REPUBLIC OF TÜRKİYE

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Electrical and Computer Engineering

WIND ENERGY CONVERSION SYSTEM-BASED PERMANENT SYNCHRONOUS GENERATOR WITH PITCH ANGLE CONTROL

Mohammed Tareq Essa AL-BAYATI

Master's Thesis

Supervisor

Asst. Prof. Dr. Hasan ABDULKADER

Istanbul, 2023

WIND ENERGY CONVERSION SYSTEM BASED PERMENENT SYNCHRONOUS GENERATOR WITH PITCH ANGLE CONTROL

Mohammed Tareq Essa AL-BAYATI

Electrical and Computer Engineering

Master's Thesis

ALTINBAŞ UNIVERSITY

2023

The thesis/dissertation titled (WIND ENERGY CONVERSION SYSTEM BASED PERMANENT SYNCHRONOUS GENERATOR WITH PITCH ANGLE CONTROL) prepared by (Mohammed Essa) and submitted on 11/03/2023) has been **accepted unanimously** for the degree of Master of Electrical and computer Engineering.

____
Asst. Prof. Dr. Hasan ABDULKADER

Supervisor

Thesis Defense Committee Members:

Asst. Prof. Dr. Hasan ABDULKADER	Department of Computer Engineering, Altınbaş University	___________________
Asst. Prof. Dr. Timur INAN	Department of Software Engineering, Altınbaş University	___________________
Prof. Dr. Naim AJLOUNI	Department of Software Engineering, Atlas University	___________________

I hereby declare that this thesis meets all format and submission requirements of a master's thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information/data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Mohammed Tareq Essa AL-BAYATI

Signature

ABSTRACT

WIND ENERGY CONVERSION SYSTEM-BASED PERMANENT SYNCHRONOUS GENERATOR WITH PITCH ANGLE CONTROL

AL-BAYATI, Mohammed Tareq Essa

M.Sc., Electrical and Computer Engineering, Altınbaş University,

Supervisor: Asst. Prof. Dr. Hasan ABDULKADER

Date: April / 2023

Pages: 90

It is impossible to conceive of modern society without electricity. When non-renewable energy sources are used up, they are completely depleted. Hence, to provide the requisite quantity of power, alternative energy development is an essential step. The usage of renewable energy sources, such as wind, solar energy, wave energy, and energy from ebbs and flows, is important right now. The most interesting source of energy is wind, though.

Also, it is unprofitable to include sparsely populated areas remote from large cities in a single energy system. Traditionally, their autonomous power supply is carried out using diesel power plants, and coal/oil boilers. In this case, the supply of fuel occurs intermittently and is accompanied by an increase in the cost of transporting fuel by land or water, and sometimes by helicopter in the Turkish area or any far zone in the world.

In this work, an autonomous wind power plant is considered. A review of existing wind energy converters is given. The permanent magnet synchronous generator mathematical model for wind energy conversion systems (BLDC). The converter's output characteristics are determined using a mathematical model that is provided. An electrical, mechanical, and power electronics component-based wind energy conversion system with a trapezoidal EMF is detailed along with its basic working principal. A mathematical description of the wind turbine has been compiled, which includes the aerodynamic and mechanical processes occurring in the installation. The aerodynamic characteristic of the selected profile of the turbine blades has been constructed. Based on the compiled mathematical description, the corresponding Simulink model is implemented. Finally, the development of new control methods of the pitch angle β of the wind turbine to enhancement output performance with low wind speed and speed control of BLDC generator to increase the efficiency of the machine by using PI controller using trusted Simulink software. Finally, the maximum value of the theoretical power coefficient (C_P) for this turbine is 0.48, indicating that it operates with the utmost efficiency achievable is (48%), which represents the theoretical efficiency of the turbine because it represents the rate of the external power divided into the inner power. The optimal value of the coefficient of tip speed ratio found is 8.2, and the determined value of the maximum torque coefficient is (0.065).

Keywords: Pitch Angle Control, Coefficient of Power, Permanent Magnet Synchronous Generator / BLDC Generator, Control System, Power Quality.

TABLE OF CONTENTS

Pages

LIST OF TABLES

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

WPP	:	Wind Power Plant
WECS	:	Wind Energy Conversion System
BLDC	:	Brushless Dc Machine
PMSG	:	Permanent Magnets Synchronous Generator
PWM	:	Pulse Width Modulation System
IGBT	:	Insulated-Gate Bipolar Transistor
PQS	:	Power Quality Standards
PQI	:	Power Quality Indicator
LCF	:	Inductive Capacitance Filter
CS	:	Control System
MOSFET	:	Metal–Oxide–Semiconductor Field-Effect
Horz.	:	Transistor Horizontal Axis
PID	:	Proportional–Integral–Derivative Controller
PI	:	Proportional–Integral Controller
WG	:	Wind Generator
VAT	:	Value Added Tax
TBW	:	Three-Bladed Wheel
EMF	:	Electromotive Force
FSK	:	Frequency Shift Keying

IoT	:	Internet Of Things
WT	:	Wind Turbine
GB	:	Gear Box Ratio
FOC	:	Field Oriented Control

LIST OF SYMBOLS

C_p	:	Coefficient Of Force P Acting In The Direction Of Rotation
P	:	Air Density
H	:	The Efficiency Of The Electromechanical Energy Converter
Λ	:	Coefficient Of Tip Speed Ratio
U_w	:	Wind Speed
W	:	The Angular Speed Of The Wind Wheel
R	:	The Radius Of The Wind Wheel
T_m	:	Torque Of The Turbine In Nm
µ	:	Electron Mobility
Λ	:	Wavelength
Ω	:	Angular Frequency
P_{el}	:	Electric Power Developed By The Wind Generator
B	:	Blade Angle Of Attack
P_{wt}	:	Power Developed By The Wind Turbine
F	:	The Current Frequency Of The Wind Generator
Λ_{opt}	:	The Optimal Value Of The Turbine Moment At Which The Coefficient Power Cp Maximum
P	:	Number Of Pairs Of Poles
J	:	Total Moment Of Inertia Of The Turbine Rotor And Generator Rotor

T_e : The Electromagnetic Torque Developed By The Generator

T_L : The Load Torque Of The Generator

Jg : The Rotor Inertia

P_m : Mechanical Losses Power

U_w : Wind Speed

W : The Angular Speed Of The Wind Wheel

R : The Radius Of The Wind Wheel

T_m : Torque Of The Turbine In Nm

µ : Electron Mobility

Λ : Tip Speed Ratio

Ω : Angular Frequency

P_{el} : Electric Power Developed By The Wind Generator

B : Blade Angle Of Attack

P_{wt} : Power Developed By The Wind Turbine

F : The Current Frequency Of The Wind Generator

Λ_{opt} : The Optimal Value Of The Turbine Moment At Which The Coefficient Power Cp Maximum

P : Number Of Pairs Of Poles

J : Total Moment Of Inertia Of The Turbine Rotor And Generator Rotor

ΣP : Total Losses

P_{cu} : Main Copper Losses In The Stator Winding

I : Gear Ratio

E : Electromotive Force

V_b : The Speed Of The Turbine Blade (M/S)

V_d : Average Rectified No-Load Voltage

Ω_{op} : The Optimal Value Of The Angular Speed Of The Turbine (RPS)

Γ : Duty Cycle

V_L : Average Voltage At The Load

V_{in} : Input Voltage Of AC/DC Converter

V_D : The Voltage Across The Diode

R_L : Active Resistance Of The Inductor

K_p : Coefficient Of Voltage Ripple In The Load In Terms Of The First Harmonic

Ls : Stator Inductance

R_{vd} : Internal Resistance On The Diode

At : The Cross-Sectional Area Of The Turbine

I_c : Current Flowing Through The Capacitor

Rs : Stator Resistance

Z_L : Inductor Operating Resistance

1. INTRODUCTION

The idea of wind energy is the conversion of useable electrical, mechanical, or thermal energy from the kinetic energy of air masses in the atmosphere. This transformation is made possible by tools like sails, windmills, wind generators (for producing electrical energy), and wind turbines (for producing mechanical energy).

