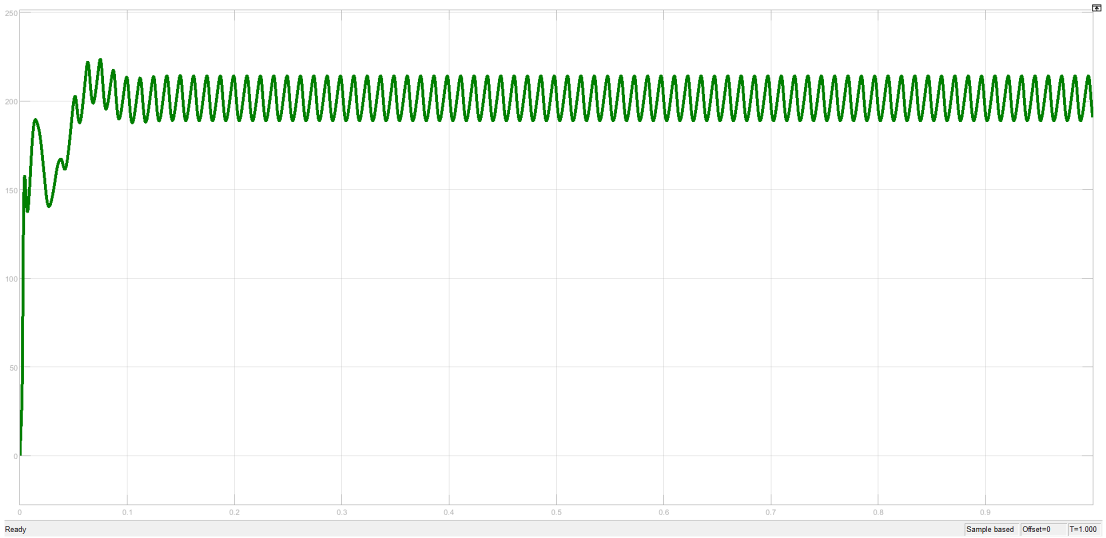


Figure 4

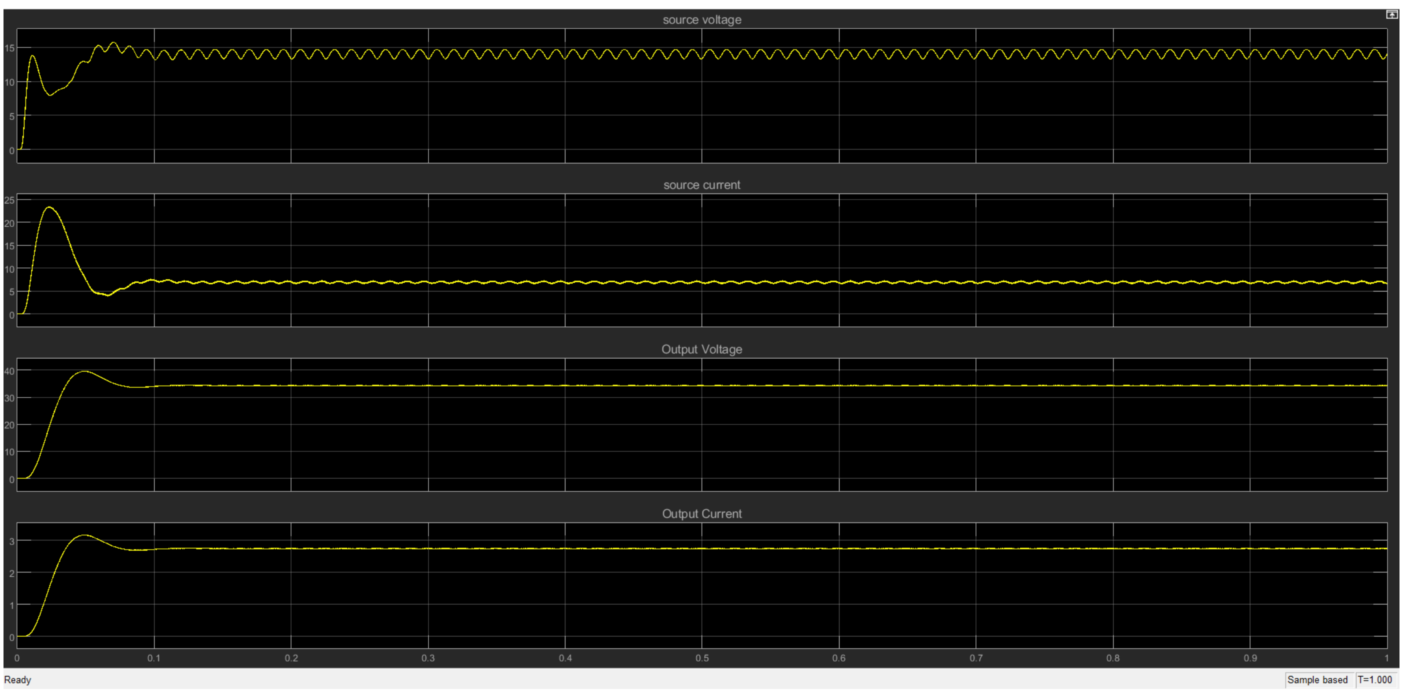


Figure 5

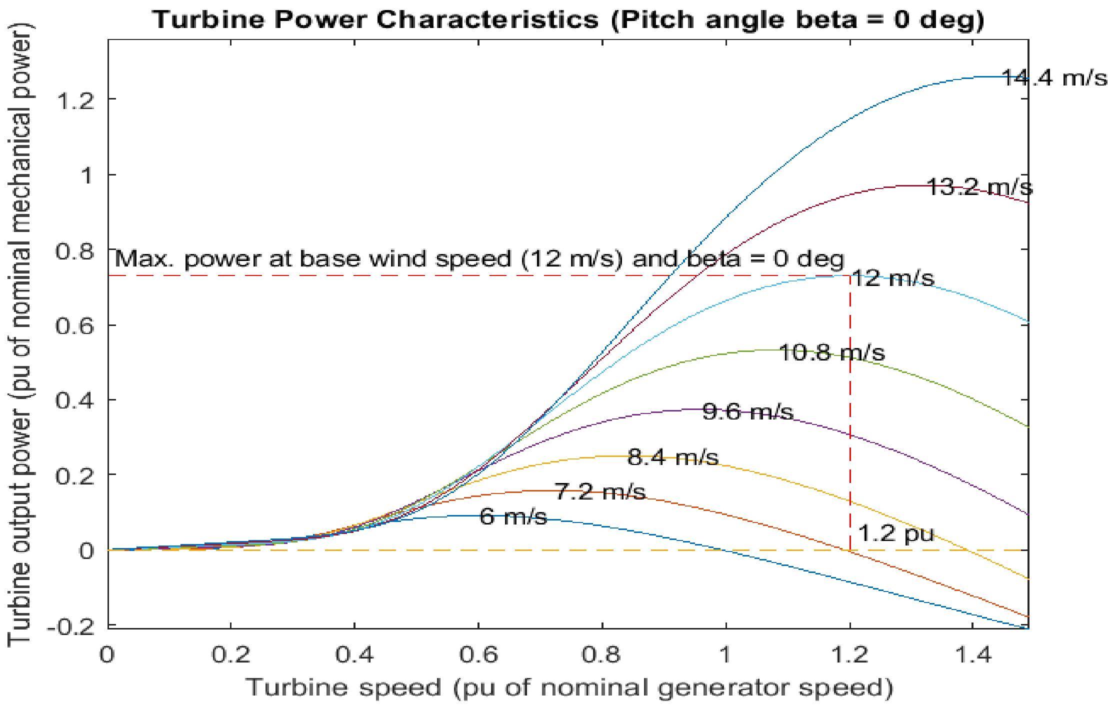
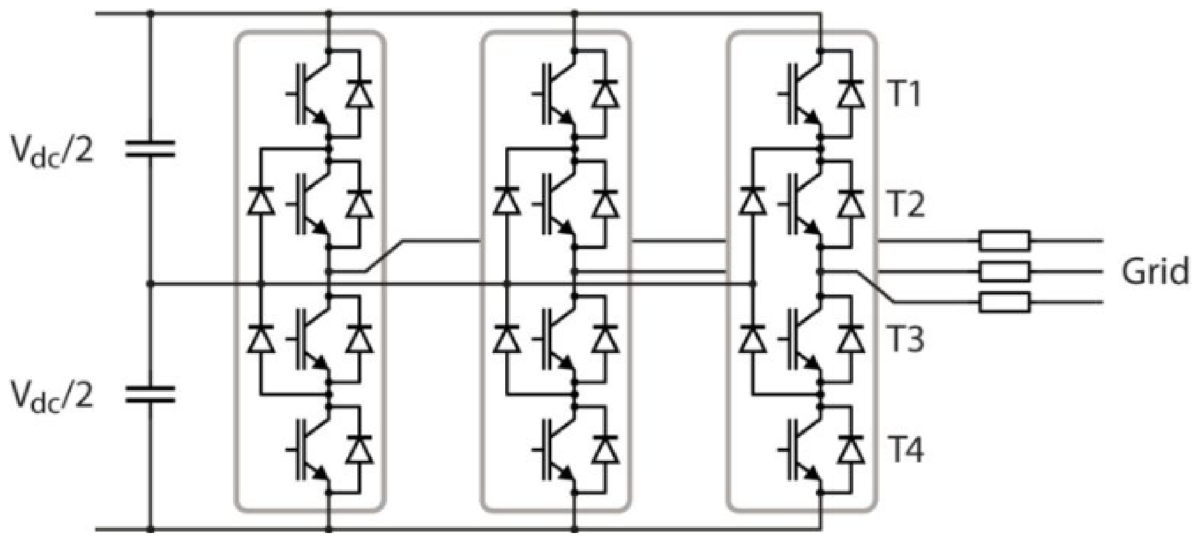


Figure 6

Theory and Working of an NPC/ANPC Converter

An NPC (Neutral Point Clamped) or ANPC (Active Neutral Point Clamped) converter is a type of power electronics converter used in wind turbines to convert the variable frequency and voltage output from the generator into a fixed frequency and voltage suitable for feeding into the grid.



