“Simulation of Wind Energy Conversion System Using PMSG”

Minor Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

BACHELOR OF TECHNOLOGY IN

ELECTRICAL ENGINEERING

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December 2021

CERTIFICATE

This is to certify that the Minor Project Report entitled “Simulation of Wind Energy Conversion System Using PMSG” submitted by Mr. Parth Nileshkumar Patel(18BEE081) towards the partial fulfillment of the requirements for the award of degree in Bachelor of Technology in the field of Electrical Engineering of Nirma University is the record of work carried out by him/her under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this minor project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

Date: 28/11/2021

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ACKNOWLEDGEMENT

I must acknowledge the strength, energy and patience that almighty **GOD** bestowed upon me to start & accomplish this work with the support of all concerned, a few of them I am trying to name hereunder.

I would like to express my deep sense of gratitude to *all faculties of Electrical Engineering Department* for their valuable guidance and motivation.

I would like to express my sincere respect and profound gratitude to **Prof. (Dr.) S. C. Vora**, *Professor & Head of Electrical Engineering Department* for supporting and providing the opportunity for training.

I would also like to thank all my friends who have helped me directly or indirectly for the completion of my training.

No words are adequate to express my indebtedness to my parents and for their blessings and good wishes. To them I bow in the deepest reverence.

- Parth N. Patel (18BEE081)

ABSTRACT

In the present scenario, the world is shifting towards the renewable energy sources like solar, wind, tidal energy and many more. Wind is one the most prominent source from all type of renewable energy resources. And now a days wind energy is used to suppress the electricity shortage and to control the fast end of fossil fuels. Wind energy conversion system (WECS) based on variable speed wind turbine with direct driven permanent magnet synchronous generator (PMSG) and transmits it electrical power to the DC grid through rectifier and DC-DC boost converter. In this report describes, operation and control of variable speed wind energy conversion system (WECS) based on gearless PMSG to developing a maximum power point tracking (MPPT) method in order to extract maximum power. The gearbox is not required due to the use of low-speed permanent magnet synchronous generator which results in higher efficiency and lower maintenance cost. The ac power output generated through permanent magnet synchronous generator is fed to the diode-based rectifier which enables the extraction of the maximum power through the optimal value of voltage and current of the DC- DC boost converter. the simulation results in MATLAB/ Simulink 2021a shows the model having good dynamic and static performance.

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LIST OF ACHRONYMS

DC	: Direct Current
AC	: Alternating Current
WECS	: Wind Energy Conversion System
PMSG	: Permanent magnet Synchronous Generator
IGBT	: Insulated Gate Bipolar Transistor
PWM	: Pulse Width Modulation
MPPT	: Maximum Power Point Tracking
P&O	: Perturb and observe
PI	: proportional Integrator
RES	: Renewable Energy Systems
VSWT	: Variable speed wind Turbine
FSWT	: fixed Speed Wind Turbine
PLL	: Phase Locked Loop

NOMENCLATURE/ ABBREVIATIONS

C_{min}	: minimum capacitance
R_f	: load resistor
V_f	: Ripple voltage
f	: Switching frequency
C_p	: power coefficient
λ	: tip speed
β	: pitch angle
L_d	: d-axis inductance
L_q	: q-axis inductance
i_d	: d-axis current
i_q	: q-axis current
V_d	: d-axis voltage
V_q	: q-axis voltage

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CHAPTER 1: INTRODUCTION

Renewable energy systems (RES) have drastically increased their production of the electrical energy since past few years. Renewable energy is environment friendly, and it also reduces the dependency of the fossil fuel-based power generation. Among the all-renewable energy based electrical energy production techniques such as solar, wind, tidal; wind energy conversion system (WECS) is the most preferred and widely used technique because of their wide availability and enhanced technology in implementation of larger capacity wind turbines. Due to steady growth in the increase of the power rating of the wind turbine (WT) and integration to the power grid, and also some advanced control strategies are required to make the wind energy conversion system more reliable and feasible for grid integration.

In present, variable speed wind turbine (VSWT) systems are widely used over fixed speed wind turbines (FSWT) because variable speed wind turbine can harness the electrical power from all speed regions by controlling their shaft speed based on the wind velocity.

Various wind turbines are available in the market such as permanent magnet synchronous generator (PMSG), doubly fed induction generator (DFIG), squirrel cage induction generator (SCIG). Among the variable speed wind turbine PMSG based wind energy conversion system received more attention due to having its several advantages like higher efficiency, gear less operation, low maintenance, low cost, low noise and higher robustness. Direct driven permanent magnet synchronous generator provides lower mechanical stress and higher power output.

In the proposed model of wind energy conversion system includes a wind turbine, permanent magnet synchronous type generator, rectifier for conversion of AC to DC, and grid which is directly connected with DC-DC boost converter. Also control strategy is used for maximizing the performance and efficiency of a PMSG based WECS. There are two types of control strategy is there that is pitch angle controller and maximum power tracking based on perturb and observe algorithm.

