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Implementation of AC to DC Converter in Wind Power Generation Using Matlab

Professor Dr.S Mani.Kuchibhatla, A.Sony, B. Nishith, B. Ruthwik
EEE, ACE Engineering College Ghatkesar, Telangana, India

Abstract- Wind power generation has emerged as a crucial component of renewable energy systems, offering a sustainable and environmentally friendly alternative to fossil fuels. However, the integration of wind energy into the grid requires efficient power conversion mechanisms due to the variable nature of wind speed and the need for compatibility with existing infrastructure. A typical wind power system involves the conversion of mechanical energy into alternating current (AC) power using a generator, which is driven by wind turbines. This project focuses on the design and implementation of an AC to DC converter in wind power generation systems. The AC to DC converter plays a vital role in transforming the variable frequency AC output of wind turbines into a stable DC voltage. In this process, the generated AC power is first converted into direct current (DC) using power electronics, which enables efficient integration with batteries or facilitates smooth conversion. This conversion process is essential for stabilizing power output, minimizing losses, and ensuring the efficient transmission of energy over long distances. Advanced AC to DC converters and control systems enhance the reliability, efficiency, and scalability of wind power systems, making them a vital component in modern renewable energy infrastructures. This is implemented in the MATLAB/SIMULINLK.

Index Terms- WECS, PMSG, MATLAB , Diode Rectifier

I. INTRODUCTION

Renewable energy sources are the sources that never get exhausted and are always replenished by natural process. Sun forms the major source of energy for all Renewable Energy Sources. The only source of energy that is freely and abundantly available is renewable energy source as their CO2 emissions are minimum. Among these, wind energy is formed because of heating of earth's surface [1].

Opportunities of Renewable Energy Sources

- Progresses with the improvement of efficiencies.
- There is rising energy demand always, since fossil
- fuels are depleting, RES have a good hold.
- People accept it socially and economically.
- It does not compulsorily require on grid connections.

In case of WECS, wind energy is the primary source,which possesses kinetic energy due to movement of air which when hits the blades of the turbine converts to mechanical energy. Generator/alternator helps in converting mechanical to electrical energy. In the last decade, WECS has achieved its highest growth. Basically, a WECS consists of a wind turbine, alternator, converters which are control system requirement along with power electronics.

There are two types of WECS

- Constant speed
- Variable speed

Variable speed WECS is more beneficial compared to Constant speed. Power electronics plays a vital role in providing solution to variable speed WECS. The WECS utilizes generators, which are classified as given below:

- Synchronous generators
- Permanent magnet synchronous generators (PMSG)

PMSG does not require any kind of excitation circuit for its operation. With its low maintenance cost and high efficiency, it has been considered for high power applications. This paper analyses the PMSG generator based WECS. The power produced from the Wind turbine is delivered to the rectifier for the conversion from AC to DC converter. The first part of the simulation focuses on AC to DC conversion with WECS. The second part of the simulation focuses on supplying the output voltage to a boost converter.

II. PMSG BASED WECS

WECS

The WECS convert kinetic energy of the wind to mechanical energy or electrical energy irrespective of different varieties of

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wind turbines. In a practical machine, wind energy from the rotor blades is converted into rotational shaft energy.

Pitch Control: In any wind turbines, the control of power output from the turbine blades is a major issue. Pitch control technology works on the principle of regulating blades by a control system.

Pitch Angle: The more convenient way to control the power is by incorporating the pitch angle control. This is useful in regulating aerodynamic torque in WECS. For any given wind velocity pitch angle is optimum indicating that power output at turbine is maximum.

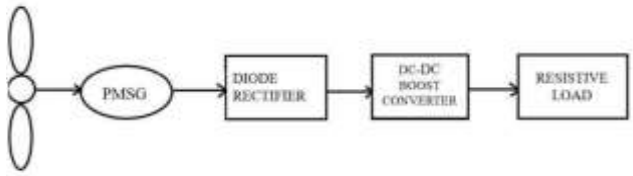

Fig.1.Variable speed wind turbine with power converter

Fig.1. represents the basic block diagram of the proposed work. Since the permanent magnet synchronous generator has a flexibility of gear less operation it is more commonly used when compared to double fed induction motor in the operations of wind industry the power electronics play a key vital role as Power electronic converter technology. For the conversion process to take place, semiconductor switches are used. These semiconductor switches are GTO, IGBT, and MOSFET etc. The devices used have undergone major operational changes from many years and thereby forms the most used switches in high power converters significantly

PMSG

Permanent Magnet Synchronous Generator are primarily used to convert mechanical energy of wind in the wind turbine to electrical energy. This electrical output can be fed to the grid. Rotor and the stator run at the similar speed, referred to as synchronous generator and the name permanent magnet because the excitation field is a permanent magnet here. Permanent magnets are used in excitation rather than an electromagnet. The flux associated with the field is constant. In permanent magnet synchronous generator, slip rings are not necessary.