Many firms involved in the generation of electricity are researching and developing in this sector due to the significance and originality of this area of energy development. As shown by a ceramic fossil of a sailing boat that was discovered in the city of Eridu [1], it is important to note that the usage of wind energy in Iraq started in the fourth millennium BC. The Renewable Energy and Environment canter was established in 2010 by the Ministry of Electricity in collaboration with Iraqi universities to integrate renewable energies into the production and distribution sectors to support the country's electricity grid and supply electricity to remote and remote areas with various capacities [2]. Despite Iraq's substantial oil reserves, there is a severe electrical deficit. Power shortages in Iraq were a topic of discussion as early as 1991. As a result, managing and developing wind power plant (WPP) projects is important for Iraq's future prosperity in the areas of energy supply, ecological, and economy.

1.1 OVERVIEW OF EXISTING WIND POWER PLANTS

The renewable energy source with the quickest growth rate is wind power. Over the previous ten years, the installed wind power capacity has grown at an average annual pace of almost 30% worldwide. By 2020, the EU Renewable Energy Directive wants 20% of the world's energy to come from renewable sources. To do this, the national European energy system (EWEA) has set a target of developing 230 GW of wind energy, of which 40 GW will come from offshore wind farms.

2010 saw a 24.1% growth in installed wind power capacity worldwide, reaching 197 GW, 86 GW of which were in Europe.

Although onshore wind turbines make up the great bulk of these, offshore wind farms are expanding even more quickly. The total installed offshore wind generating capacity in Europe increased by 883 MW in 2010 to reach 2946 MW [1].

Since 1990, onshore and offshore wind farms have increased, and Figure 1 projects this growth through the year 2030. There will be 400 GW of installed wind power by 2030, with 150 GW of that being offshore wind power. However, as illustrated in Figure 2, offshore wind power will generate nearly half of all wind energy due to power factor increases. Onshore wind turbines (WTs) are expected to produce 350 GW by 2050 and offshore ones by 250 GW Thus, 50% of the demand for electricity in the European Union may be satisfied by wind turbines [1].

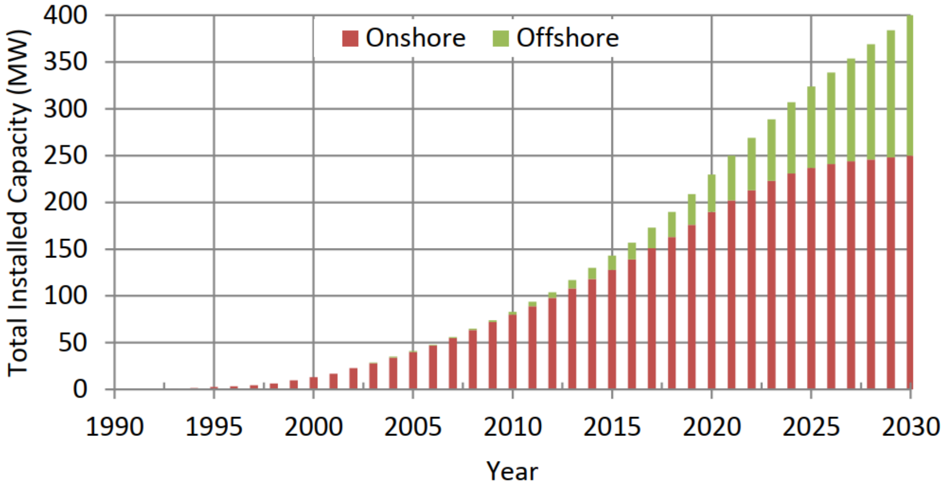

Figure 1.1: Total Installed Wind Power Capacity In The EU, Projected Up To 2030 [1].

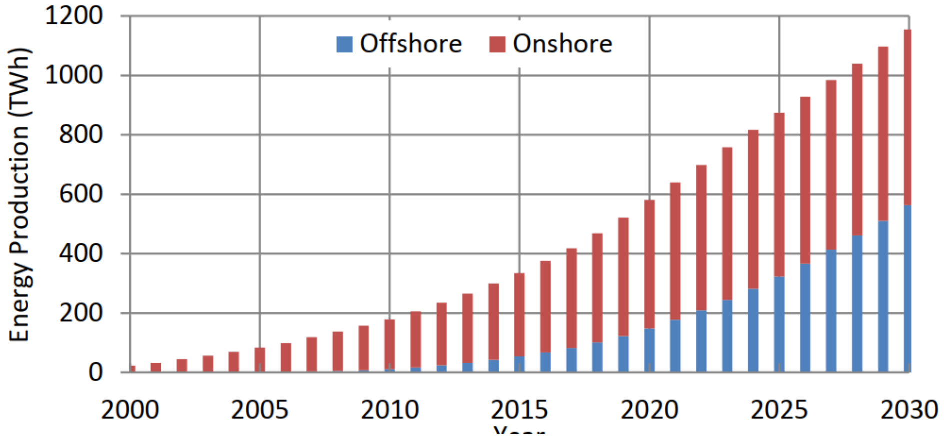

Figure 1.2: Wind Power Production In The EU, Projected Until 2030 [1].

A major issue for many nations now due to the world's present rapid economic development is the lack of energy. Small wind turbines are being used by more houses and companies to lower energy costs and carbon emissions because of growing fossil fuel prices and the development of advanced technology (BWEA, 2009). The UK has overtaken China as the world's second-largest market for modest wind power. Between 2005 and 2008, the UK saw a significant increase in the number of small wind turbines installed there. The total installed capacity of tiny wind turbines was 7.24 MW by 2008. (BWEA, 2009).

In addition to having a substantial market for tiny wind turbines, the UK also produces small wind turbines, making up roughly half of all wind turbines produced worldwide (BWEA,

2009) [1]. For this reason, the results of the wind energy in variable power output rely on the generator of the wind turbine since the wind energy taken by the wind turbine is not constant as the wind speed fluctuates.

It is not practicable to connect the generator directly to the electrical network from the standpoint of utilities because of variations in the generator's power. It is important to employ a regulator to regulate the output power produced by the wind turbine generator to fulfil the requirement that the generator output power is suitable for the electrical network [1].

Concerning controlling the generator speed, torque, pitch angle, and peak output, big wind turbine control technology is complicated (MPPT). But managing tiny wind turbines still needs more focused efforts on the fronts of wind turbine protection, overload, and maximum power output [1].

Voltage Source Converters (VSC) are self-commutated converters to connect HVAC and HVDC systems, is the most contemporary technology for data transmission at sea, which necessitates a connection at a distance (VSC). In addition to facilitating asynchronous communication between the WECS marine power system and the shore power grid, VSC-HVDC permits full and independent control of both active and reactive power. As a result of the transmission of VSC-HVDC, it is projected that the integration of WPP into the power system grid would increase. Power electronic converters, on the other hand, are used by the wind turbines themselves to boost their own controllability and flexibility [2].

Distributed energy, which is an incentive for the energy transition from the energy system of the 20th century to new technologies, advancements, and innovations of the 21st century, is one of the primary development trends in the power supply of remote locations. Most Western European nations, the United States, and other nations are implementing policies to promote the use of renewable energy sources and work toward carbon-free energy, which lessens their reliance on the export and import of energy resources. The cost of installing renewable energy sources has decreased significantly with the advancement of their technical process at the same time as methods to lower costs in the production of electricity from the sun and wind have been sought. It is important to note that, as indicated in Figure 1.3, the price of power obtained from wind farms reduced by about three times between 1990 and 2020 [3].

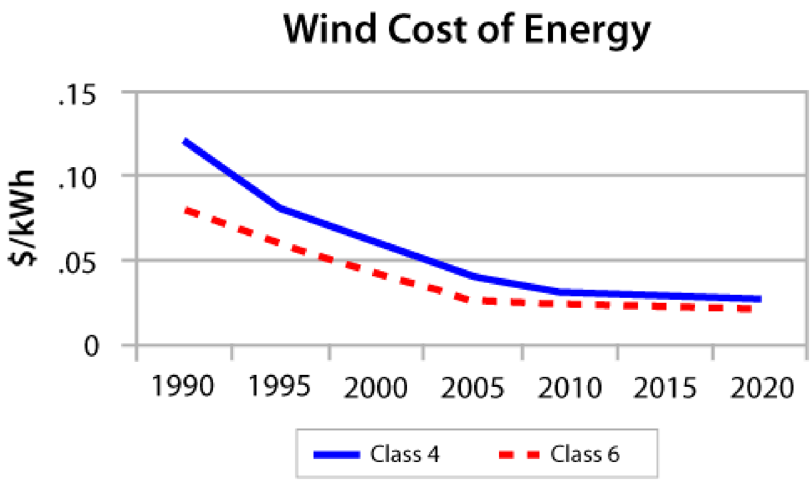

Figure 1.3: The cost of electricity received from wind farms in the period 1990-2020 [3].