Pitch angle controller enable the turbine to operate in wind speed which is higher than the rated wind speed. Without pitch angle controller this would not be possible. To improve the energy capture efficiency in wind energy conversion system, an efficient and advanced maximum power point tracking method is required. In the proposed model P&O technique is implemented for maximum power point tracking.

CHAPTER 2: SYSTEM CONFIGURATION

The configuration of the proposed wind energy conversion system (WECS) is shown in the below figure 1. The system consists of a direct driven permanent magnet synchronous generator, diode-based rectifier, dc-dc boost converter with control strategy for a standalone wind energy conversion system. The boost converter is incorporated with the maximum power point tracking (MPPT) control strategy which generates duty cycle according to the available wind speed. The pitch angle controller is initiated when the wind velocity exceeds the rated wind speed. The pitch angle command controls the angle of the blade in such a way that the rotation speed of the shaft is kept at an optimal value.

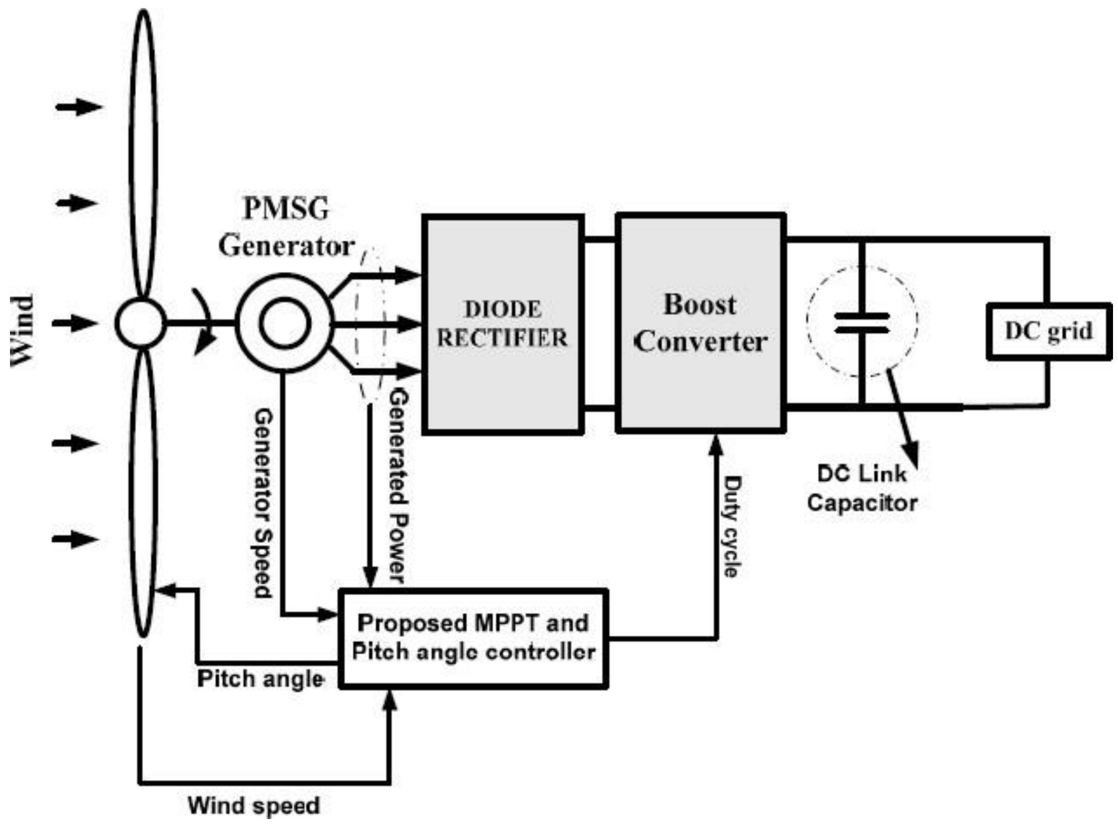


Fig 1. proposed configuration for the permanent magnet synchronous generator (PMSG) based wind energy conversion system

CHAPTER 3: COMPONENTS OF THE WECS USING PMSG

In a wind energy conversion system (WECS), wind turbine with two or more blades captures the wind's kinetic energy in the rotor mechanically coupled to an electric generator. The rotation of electric generator generates electricity and this output is maintained by some control techniques. The output power or torque depends on some factors like size of wind turbine, wind velocity etc.

3.1 WIND TURBINE

The wind energy conversion system is a complex system which converts wind energy to mechanical energy and electrical energy. Output power is defined by various factors such as wind speed, turbine shape and dimension of wind turbine. With respect to wind power generation, wind turbines having different characteristics play important role in power generation.

The wind turbine model is performed depending upon the air dynamic productivity coefficient $Cp(\lambda, \beta)$. Where β is the pitch angle of blade and λ is the speed rate. The air dynamic model is determined depending of wind speed.