As shown in Fig. 1, a PMSG is utilized to transform wind energy to electrical energy. PMSG yields adjustable magnitude and adjustable frequency voltage.

Advantages of PMSG

- For the excitation circuit separate DC circuit is not necessary.
- PMSG elude the usage of slip rings, simple in use and repairs free.
- The generator is brush less.
- Higher efficiency, as the copper loss in the rotor disappear.

In WECS, shaft is used to mechanically couple the turbine and generator. In MATLAB Simulink model, generator is a PMSG. Inbuilt PMSG is utilized.

III. POWER CONVERTER TOPOLOGY

Because of the advent of power electronic converters,variable speed WECS's are very common these days which helps in smooth variation of wind speeds. Depending on the type and rating of load connected, the choice of power electronic converter is made. There can be two types of loads either AC or DC. If it is AC load then DC can be used to store the excess power if necessary. If the load is DC then only ACDC conversion is sufficient. A simple bridge rectifier incorporated with a capacitor filters is sufficient but for high power applications, more appropriate Power electronic switch need to be used like SCR's/IGBT/MOSFET etc. In this paper, a three-phase diode bridge rectifier is used in first stage, which converts three-phase AC output of WECS into DC output. This DC output is also stepped up in second stage using a boost converter.

Three Phase Diode Rectification

Rectification is the process of converting AC to DC signal. Rectification by means of diodes as the semiconductor switches is more feasible as they are inexpensive, small and robust. Rectification process can be either single phase or three phase. In this paper, three phase uncontrolled rectifier is used which is supplied by a three phase balanced supply. Diode rectification happens with supply being taken from the grid or from any other three-phase AC source. This is converted to DC output level.

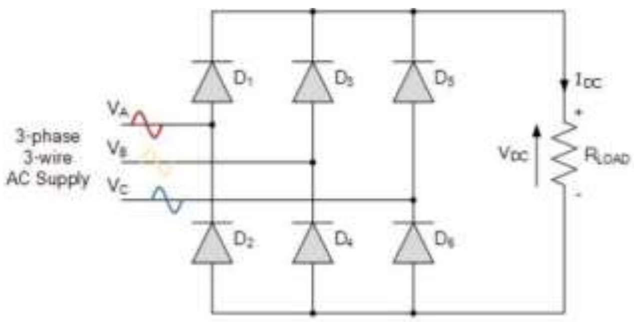

Fig. 2: Full wave three phase uncontrolled rectifier.

Fig. 2 represents the full wave 3-φ diode bridge rectifier circuit, in which two diodes will be existing per phase. Each phase is sandwiched between a pair of diodes as shown in the

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Fig .2. One diode from the upper leg and one diode from the lower leg will conduct for 60º in pairs. During positive half cycles D1, D3 and D5 conducts whereas during negative half cycles D2, D4 and D6 conducts. Basically, diodes operate in pairs in the above circuit as shown in Fig.2, which shows that they are operating in series. Therefore, 60º is the commutation angle of pair of diodes with each diode operating for a conduction angle of 120º.