Iraq is behind schedule in getting autonomous energy facilities up and running. Financial and legal barriers prevent the execution of large-scale projects because installations require a lot of cash and because there is no regulatory or legal framework to support the sector in the field of renewable energy.

Even though there will be a long-term financial advantage from using autonomous complexes powered by renewable energy sources, potential buyers lack the investment capital to buy them. This can be fixed, and renewable energy projects supported by reasonable finance methods. Among these mechanisms are:

a. Tax incentives when investing in renewable energy sources.

b. Reduced or zero VAT on renewable energy equipment.

c. Favourable credit system.

d. Accelerated depreciation of equipment; etc.

The strategies to promote renewable energy from the state are currently being put into practice in several European nations and the United States. It is important to remember that, in the past, power and gasoline prices in Iraq were far cheaper than those in Europe and the US. Therefore, implementing green energy projects was not financially viable. A significant amount of effort is being done to commission new energy complexes as of this writing.

The possibility of utilizing low-capacity hybrid power plants with renewable energy sources for autonomous electrical supply of facilities with a load of up to a few tens of kW is now being investigated by a corporation at the state level in Iraq. These things consist of means of detecting leaks of oil transmitted through pipelines.

e. Nodes of linear communication, tele control, and tele signalling.

f. Electrochemical protection centres against rust and corrosion on the pipeline.

g. Shut-off valve systems on pipelines through which oil and natural gas are transported.

Power plants based on wind energy converters typically have higher equipment costs but can compete with traditional power plants in places far from centralized electrical networks, where building long power lines and transformer substations is expensive, in places with expensive imported fuel, where replacing a traditional energy carrier becomes economically viable, as well as in situations where the quality and reliability of the power supply degrade.

Analysing the installations, it is connected to is important before selecting and computing the converter that is the focus of this effort. A wind turbine serves as the source of power for the controller in these setups, and power receivers are linked to the converter through an inverter, a DC bus, and a battery.

1.2 MAIN CHARACTERISTICS AND DESIGNS OF WIND GENERATORS

To begin with, it is necessary to consider the main types of wind turbine systems available. Depending on their location to the wind flow and on their design features, three classes of wind wheels can be distinguished. These classes include [4].

a. Wind turbines have a vertical axis of rotation of the wind wheel.

b. Vane wind turbines.

c. Drum wind turbines.

Wind turbines with a vertical axis of rotation are divided into the following types [4]:

a. Carousel. Non-working blades are either turned sideways against the wind or are hidden behind a partition (Figure 1.4).

Figure 1.4: Carousel Type Vertical Axis Wind Turbine [5].

b. Rotary (wind turbines designed by Savonius (Figure 1.5)).

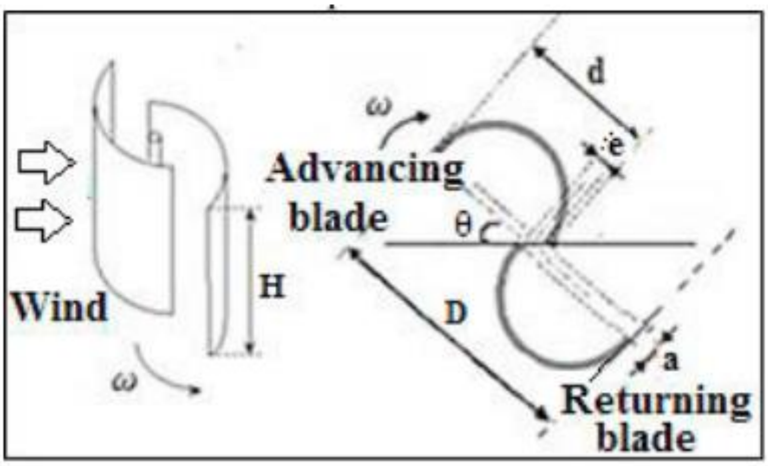

Figure 1.5: Savonius Wind Turbines [6].

Several vertical axis wind turbine models exist; the most typical are seen in Figure 1.6.

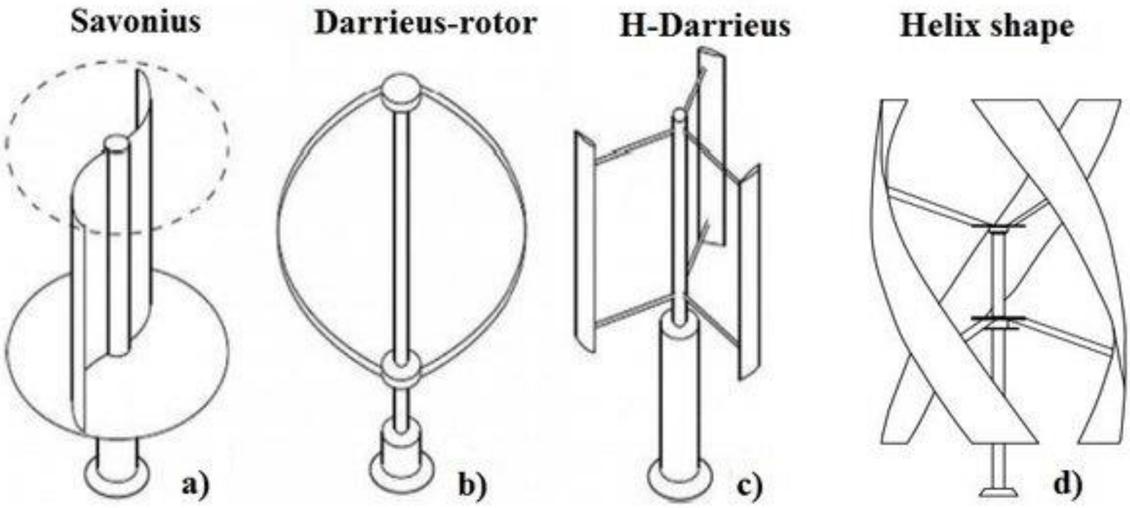

Figure 1.6: Different Types of Vertical Axis Wind Turbines [7].

The second group of wind turbines is vane wind turbines. In this type, the plane of rotation of the wind wheel is perpendicular to the wind flow, and the wind wheel itself is in a vertical plane. Thus, the wheel axis is directed parallel to the oncoming wind (Figure 1.7). Depending on the type of wind wheel and speed, there are three groups of vane wind turbines H-Darrieus.

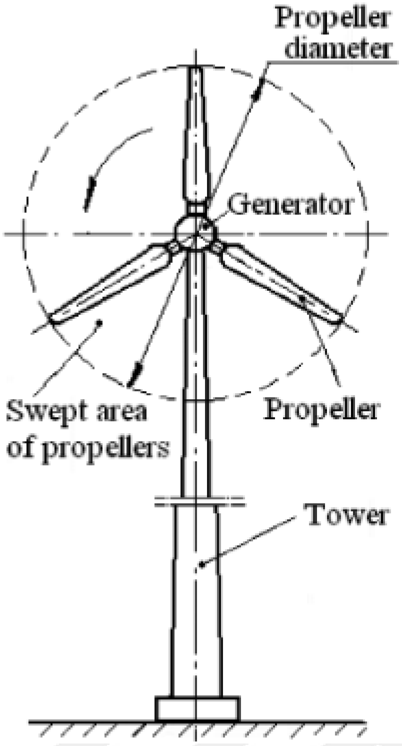

Figure 1.7: Vane Wind Turbines [8].

The speed of the wind wheel is the ratio of the angular speed of rotation of a point located at the end of the wheel blade to the speed of the wind flow. Thus, the speed of the wind wheel λ is calculated by the following formula:

$$\lambda = \frac{\omega \cdot R}{\upsilon} \tag{1.1}$$

where λ – the speed of the wind wheel; ω – the angular speed of the wind wheel, rad/s; R – the radius of the wind wheel, m; υ – wind speed, m/s.

Depending on the speed, winged wind turbines are divided into three types:

a. Low-speed, multi-blade wind turbines ($\lambda \leq 2$).

b. Low-speed, low-bladed wind turbines ($2 < \lambda \leq 3$).

c. High-speed, small-bladed wind turbines ($\lambda \geq 3$).