Mechanical power extracted by the blades can be written as:

$$P = 1/2\, \rho S v^3$$

ρ= air density
S= surface area of the turbine
v=wind speed

After that wind turbine is used to convert wind energy into mechanical torque. It may be determined from the mechanical power at the turbine extracted from the wind turbine. The power coefficient of the turbine Cp is defined as the ratio between mechanical power (Pm) and wind power (Wp).

The power coefficient of is the function of pitch angle and tip ratio. And pitch angle can be defined as the angle of turbine blade and tip ratio is the ratio of rotational speed and wind speed. The maximum value of power coefficient as denoted by betz's limit and its value is equal to 0.593. so it can be say that power extracted from the wind turbine can be no longer than 59.3 %.

The power coefficient can also be written in terms of pitch angle and tip speed ratio.

The equation express the mechanical power output and mechanical torque can be mentioned by below equation:

$$Pm = Cp(\lambda,\beta)\, ½\, \rho S\, vwind$$

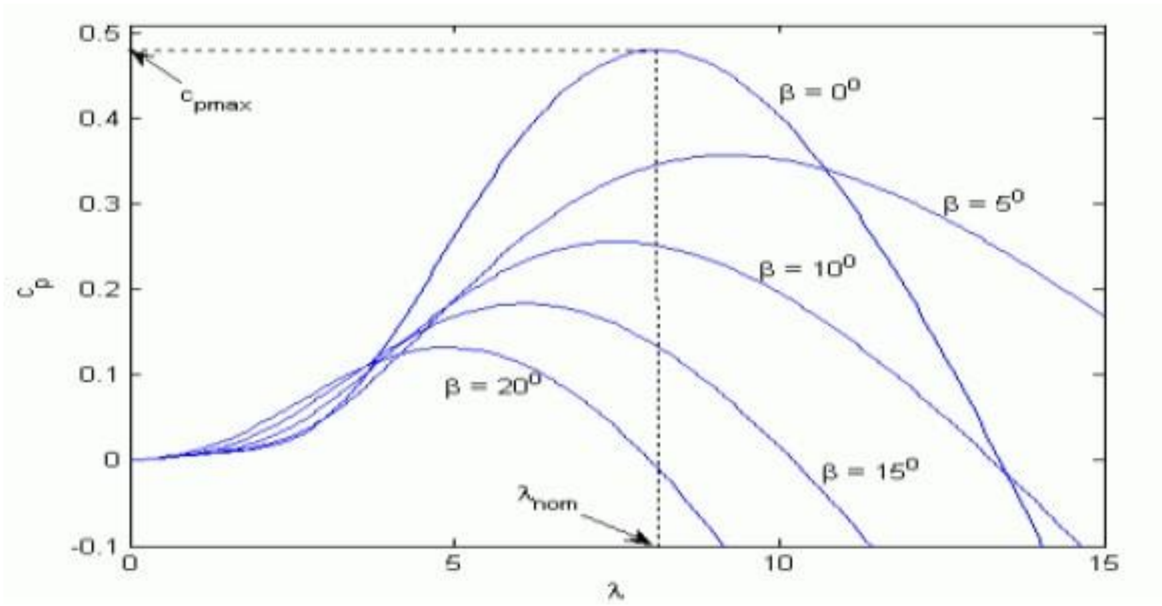


Fig 2. Cp - λ Curve characteristics curve for different values of beta

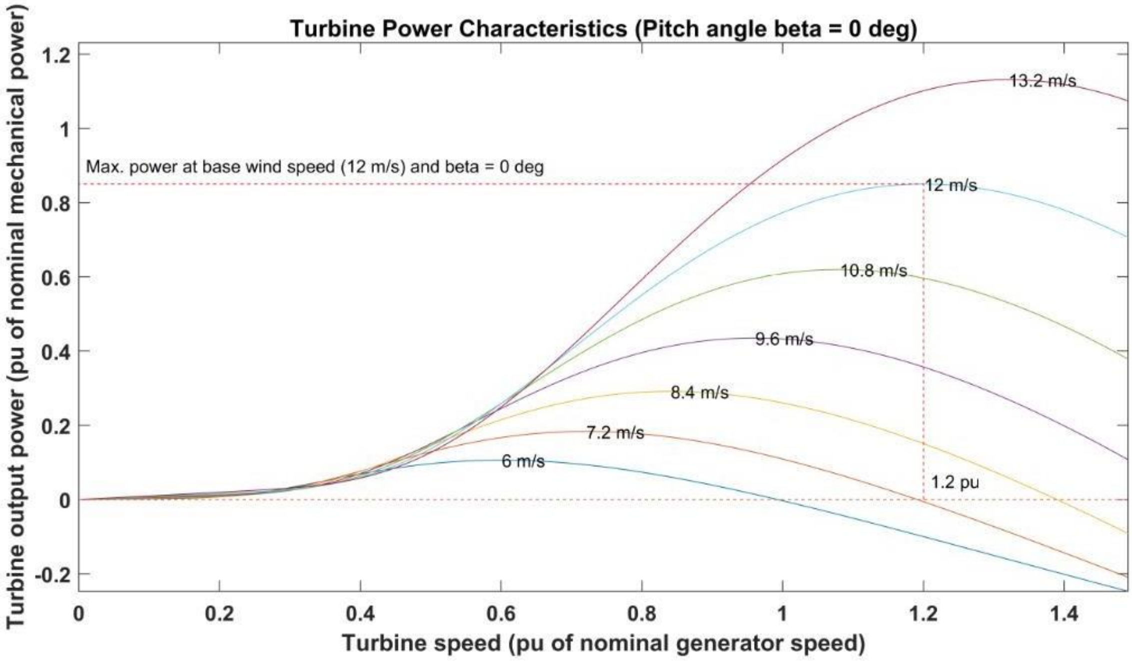
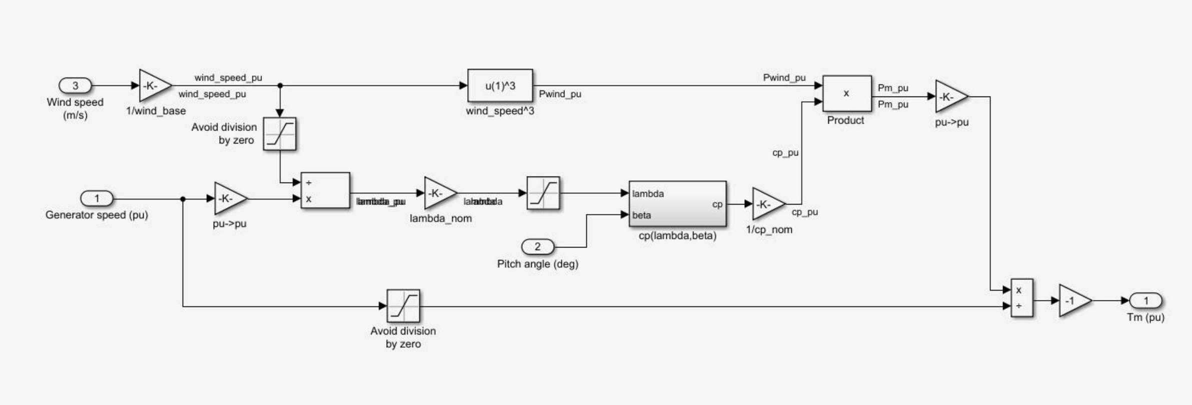


Fig 3. Power in turbine vs. speed of rotor characteristics of a wind turbine

The MATLAB/ Simulink model of wind turbine is shown in the below figure 4.



Fig, 4 Simulink model of wind turbine