Topology of a three-phase Neutral Point Clamped (NPC) inverter

Figure 7

An NPC/ANPC converter works by switching the input voltage to a series of capacitors and inductors to make a fixed waveform of output voltage. In an NPC converter, the capacitors are clamped to a neutral point. This reduces the voltage stress on the power devices and makes the system more efficient as a whole. On the other hand, an ANPC converter uses active clamping to reduce the voltage stress on the power devices and increase the system's efficiency.

The working of an NPC/ANPC converter can be divided into three main stages:

- Rectification: The three-phase AC output from the generator is rectified using diodes to produce a DC voltage.

- Inverter: The DC voltage is then converted into a high-frequency AC voltage using a series of switches (IGBTs or MOSFETs). The switches are controlled by a pulse width modulation (PWM) signal to generate a sinusoidal waveform with the desired frequency and voltage.

- Clamping: In an NPC converter, the capacitors are clamped to the neutral point using a series of diodes, which reduces the voltage stress on the power devices. In an ANPC converter, the clamping is done using active techniques, such as resonant snubbers or auxiliary switches, to further reduce the voltage stress and improve the efficiency of the system.

Overall, the NPC/ANPC converter is a key part of turning the wind turbine generator's variable output into a stable AC voltage that can be fed into the grid. By using advanced power electronics techniques such as active clamping and PWM, the converter can achieve high efficiency and reliability, which are essential for the successful operation of modern wind turbines.

Theory of 3 Phase Rectifier and Buck Boost

A 3-phase full-wave rectifier is a type of rectifier circuit that converts three-phase AC power into DC power. It typically consists of six diodes arranged in a specific configuration to rectify the AC input voltage. The output of the rectifier is a pulsating DC voltage with a frequency three times that of the input AC voltage.

On the other hand, a boost converter is a DC-to-DC converter that steps up the voltage of a DC power source. It typically consists of an inductor, a switch, a diode, and a capacitor. When the switch is closed, the inductor stores energy from the input voltage. When the switch is opened, the inductor releases its stored energy to the output capacitor, which results in an increased output voltage.

Combining a 3-phase full-wave rectifier with a boost converter can provide a higher DC output voltage than just using a rectifier alone. This is because the boost converter can increase the rectified voltage to a higher level. Additionally, the boost converter can also help regulate the output voltage, which is important for applications that require a stable DC voltage.

One potential application of a 3-phase full-wave rectifier with a boost converter is in renewable energy systems, such as wind or solar power. These systems often produce low-voltage DC power that needs to be stepped up to a higher voltage before it can be used by the electrical grid or other applications. The rectifier and boost converter combination can help accomplish this task efficiently and reliably.

Conclusion

Our work done till now focuses on the use of a 3-phase full-wave rectifier and boost converter in wind turbine systems. The 3-phase full-wave rectifier along with a boost converter model is a widely used circuit topology for AC-DC power conversion in various applications. We have chosen these components to be the base level as we attempt to increase the efficiency and reliability of the power conversion process in wind turbines. We have made use of simulation techniques to model and test the behaviour of these components in various scenarios. The graphs and waveforms above provide valuable insights into their optimal design and operation.However, as technology advances and requirements for power electronics systems evolve, it is important to explore alternative circuit topologies.Here are some reasons why exploring alternative circuit topologies is important:

1. **Efficiency**: The efficiency of a power electronics system is a crucial factor that determines its effectiveness and cost-effectiveness. Alternative circuit topologies can

potentially offer higher efficiency than the 3-phase full-wave rectifier along with a boost converter model, which can lead to energy savings and reduced operating costs.

2. **Performance**: Alternative circuit topologies can provide improved performance in terms of power quality, reliability, and noise immunity. For example, some circuit topologies can offer better power factor correction, reduced harmonic distortion, and improved voltage regulation.
3. **Cost-effectiveness**: The cost of power electronics systems is a key consideration for many applications, and alternative circuit topologies can potentially offer lower component count, reduced complexity, and lower manufacturing costs.
4. **Size and weight**: Alternative circuit topologies can potentially offer smaller and lighter solutions compared to the 3-phase full-wave rectifier along with a boost converter model, which can be beneficial for applications where space and weight are critical factors.

Hence we plan to explore alternative circuit topologies in order to identify better solutions that can offer improved performance, efficiency, cost-effectiveness, and other benefits compared to the 3-phase full-wave rectifier along with a boost converter model.NPC convertor seems like a promising start and we hope to build upon that.

Work to be done Post Midsem

After midsems we plan to make and stimulate more simulink circuits with and without various converters. We will mainly be focusing on the NPC converter and how it can help us increase the efficiency as well as the reliability of the wind turbine.

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