The main disadvantages of carousel and drum wind turbines follow from the system of blades arrangement in the wind flow. The first disadvantage is the uneven wind load acting on the blades because the working surfaces of the wind wheel move in the direction of the wind. Thus, each blade experiences an intermittent load *P*. The value of this load for a blade moving in the direction of the wind is determined by the following formula:

$$P = C_R \cdot F \cdot \frac{\rho}{2} \cdot (\upsilon - v)^2, \tag{1.2}$$

where *P* – is the force acting on the wind turbine blades, N; C_R – the coefficient of force *P* acting in the direction of rotation; *F* – the cross-section of the working plane of the wind wheel m^2; ρ – air density kg/m^3; *v* – the speed of movement of the wind turbine blades, m/s.

If the blades of the opposite side of the wind turbine are covered with a partition, then they experience resistance P_{res} to movement, determined by:

$$P_{res} = C_x \cdot F \cdot \frac{\rho}{2} \cdot v^2, \tag{1.3}$$

where P_{res} – is the force of resistance to the movement of the wind turbine blades, N; C_x – the resistance force coefficient. If they go with an edge to the wind, then the resistance force P_{res} is determined by the expression below:

$$P_{res} = C_x \cdot F_p \cdot \frac{\rho}{2} \cdot (\upsilon + v)^2, \tag{1.4}$$

where F_p – the lateral resistance surface of the ribs, m^2. As a result, the energy utilization factor of the wind flow does not exceed 10%, which was determined empirically in the course of the relevant experiments [9].

The second disadvantage of these types of wind turbines is the presence of a small rotational speed of the blades, because the speed of movement of the working planes cannot exceed the wind speed.

Finally, the third drawback is that the dimensions of the wheel surface swept by the wind are small in comparison with the dimensions of the wheel itself. The presence of this fact significantly increases the weight of the structure.

Vane-type wind turbines are deprived, as practice and theory have confirmed, of the above disadvantages of carousel and drum wind turbines. As a result, they found the widest distribution. In addition, this type of wind turbine has good aerodynamic performance, light weight per unit of installed power, as well as the possibility of production at high power.

Before proceeding directly to the analysis of electric generators associated with the converter, it is necessary to determine the powers that the wind wheel can develop. The connection of the electric power developed by the wind generator with the average annual wind speed V_{av} is determined by the following relationship [10]:

$$P_{el} = 0.5\pi \cdot \xi \cdot R^2 \cdot \rho \cdot \upsilon_{av}^3 \cdot \eta, \tag{1.5}$$

where ξ is the coefficient of wind energy utilization (for high-speed wind turbines in the nominal mode it reaches its maximum ξ_{max} = (0.4 ,0.5)); *R* – the radius of the wind turbine rotor, m; ρ – air density, kg/m^3; v_{av} - average annual wind speed, m/s; η - efficiency of the electromechanical energy converter. Under nominal conditions, the air density can be assumed to be 1.204 kg/m^3. The efficiency of an electromechanical converter includes the efficiency of a wind turbine and a gearbox and, as a rule, lies within the range η= (0.7 ,0.9) [11].

For most wind turbines, the starting wind speed is (2 3) m/s; nominal wind speed varies for different wind turbines from 6 m/s to (14-20) m/s. So, at R=2 m and Vav=12 m/s, the power can reach up to 5 kW, which is quite enough to provide electricity to a small house (excluding the operation of a diesel generator and a solar panel), which approximately corresponds to the task. Now consider those electric generators that are used in a wind power plant.

1.3 TYPES OF ELECTRIC GENERATORS FOR WIND TURBINE

Wind turbines use the following types of generators:

a. Asynchronous generators with a squirrel cage (induction machine).

b. Synchronous generators using electromagnetic excitation.

c. synchronized synchronous generators.

d. Asynchronous generators with a phase rotor.

e. Synchronous generators with excitation from permanent magnets (PMSG).

f. SG for special purposes: generators with a claw-shaped rotor, inductor SG and many others.

The usage of PMSG is determined to be the most acceptable for wind turbines used with autonomous power supplies, whose power does not exceed 200 kW, as it has benefits in terms of their economic indicators, in terms of a small number of losses, in terms of power level, and terms of efficiency. This is made easier by the emergence of new generations of PMs with significant technical and economic characteristics as well as strong coercive force values and the capacity to sustain them for an extended period.

Low-power setups employ SG with electromagnetic excitation. With a gusty wind, the values of the variable components occur in the generator because the SG directly depends on the wind flow for the frequency of the output EMF, which has a negative impact on the power receivers' operating modes. As a result, the synchronous generator can't be used in places where the wind is constantly changing. Its application is therefore restricted to places with intermittent power supplies.

Asynchronous generators are easy to maintain and have a straightforward architecture. They also exhibit little variations in the power they produce, but a source of reactive power is necessary for them to function. The wind power plant also makes use of DC generators, which maintain a steady voltage even when the wind rotor is subject to significant oscillations. It is important to note that (176-276) V are the acceptable ranges for the converter's input levels as well as the alternator's output voltage. (20–50) V for DC generators.

PMSGs are therefore appropriate for the wind turbines employed in this experiment. The computation for such a generator is provided in the second chapter of this paper, along with a derivation of the output parameters' dependences on wind speed. Consumers of electrical energy from the wind power plant.

As noted above, wind turbines begin to generate electrical energy at wind speeds of the order of (2-3) m/s. Therefore, they work for a longer period with a shortage of the required power level. This causes fluctuations in the frequency of current and voltage within wide limits.

In variable power mode, the energy fraction is very high. So, with an average annual wind flow of 4 m/s, a wind turbine that develops a rated power at V_{av} 8 m/s generates 60% energy in the variable power mode. Thus, it is most advantageous to use wind turbines for power supply to consumers, the operation of which is possible with voltage and frequency fluctuations within wide limits. These include:

a. Electric heaters.

b. electromotive desalination units.

c. Centrifugal, vortex, and vibration pumps.

d. Drive with an asynchronous electric motor.

It is known that when a wind turbine is operating on a linear active load, for example, on electric heaters, the power consumption P_C is proportional to the voltage V squared:

$$P_c = P_{n1} \cdot (\frac{V}{V_n})^2, \tag{1.6}$$

where P_C – is the power consumed by the electric heater, W; P_{n1} - rated power of the device, W; V - voltage falling on the electrical appliance, V; V_n - rated voltage falling on the electrical appliance, V. On the other hand, the maximum power P_{wt} developed by the wind turbine is proportional to the current frequency f to the cubic power:

$$P_{wt} = P_n \cdot (\frac{f}{f_n})^3, \tag{1.7}$$

where P_{wt} – is the power developed by the wind turbine, W; f – the frequency at the output of the wind generator, Hz; P_{n2} – the rated power of the wind generator, W; f_n – the rated current frequency of the wind generator, Hz.

Based on the equality of the power consumed and the power developed by the wind turbine, we obtain the following relationship between the voltage and frequency of the generator (for an AC generator), corresponding to the most favourable conditions for aggregating a wind turbine with an active load:

$$\frac{V}{V_n} = (\frac{f}{f_n})^{3/2}, \tag{1.8}$$

As already mentioned, another area of application for a stand-alone wind turbine is a drive with an asynchronous motor. The optimal ratio between voltage and frequency for asynchronous motors was obtained by academician M.P. Kostenko [12].

$$\frac{V}{V_n} = (\frac{f}{f_n}) \cdot (\frac{T_r}{T_n})^{1/2}, \tag{1.9}$$

where T_r – is the current value of the load resistance moment, N.m; T_n is the nominal value of the moment of resistance of the load, N.m.

Having decided on those levels of voltage and frequency of the generator and with consumers of electrical energy, it is also necessary to briefly characterize what the converter is connected to form the requirements for the converter, i.e., rechargeable batteries.

1.4 RECHARGEABLE BATTERIES

An important link that is part of the electrical part of the wind turbine of an autonomous energy complex is the battery. To select the number and type of batteries, as a rule, they are guided by the following two principles:

a. Voltage level on the low side.

b. Charging current, which can come from several sources and should not exceed 10% of the rated current for acid batteries and (25-30) % of the rated current for alkaline batteries.

To work in autonomous systems, special batteries with a service life of up to 10 years or more are used:

a. flooded lead acid batteries.

b. Absorbent glass mat batteries (AGM batteries) (expensive compared to lead-acid batteries);

c. Helium batteries (selected when it is impossible to ensure the ventilation of the batteries or their installation in the required position).

d. nickel-cadmium or iron-nickel batteries (used in extreme conditions at low temperatures, have a long service life).

e. lithium-ion batteries (they have a large charge/discharge cycle - up to 10,000 cycles).