The specifications used for the model are mentioned in the table 1.

Table 1. Wind turbine parameters

Parameter	value
Mechanical output power	12.3e3 W
Base power of the electrical generator	12.3e3/0.9
Base wind speed	12 m/s
Maximum power at base wind speed	0.85
Base rotation speed in pu	1.2

3.2 PERMANENT MAGNET SYNCHRONOUS GENERATOR (PMSG)

Permanent magnets are widely used in synchronous machines because of its advantages of simple rotor design without field winding, slip rings and excitation. The permanent magnet synchronous generator is becoming very popular because of its higher power density, compact size, higher reliability and robustness. For offshore wind power installation, the gearless permanent magnet synchronous generator becomes more reliable then geared doubly fed induction generator or squirrel cage induction generator.

The equivalent circuit of permanent magnet synchronous generator (PMSG) based WECS is shown in the fig. 4. The model is created in d-q synchronous reference frame.

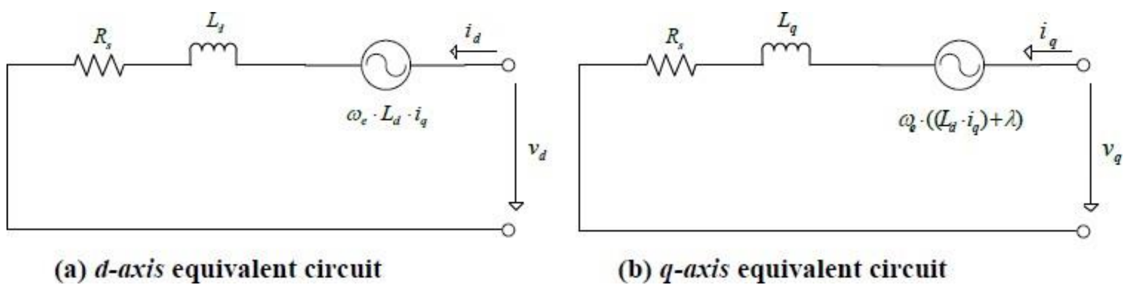


Fig 5. Equivalent circuit of PMSG in d-q reference frame

The dynamic model of permanent magnet synchronous generator is derived from the two-phase synchronous reference frame in which the q-axis is 90° ahead of the d-axis with respect to the direction of rotation. The synchronization between d-q rotating reference frame and abc- three phase frame is maintained by a phase locked loop (PLL).