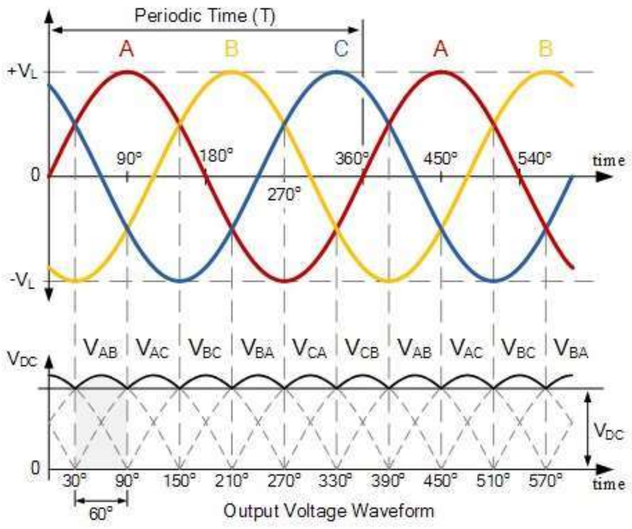

Fig. 3: Output Voltage Waveform

In Fig. 3, each diode operates for 120º, and each pair of diode will operate for only 60º of cycle at any given time.
Therefore, each phase is separated by 360º/3 = 120º. Which requires 2*3 diodes. Using three-phase diode rectification it provides an average output voltage of a fixed value.

- Conduction period for each diode is 120º and conduction period for each diode pair is 60º.
- The load voltage consumes a ripple, and the frequency of this ripple is 300 Hz.

When two diodes are operating at any instant magnitude of the DC voltage is the sum of magnitude of voltages, which is the line voltage, based on the diode pair conducting.

DC – DC Converter
These converters help in converting one DC voltage to another. IC's vary over a wide range of values for different electronic devices. By means of DC-DC Converters, the efficiency, ripple & load-transient response of the system can be enhanced. DC-DC Converters must be able to operate as a step up or step down voltage supplier to deliver constant load voltage over the whole battery range over the operation.

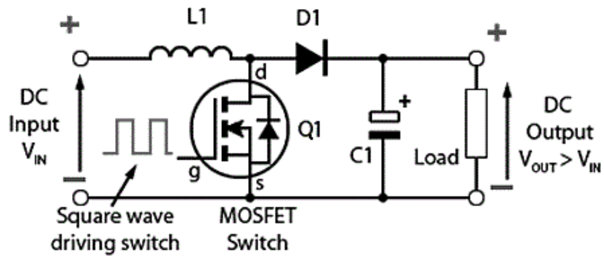

Fig. 4: working principle of DC-DC Converter

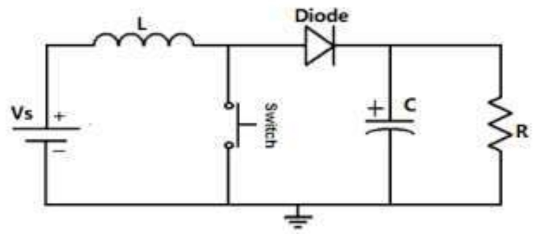

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Fig. 5: Boost Converter

As shown In Fig.4 and In Fig.5 the inductor stores the energy in the form of magnetic energy during Turn On condition of the switch. It releases the energy during the turn off condition of the switch. ,Step-up/Boost converter is used to boost the output voltage compared to the input voltage. In this paper, the output of rectifier is boosted to a certain voltage according to the requirement of the load..

IV. MATLAB SIMULINK MODEL OF WECS

The PMSG based WECS is simulated in MATLAB in three different stages. In the first part of the simulation, only WECS is simulated in the second part of the simulation the output is fed to diode rectifier to convert AC to DC voltage. In the third part, in order to boost the voltage to the load requirement, it is connected to a step-up converter.

Wind energy conversion system
Analysis of WECS is carried out under normal operating conditions. The power developed by the rotor of the wind turbine is given by,

$$p_w = \frac{1}{2} C_p \rho A v^3$$

Where,

- Cp is power coefficient.
- ρ is air density.
- A is swept area of the wind turbine rotor.
- v is the wind speed.

Here, note that mechanical torque of the turbine can be determined with the help of mechanical power that is extracted at the turbine rotor. Power coefficient helps to understand how much power is extracted at the rotor shaft of

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the wind turbine. Pitch angle is the turbine blade angle. Ratio of rotational speed and wind speed is tip speed.