To date, lithium-ion batteries are at the peak of popularity in terms of application. Accepted battery charge voltage levels are multiples of 12 V, i.e., 12/24/36/48/96 V [14]**.** For a wind turbine, which is part of an autonomous low-power energy complex, nickel-cadmium or AGM batteries with output voltage levels of 12/24 V are suitable.

1.5 WIND TURBINE APPLICATIONS OF A BRUSHLESS DC

The development of clean energy solutions has received attention on a global scale during the past several decades as a response to nuclear power and the dependence on fossil fuels. The fastest-growing renewable energy source for contemporary distributed electric power generating among alternative energy production methods has been wind energy. As a result, scientists have been compelled to create systems for converting wind energy that is designed and composed of optimal components, involving power electronic converters, electric generators (electrical machine), wind turbines, and their controls.

1.5.1 Wind Energy Conversion Technologies

Electricity is generated by the wind converting system into electrical energy, as it consists of the turbines, which is the primary part of converting wind movement into energy and the mechanic energy is transferred by the irrigation of the turbine. Which can be connected directly or by using the gear system. It is also possible to store the electrical energy through the batteries and it is possible to store the electrical energy generated in batteries or are used to operate the loads from the remote that are provided through an electric network (Figure 1.8).

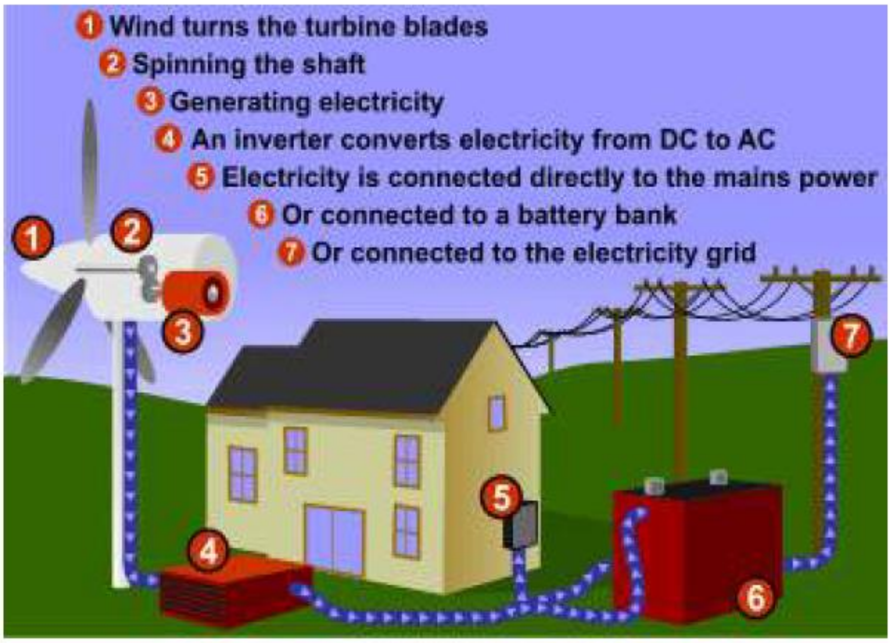

Figure 1.8: Shows A Schematic of A WECS (Wind Energy Conversion System) [13][14].

The mechanical part (represented by the turbine group) and the electrical part (represented by the generator and the inverter electronic power adapter). For the sake of the effective reliable conversion of wind energy to electrical energy, a third category associated with control and control systems for all mechanical parts were developed.

To improve the effectiveness of the WECS, other arrangements and designs of the elements may be used. Micro-wind turbines may be divided into two categories based on the orientation of their rotor axes: horizontal axis and vertical axis (figure 1.9).

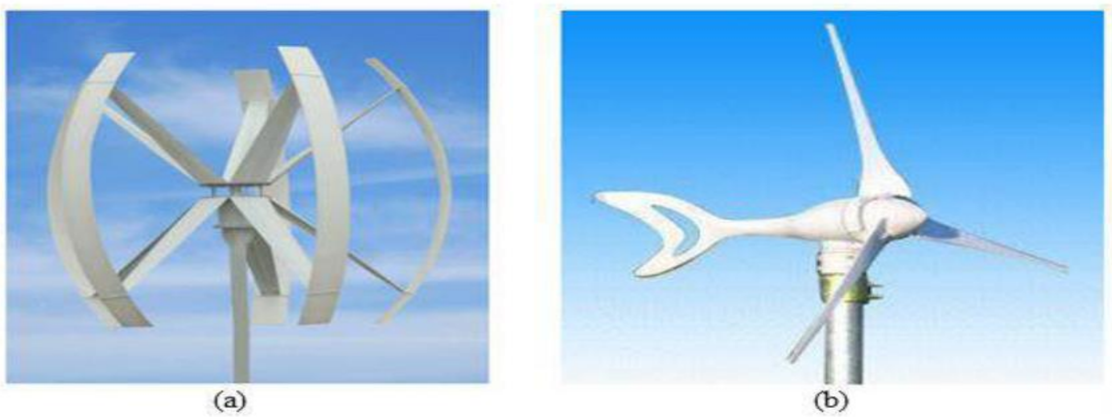

Figure 1.9: The Construction Of A Miniature Wind Turbine With Its (A) Horizontal Axis And (B) Vertical Axis, Respectively [14]**.**

The advantages and disadvantages of each structure are shown by several comparison studies that can be found in the technical literature [14] [15] which are summarized in Table 1.1.

Table 1.1: Comparison between Horizontal axis and vertical axis vertical axis of wind turbine [14].

Type	**Advantages**	**Disadvantages**
wind turbine with a horizontal axis	greater effectiveness in converting wind energy . Due to the tall tower, there is access to greater wind. Power regulation at high wind speeds using stall and pitch angle control	More expensive installation and a stronger tower to support the nacelle's weight. A longer rope connecting the tower' s top to the bottom. Orientation is necessary (yaw contr ol)
wind turbine with a vertical axis	Less expensive to build and simpler to maintain because the gearbox and generator are on the g round. Independent operation from wind direction Suitable for rooftops (stronger wind without need for tower)	Less efficient conversion of wind energy More frequent changes in torque and a propensity for mechanical vibrations Insufficient choices for power regulation in high wind conditions

But as stated in [14], the drive train design serves as the primary classification criterion for WECS topologies.

a. Topology of a fixed-speed drive train

Fixed speeds are the first to have been created and developed in wind systems (Figure 1.10). Where it consists of consisting of a multi -stage gearbox tied with a cage incitement (CIG), which was directly connected to the network from a transformer, but it lacks an energy transformer unit and instead it contains an intensive bank to balance interactive energy.

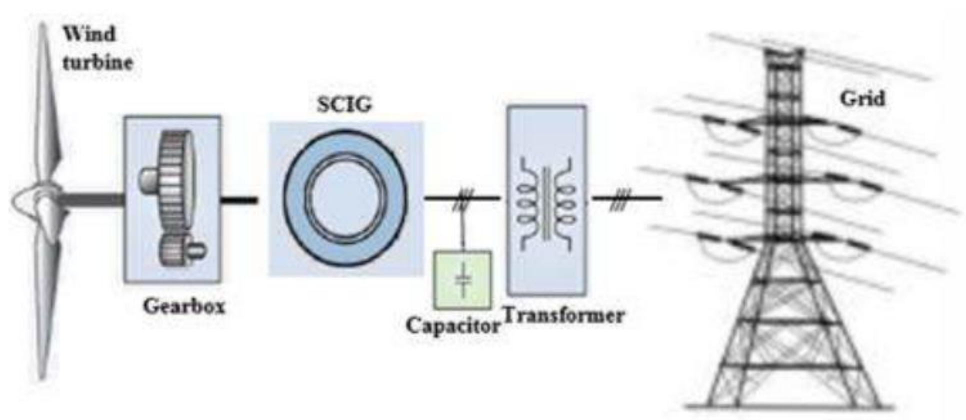

Figure 1.10: The Structure Of A Fixed-Speed Wind Turbine System Powered By A Cage Induction Generator [14].

Despite the ease of implementation and its relatively low costs, the internight and variable wind turbines are receiving wide and large attention due to the difficulty of controlling the few speeds that can be available, which leads to a decrease in total efficiency and increased mechanical pressure on the system [14] [16].

b. Variable speed drive train topology

The wind turbine's usable life is increased by variable-speed operation, which also reduces mechanical stress and maintenance requirements. Pitch adjustment and maximum power point tracking (MPPT) management enable variable-speed operation to regulate and optimize wind power extraction. Wind turbine systems in this category can use partial or fully -range electrical transformers when connected to the utility network. Although there are relatively high costs of production and significant energy conversion, these systems continue to advance on the wind turbine market.

a. Power converter class with variable speed and partial scale

Connection with a back-to-back power converter, as shown in fig. 1.11, permits bidirectional power flow in the rotor circuit. The DFIG architecture has become the standard in the modern wind industry because of its great overall efficiency and improved dynamic characteristics [14].