The voltage equation of PMSG can be written as,

$d/dt\ id = 1/Ld\ vd - RLd/id + Lq/Ld\ pwriq$ .... (i)

$d/dt\ iq = 1/Lq\ vq - RLq/iq - Ld/Lq\ p\ wr\ id - \lambda\ p\ wr/Lq$ .... (ii)

The electromagnetic torque is written by the following equation,

$Te=1.5\rho[\lambda iq+(Ld-Lq)*idiq$

Where,
$L_{d=}$ d-axis inductance
L_q= q-axis inductance
R=resistance of the stator windings
i_d= d-axis current
i_q= q-axis current
V_d = d-axis voltage
V_q =q-axis voltage
W_r =angular velocity of rotor
P=number of poles

The dynamic equation can be written as,

$d/dt\ wr=1/J\ (Te-Fwr-Tm)$
$d/dt\theta=wr$

Where,
J = inertia of rotor
F =friction of rotor
θ= rotor angular

PMSG block can be found in MATLAB/ Simulink library. The specifications used in this permanent magnet synchronous generator are in table 2.

Table 2. Generator parameters

Parameter	**value**
Rating	12.3e3 W
Base rotor speed	98 rad/sec
Stator phase resistance	0.0485
Armature inductance	0.395e-3
Flux linkage	0.1194
Number of poles pair	4

3.3 THREE PHASE DIODE RECTIFIER & BOOST CONVERTER

Diode rectifier is the most simple, cheap and rugged topology used in power electronics. In diode rectifier, the current is allowed to flow in only one direction in three phase uncontrolled rectifier, since it is unidirectional device. In WECS diode rectifier converts AC voltage generated by permanent magnet synchronous generator to DC Voltage which is given to the DC-DC boost converter.

Switched mode power supply can be used to create DC-DC boost converter. Boost converter gives output voltage greater than its input voltage. DC-DC boost converter consists of a diode, capacitor, inductor and switch with switch control circuitry.

In the closed loop DC-DC converter error signal is being generated by comparing the input voltage and current, output voltage and current and wind velocity (V_{Wind}). The error signal is fed to the PI controller and it generates the gate pulses which is given to the IGBT. With the help of insulated gate bipolar transistor (IGBT), controls the duty cycle of the boost converter.

For the regions where value of inductor $L>L_M$ the DC-DC converter works in continues conduction mode

Where,

$$L_M = \frac{(1-d)^2}{2f} Rd$$

the capacitor limits the ripples from the output voltage.

The minimum capacitance of the filter required calculated by,

$$C_{min} = \frac{Vod}{VrRf}$$

d=duty ratio
f=switching frequency
R_f= load resistor
V_f= Ripple voltage

CHAPTER 4: CONTROL STRATEGY OF WECS

Wind energy conversion systems faces the various challenges like rapid variation in wind speed and a lot of uncertainty. That's why an advanced controller is required to solve them efficiently. Integrating an advanced controller into wind energy conversion system is done in order to increase efficiency in terms of power conversion.

The most preferred control strategy for producing optimal power from wind energy conversion system are the pitch angle controller and maximum power point tracking (MPPT).

4.1 MAXIMUM POWER POINT TRACKING (MPPT)

The MPPT algorithm used in the proposed system is perturb and observe (P & O) algorithm.

The most recommended method is P&O method because of its simplicity and ease of implementation. The output from this method has some oscillations which can be reduced by minimizing the size of perturbation.

The P&O methods operates periodically by incrementing or decrementing the voltage or current by comparing the output power P(n+1) with the previous value of power P(n). if the perturbation in the voltage leads to increase the power, then (dP/dV=0). Then perturbation must be kept in the same direction or else it should be moved in the opposite direction. The cycle of perturbation must be repeated till the maximum power is reached.

Flow chart of the P&O algorithm is shown in the fig 6.

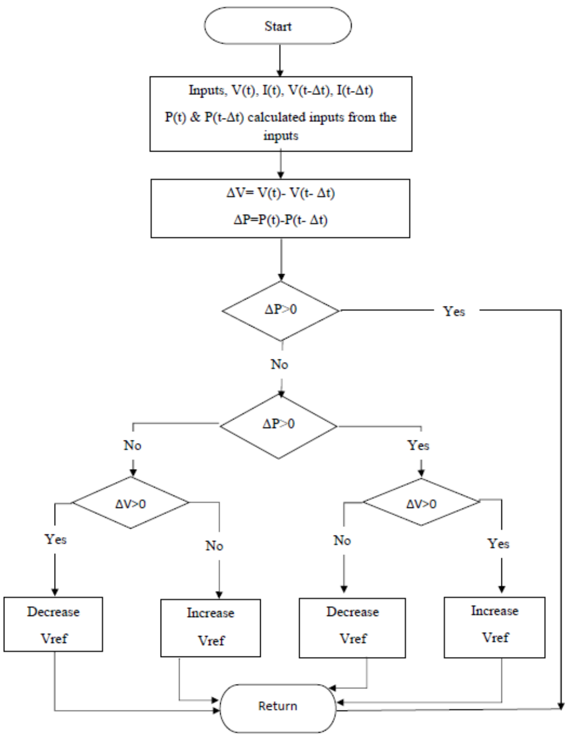


Fig 6. Flow chart of P&O algorithm

4.2 PITCH ANGLE CONTROL

Pitch angle control is applied to control the mechanical power input at a nominal value and it also helps to prevent the electrical power output becoming so high. Generally, it is active in the condition of high wind speed. In this situation, rotor speed can not be controlled by increasing the generated power because this would make overloading of generator. Thai is why pitch angle of blade is modified for limiting aerodynamic efficiency of the rotor which is helpful to control the rotor speed to becoming high. In this criterion the turbine blades are turned away from the wind for minimum power extraction.