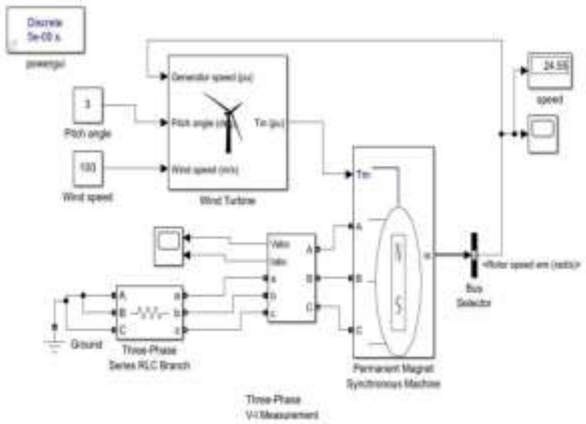

Fig. 6: MATLAB Simulink model of WECS

In Fig.6, Input to the WECS will be the generator speed, pitch angle and wind speed. For the reference, wind speed is kept to 1000 m/s and pitch angle is kept to 3º.

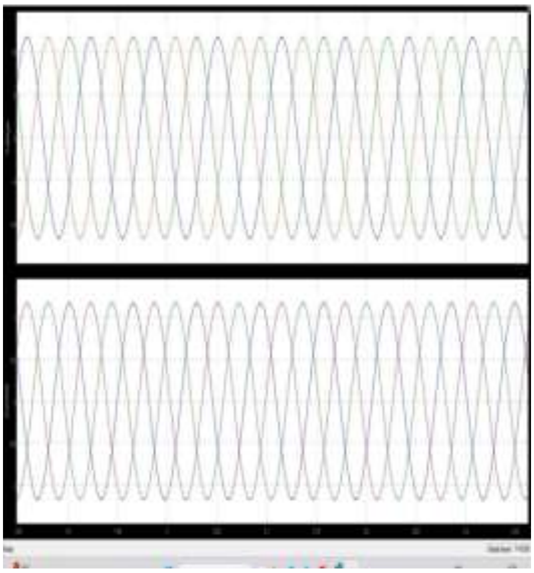

Fig. 7: Wind voltage profile

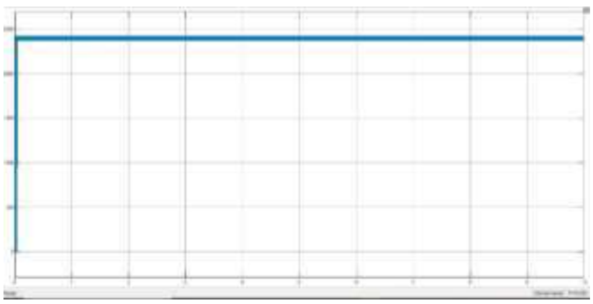

Fig. 8: The Speed of the motor

From Fig.7 & 8, we can observe Wind voltage profile and the speed of the motor .The speed found to be 2397 rpm. Speed of the motor will vary based on the pitch angle and the wind speed across the wind turbine..

WECS with uncontrolled Rectifier

The rectifier model has been recognized using a three phase uncontrolled bridge rectifier simulated in

MATLAB/Simulink. It uses six diodes connected in a three leg format. When a rectifier operated no two switches in the same leg has to be ON at the same time as it will lead to short circuit condition.

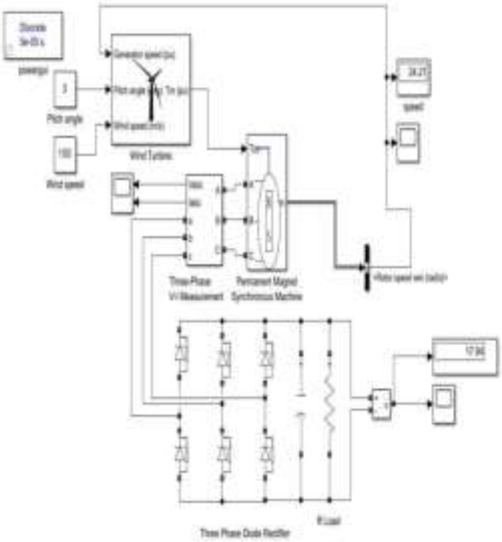

Fig. 9: WECS connected to uncontrolled rectifier.

Fig. 10: Rectifier output without filter

WECS connected to uncontrolled rectifier is shown in Fig.9 & its output without filter element is as shown in fig.10

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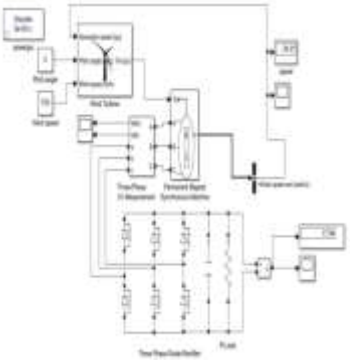

Fig.11: WECS connected to uncontrolled rectifier with filter element

In order to reduce the harmonic content, the rectifier is connected to a capacitor (filter element) to reduce the ripple factor. The output of the same is as shown in Fig. 12.