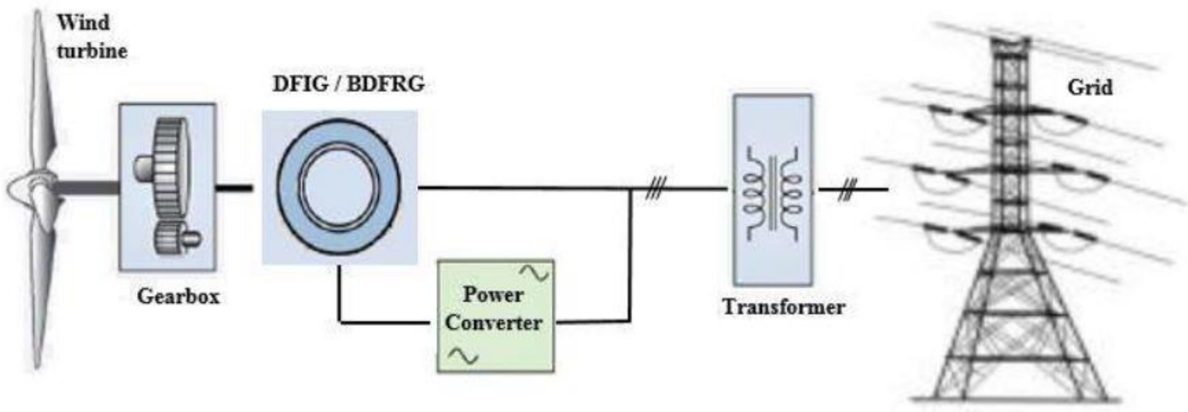

Figure 1.11: Partial-scale power converter and DFIG-based variable-speed wind turbine [14].

The BDFRG brushless doubly fed reluctance generator is also included, which features cost and efficiency, in this category in the latest scientific research [17].

It is also a discussion option for wind energy conversion system, however, due to the lack of an electromagnetic design process that is a good use.

a. Class of full-scale power converters with variable speed

A full-scale power converter can be used to get improved results. Both direct-drive and geared configurations employ this architecture. The wind turbine's dependability is increased when the gearbox is removed, but the cost and weight go up. The prevailing belief in designers was that the gearbox systems are more expensive in terms of payment due to the cost -related cost [14]. but in recent years the clear and large progress was made in the decrease in weights and the cost in the turbine systems.

It was previously believed that the gearbox system is more expensive than the direct payment system due to the costs associated with high -speed generators, as permanent generators were used for magnet (PMSG) as it is considered one of the most common and common generators (Figure 1.12) [17].

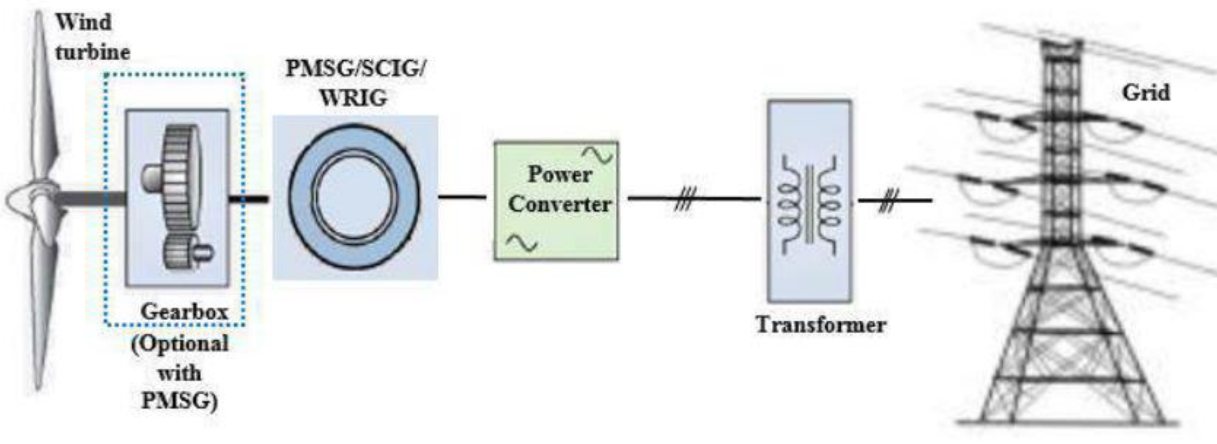

Figure 1.12: A Full-Scale Power Converter With A Variable-Speed Wind Turbine System [14] [16].

1.5.2 Power Electronic Converters for Systems with Wind Turbines

Special power electronic transformers) power convertor) are designed and for users in independent or used wind power systems. The wind turbine system can achieve a two -way power flow from the generator to the utility network if IGBT or MOSFET power devices are used, which are constantly controlled and frequently using PWM display signals (PWM), in a successive arrangement.

Figure 1 13: The following categories apply to back-to-back power electronic converters: voltage source converter (VSC), neutral point clamped (NPC), flying capacitor (FC), two levels (L), three levels (L), and four levels (L) (four levels) [14].

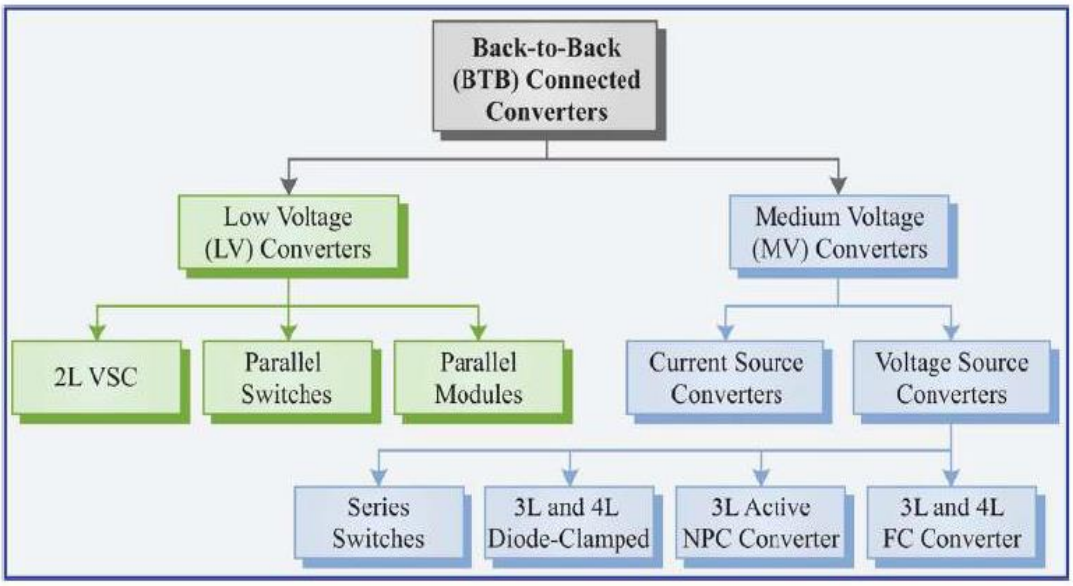

Figure 1.13: The Following Categories Apply To Back-To-Back Power Electronic Converters: Voltage Source Converter (VSC), Neutral Point Clamped (NPC), Flying Capacitor (FC), Two Levels (L), Three Levels (L), And Four Levels (L) (Four Levels) [14].

Figure 1.13 presents several power converter topologies that can be employed in a back-to-back configuration. Multi-level converters' complexity and higher cost make them unsuitable for use in micro-wind turbine systems due to their complexity expense.

1.6 EXPLANATION OF WIND ENERGY CONVERSION TECHNOLOGY

The many considerations must be made to choose a wind energy conversion system (WECS) that will satisfy the criteria and produce the desired outcomes. Here are descriptions of a few of these elements: Drive train engineering, operating wind speeds, type electric generator and the associated power adapter electronics, control technologies, design, and features of small wind turbines (tip speed, power coefficient).

Many of the above standards will be discussed in this chapter, especially those related to the mechanical and electrical components of the system. Figure 1.14 which also depicts the WECS design under investigation, displays the existing wind turbine, electric generator, analogous / continuous current / AC current (modified) and continuous current transmission.