Whenever there is an unbalance between power input and input wind energy, the pitch angle controller is implemented to keep the balance between mechanical input and electrical output. And after the fault clears, the pitch angle again retains its optimum value for maximum power output extraction.

Power coefficient, C_p is the function of tip speed λ and blade pitch angle β. So, by changing in the β would also modifying the value of C_p. therefore, it will help to control the rotational speed as well as generator output. And the minimum value of C_p is attained when the blade pitch angle β is zero it means that the condition when pitch angle control is not required it means that turbine is operating at the nominal wind speed. But when the wind speed exceeds the rated wind speed by some extent where the rotor speed exceeds its rated value then the control methos must apply. The value of pitch angle β will be increased by mechanism to decrease the value of C_p to maintain the balance between input power and output power. We have implemented proportional integral method for pitch angle controller.

The method of pitch angle control uses the difference of rotor speed and a reference value of rotor speed to control the pitch angle. And reference value is set to compare the given input rotor speed. Whenever the rotor speed exceeds the reference value, the difference in the signal found out and controller will operate. The error signal is followed by the controller block, rate limiter and angle limit which is shown in the figure.

Fig 7. Shows the simulation model of pitch angle controller.

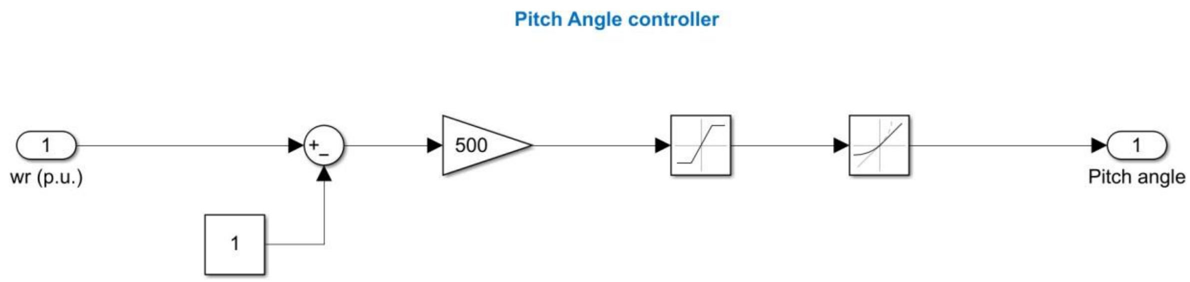


Fig. 7 MATLAB/ Simulink model of pitch angle controller

CHAPTER 5: MATLAB/ SIMULINK MODEL OF WECS

Wind energy conversion system (WECS), it includes wind turbine, permanent magnet synchronous generator (PMSG), diode rectifier, DC link and grid with pitch angle controller and maximum power point tracking. In this system the wind generation block consists of masked wind turbine block, PMSG and after then with the help of converters and DC link, it is integrated with the grid.

Fig 8 shows the wind energy conversion system using PMSG model implemented in MATLAB/ Simulink.

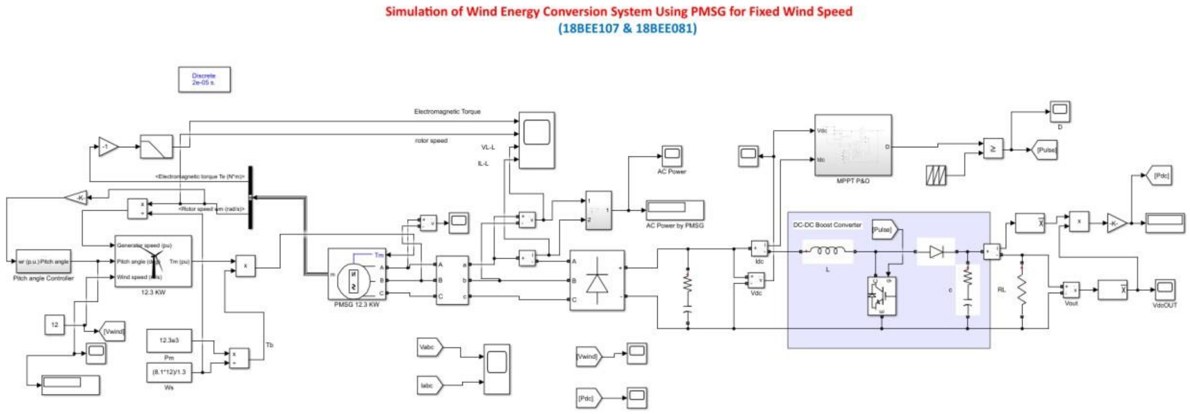


Fig. 8 MATLAB/ Simulink model of WECS Using PMSG

CHAPTER 6: RESULTS

The following curves found as below figure 9 & 10. it shows the rotor speed and electromagnetic torque for the base wind speed 12 m/s. in the figure 9 rotor speed initially fluctuates until it comes to stable state after 0.15 second. In figure 8 after some fluctuations electromagnetic torque become stable after 0.15 second.