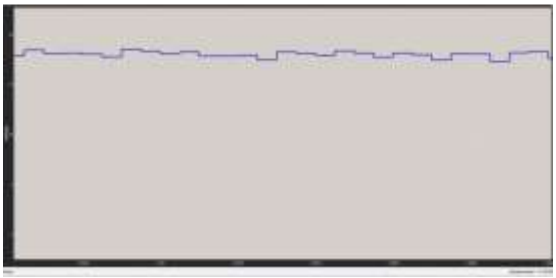

Fig.12 represents the rectifier output with filter. Here the value of capacitor is taken to be 10mF.

WECS with uncontrolled Rectifier connected to a boost converter

The output of the above MATLAB configuration was obtained to be around 17.67 volts. For many applications, the output of this can be boosted to any required value using a boost converter. Therefore, a simple model of a step-up converter is connected to the output of WECS based rectifier, output voltage is boosted from 17.94 volts to 27.76 volts.

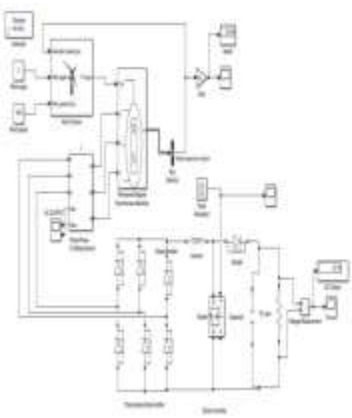

Fig.13: WECS Based rectifier fed boost converter

.In Fig.13 output of rectifier is connected to a boost converter. In a boost converter a inductor, switch and a diode is used and connected to a simple R load. Switch used is MOSFET.

Boost Converter Specification

- Inductor value (L) = 1mH, C = 10mF
- R value = 10Ω
- MOSFET switch: Pulse width = 5, period = 10
- Sample time = 1

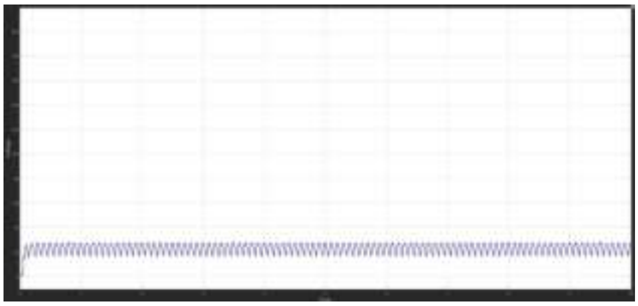

Fig.14: Boost converter output waveform

V. CONCLUSION

A great number of technology choices prevail in wind turbine designs. A complete valid simulation model of a gear less variable speed wind turbine scheme with permanent magnet synchronous generator have been confirmed in MATLAB software environment. The modelling of wind turbine based AC to DC converter using MATLAB/Simulink. The model comprises of wind turbine, PMSG, pitch angle control, AC to DC converter and DC-to-DC converter. Rectifiers play a key important role in converting PMSG voltage into DC-voltage. The simulation also enabled the operation of DC-DC converter. i.e., boost converter at the output terminal. The output voltage is boosted to highest level of the approach.

Future Scope

The future scope for power electronic converters in wind turbine AC to DC conversion includes improving efficiency, enhancing grid stability, supporting energy storage, and enabling the integration of wind energy into more decentralized, intelligent, and electrified systems. Advanced Converter topologies, Research will continue to explore new converter designs such as multi-level converters, matrix converters, and hybrid topologies. These can reduce power losses, improve voltage quality, and enhance reliability.Gear less variable speed wind systems with PMSGs are well-suited for use in offshore wind farms, they are more reliable and require less maintenance than traditional wind turbine systems.Gear less variable speed wind systems with PMSGs can be combined with solar photovoltaic (PV) systems to create hybrid wind-solar systems that can provide a reliable and affordable source of electricity.These developments will

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be pivotal in shaping the next generation of renewable energy infrastructure.

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