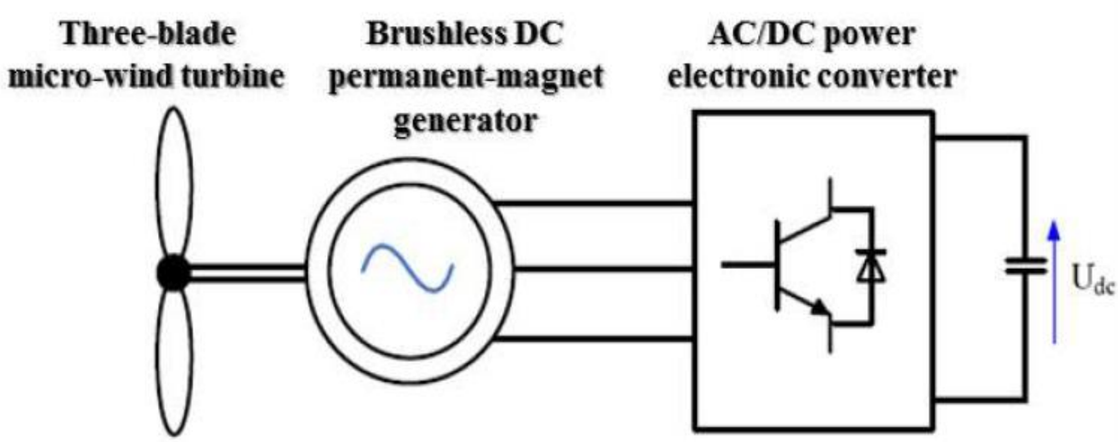

Figure 1.14: A wind energy conversion technology that is being researched [14].

This structure serves as a good illustration of a complex WECS because it combines components from various physical domains, including aerodynamic, mechanical, and electrical, which creates strong interdependencies and forces designers to take the whole system into account rather than just individual parts. To achieve competitive performance, the strategy based on design optimization, which serves as the thesis's goal, is therefore justifiable and probably even required.

In this study, the BLDCPM trilogy is used without brushes with the surface -installed external vertigo and the focused parts that create semi -perverted electromagnetic fields are the most convenient electric generator and used for wind systems applications. The BLDCPM generator has a simple structure that depends on the rolls. Because there are no brushes in this arrangement, this topology has higher power density, better dependability, longer life with less maintenance, and a higher torque to weight ratio [14].

1.7 BLDC MACHINE

Modern drive technology has grown significantly influenced by brushless DC machines, sometimes known as BLDC machines. Due to their quick rise in popularity, a wider number of industries, including consumer electronics, the automotive industry, industrial automation, chemical and medical, and aerospace and instrumentation, are using them. Although brushed DC machines have dominated the sub-kilowatt market for a while now and have long been utilized for drives and power production, this market has always been ambiguous. However, the advancements in power electronics and microprocessor technology have made it possible for tiny Brushless DC machines to flourish in terms of both performance and cost [18].

1.7.1 The BLDC Machines Construction

The fundamental structural distinction between brushed and brushless machines is the electric switch circuit used in place of the mechanical commutator. Considering this, a BLDC motor is a form of synchronous machine in that both the rotor and the stator produce a magnetic field that oscillates at the same frequency.

Three different configurations of brushless motors are offered: single-phase, two-phase, and three-phase. The three-phase BLDC is the most popular of them. An illustration of a BLDC machine's cross-section may be found in figure 1.15 below:

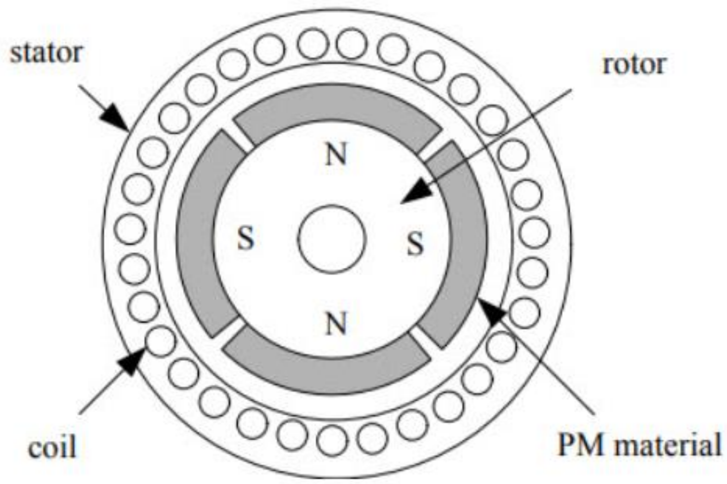

Figure 1.15: BLDC Machine Constriction [18].

A BLDC motor is made up of two primary components, the stator, and the rotor, as seen in the illustration.

A BLDC machine stator shown in figure 1.16 is constructed similarly to an induction machine.

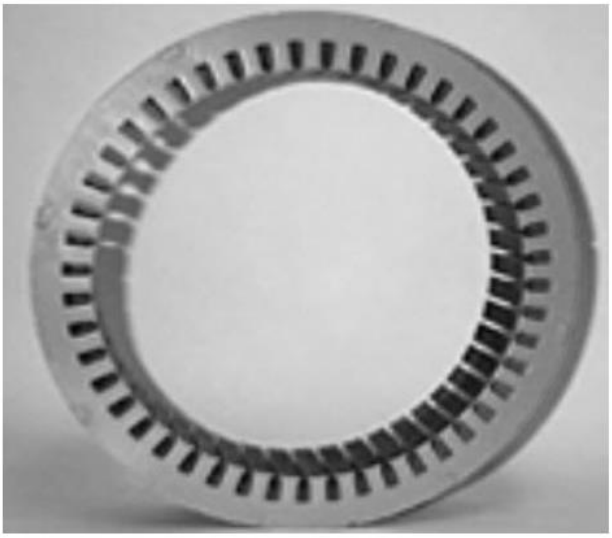

Figure 1.16: Stator of BLDC Machine [18].

The fixed part consists of stacked steel sheets with hoops that have been cut. BLDC machines also have somewhat different files from traditional induction machines.

The fixed part of the BLDCPM generator is usually created from the plate of steel stacks of the stars -connected phase files. Depending on the rotor columns, stage number, and wrapping, the number of vents of the fixed part is determined. For the BLDCPM generator, many configurations are possible, such as the arrangement of the rotating or surface-installed part with the surface, and the internal or exterior dizziness battology, etc. It provides a practical solution to small wind turbine applications without gears. Rare ground alloys such as ND-FE-B, which increases electromagnetic torque and the density of the magnetic flow of the air gap in low rotor sizes, such as PM.

The magnetic attraction and incompatibility between the poles of the fixed and vertigo are the basis for the principle of BLDCPM operation. The continuous excitement created by a permanent dizziness magnet for the BLDCPM generator causes the rear EMFS dynamics in the rolls of the fixed-engine-motor part when the rotor column is pushed into the movement with a fine wind turbine. Because of the non -gap distribution of the density of the magnetic flow of the air gap in relation to the dizzy site, the stator-phase back-EMF voltage has a quasi-trapezoidal form and is proportional to the intensity of the magnetic field. As a result of several variables including manufacturing, leakage flux, material saturation, etc., this waveform is not exactly trapezoidal in practice.

Most BLDC motors typically have three stator windings coupled in a 'Y' or star pattern (without a neutral point). The stator windings are further separated into Trapezoidal and Sinusoidal Motors depending on the coil interconnections [14][19].

The load relates to the ends of the fixed part of the BLDCPM generator. A dynamic three - phase electrical current produces in the common circuit of phase files in the fixed part. The rotation part is located, and the rotation angle is located by hall Senser or by Encoder as well as the direction and mark of the EMF rear part and the current. The position of the rotor can also be detected by rotating encryption or by the strategic arrangement of the hall effect devices to synchronize the current flow in the files of the fixed part with the instant rotary position (Figure 1.17).