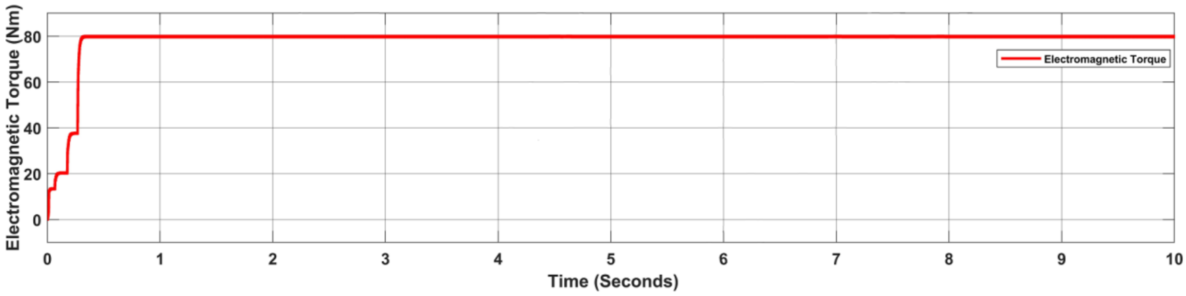


Fig 9. Waveform of Electromagnetic torque

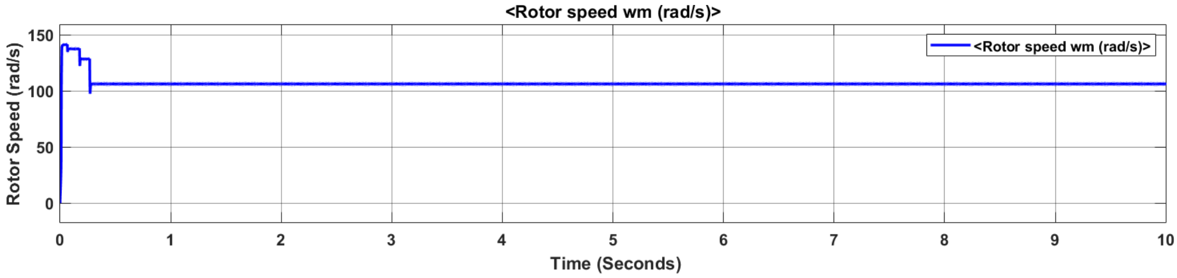


Fig 10. Waveform of Rotor speed at wind speed 12 m/s

The following waveforms (Fig 11 & 12) are found from scope displays three phase line-line output voltage and three phase current.

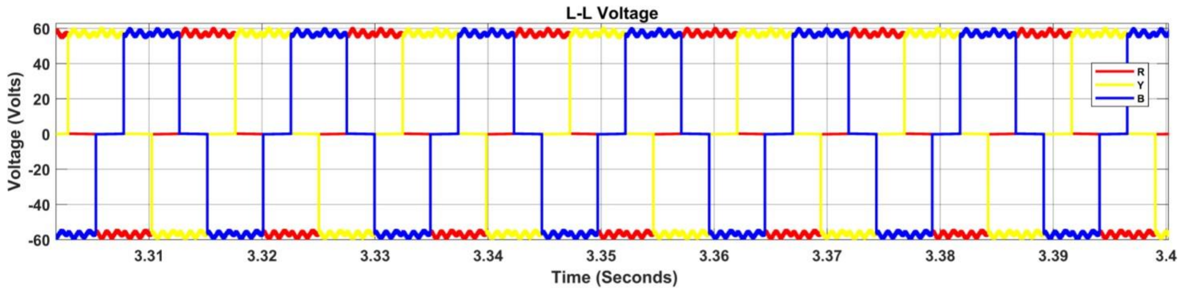


Fig 11. Three phase Voltage

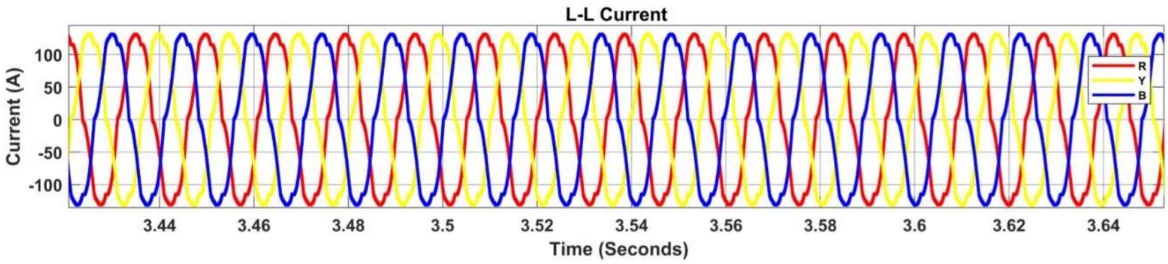


Fig 12. Three phase Current

The below figure 13 shows the DC link voltage, output of the boost converter which is at load side. The value of DC link voltage is approximated 280 volts.

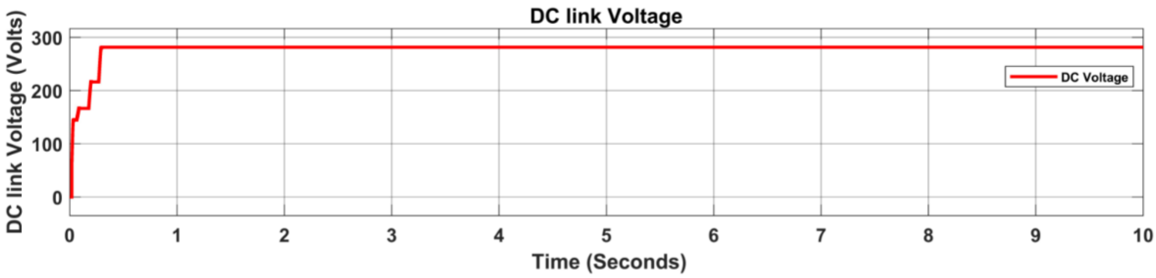


Fig 13. DC link voltage

In the below fig 14. output power across load for wind velocity of 12 m/s is shown. And output power across load is directly proportional to wind speed.

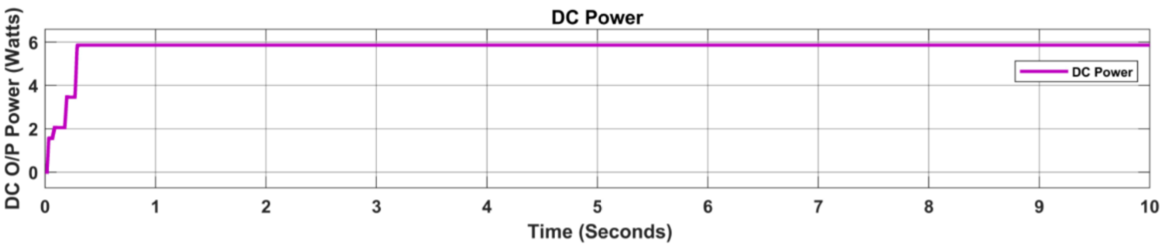


Fig 14. DC power output

CHAPTER 7: CONCLUSION AND FUTURE SCOPE

In this project, we present a complete model of wind turbine with permanent magnet synchronous generator. The WECS model consists of a wind turbine, direct driven PMSG, rectifier and DC grid or load which is directly connected with DC-DC Boost converter.

The proposed system uses and boost converter that has reduced the current ripples to a larger extent. This DC-DC boost converter has fast transient response and also it uses to increase the reliability of the system.

Model also consists of some control strategy like pitch angle controller and to extract maximum power from wind maximum power point tracker with perturb and observe algorithm is used. This algorithm is fast, efficient and it works satisfactorily for maximizing power output.

From the simulation results, we can say the controller works very well hence the output will get the optimum power supply to the grid.

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APPENDIX

MATLAB CODE OF PERTURB AND OBSERVE ALGORITHM

```
function D  = PandO(Param, Enabled, V, I)

%MPPT controller based on the perturb and observe algorithm
%D output= Duty cycle of the Boost Converter (value between 0
to 1)
%Enabled input= 1 to enable the MPPT controller
%V input= 3 Phase Diode Rectifier Voltage from PMSG (V)
%I input= 3 Phase Diode Rectifier Current from PMSG (I)

Dinit = Param(1);  %Initial value for D output
Dmax = Param(2);   %Maximum value for D
Dmin = Param(3);   %Minimum value for D
deltaD = Param(4); %Increment value used to increase/decrease
the duty cycle D
persistent Vold Pold Dold;

%(increasing D = decreasing Vref)

dataType = 'double';

if isempty(Vold)
    Vold=0;
    Pold=0;
    Dold=Dinit;
end
P= V*I;
dV= V - Vold;
dP= P - Pold;

 if dP ~= 0 & Enabled ~=0
%     if dP>1e-9  & dP<-1e-9 & Enabled ~=0
    if dP < 0
        if dV < 0
            D = Dold - deltaD;
        else
            D = Dold + deltaD;
        end
    else
        if dV < 0
            D = Dold + deltaD;
        else
            D = Dold - deltaD;
        end
    end
```

```
else D=Dold;
end

if D >= Dmax | D<= Dmin
    D=Dold;
end

Dold=D;
Vold=V;
Pold=P;
```

* * * * * * *