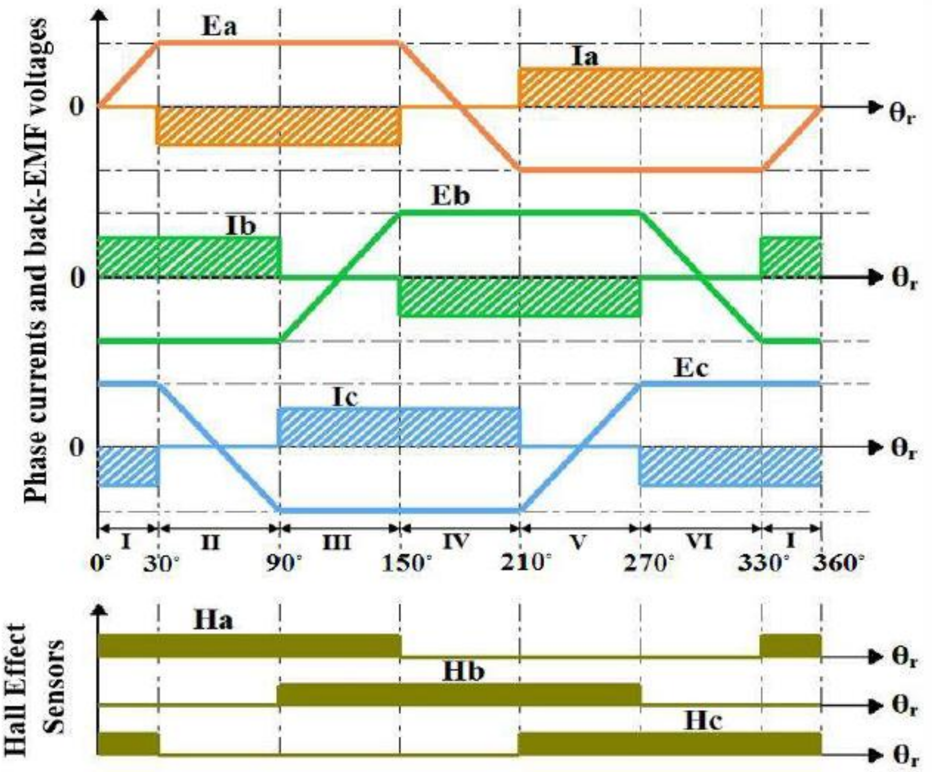

Figure 1.17: The Idealized Stator-Phase Back-EMF Voltage And Current Waveforms In Relation To The Waveforms Of The Hall-Effect Rotor-Position Sensors [14].

The resulting signal changes from each Hall sensor every 60 degrees electrical, so only six steps are needed to complete the electrical cycle, and this is implemented by only two stages of the three stages for 120 degrees. This is adjusted by setting the current part (stator part) three phases almost rectangular to form a phase of semi -deviated voltage from the fixed part, resulting in a persistent and unilateral rear -directional torque.

Or does it related to the electrical -generated electronic power transformer, an electrically generator, which is a conventional three -stage bridge and phases with six electronic devices that operate the switch card with diodes installed against parallel, as shown in the figure 1.18.

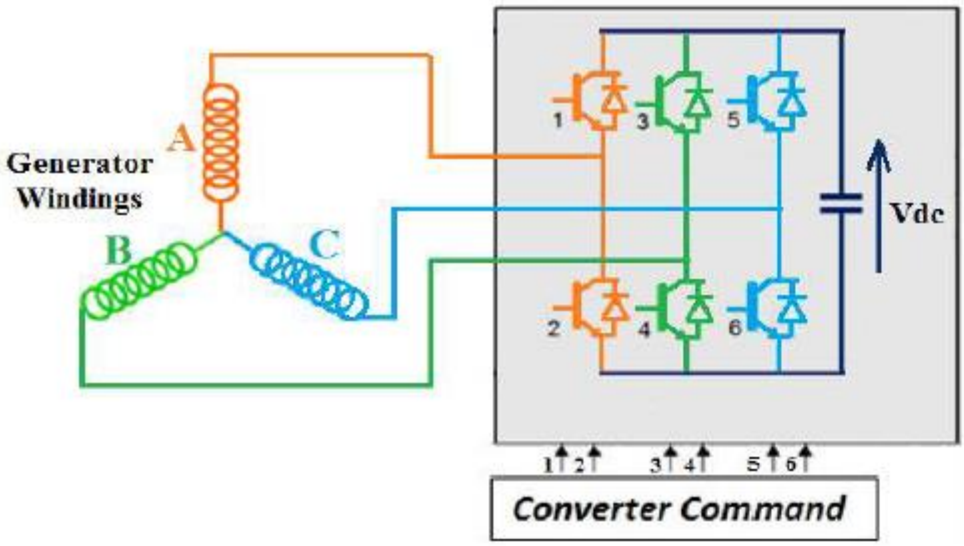

Figure 1.18: Active Rectifier With A Three-Phase Star-Connected BLDCPM Generator [14].

The PWM Peddling Signs (PWM) is given to the electronic devices for modified energy (IGBTS) by the switching pattern, which depends on the information received from the sensors and sensors in place of the rotation of the hall sensor, are often used to regulate the stater phase currents in a basic electronic manner. An electrical cycle may be separated into six phases or segments, each having a 60° electrical angle, using the sensor data. Each sector, in turn, is made up of (i) a conduction interval, when only two phases are electrified by the PWM rectifier's operational states, and (ii) The timeline of the switch, when all the three stages are active due to the remaining free current in the stage that has just been closed.

(iii) Delivery period with only two phases is activated by the PWM rates.

2. REVIEW AND ANALYSIS

2.1 OVERVIEW AND INFORMATIONS ABOUT WIND ENERGY

A major issue for many nations now due to the world's present rapid economic development is the lack of energy. Small wind turbines are being used by more houses and companies to lower energy costs and carbon emissions because of growing fossil fuel prices and the development of advanced technology. The UK has overtaken China as the world's second-largest market for modest wind power. Between 2005 and 2008, the UK saw a significant increase in the number of small wind turbines installed there. The total installed capacity of tiny wind turbines was 7.24 MW by 2008.

In addition to having a substantial market for tiny wind turbines, the UK also produces small wind turbines, making up roughly half of all wind turbines produced worldwide [1]. For this reason, the results of the wind energy in variable power output rely on the generator of the wind turbine since the wind energy taken by the wind turbine is not constant as the wind speed fluctuates.

It is not practicable to connect the generator directly to the electrical network from the standpoint of utilities because of variations in the generator's power. It is important to employ a regulator to regulate the output power produced by the wind turbine generator to fulfil the requirement that the generator output power is suitable for the electrical network [1].

Concerning controlling the generator speed, torque, pitch angle, and peak output, big wind turbine control technology is complicated (MPPT). But managing tiny wind turbines still needs more focused efforts on the fronts of wind turbine protection, overload, and maximum power output [1].

The most recent technology for data transmission at sea, which requires a connection at a distance, is HVDC (VSC-HVDC) based on a voltage source converter (VSC). VSC-HVDC allows comprehensive and independent management of both active and reactive power in addition to enabling asynchronous communication between the WECS maritime power system and the shore power grid. The integration of WPP in the power system grid is thus anticipated to expand as a result of the transmission of VSC-HVDC. The wind turbines themselves, on the other hand, utilize power electronic converters to increase their own controllability and flexibility [1].

2.2 REVIEW AND ANALYSIS ON WIND TURBINE USED BLDC MACHINES

In contrast, Permanent Magnet Synchronous Generators (PMSG) are more effective, do not require electrical stimulation, and will exhibit a better weight/force ratio compared to other generator technologies [20]. The use of PMSG in a variety of applications, including gas turbines [21], hydroelectric power plants [22], diesel generators, flywheels, and wind power systems, has been investigated by several writers because of these findings. Given that WECS's footprint is expanding globally and that the installed capacity is anticipated to increase over the next few years, its utilization is particularly intriguing to WECS [23]. The main exciter and the main generator make up the two phases of the Brushless DC Alternator (BLDC) created by the Combat Vehicles Research and Development Establishment (CVRDE) in Chennai. Part of the generator control unit is the primary exciter, which has a stator bias winding and is managed by a voltage regulator (GCU).

The primary generator couldn't deliver the 5 kW of electricity that it was designed to over the speed range of 10,500 rpm to 13,700 rpm. CVRDE suggested undertaking combined electromagnetic, thermal, and CFD simulations in compliance with CVRDE standards at Ramai University of Applied Sciences to improve the design of DC generators based on electricity and cooling points [24]. The electromotive force (EMF) created in their convoluted stator serves as the foundation for the permanent magnet brushless direct current generator (PMBLDC). The induction EMF form on the stator terminals of the PMBLDC machine is trapezoidal because of the surface mount PM on the rotor.

To solve the severe issue of power shortages, wind power conversion systems (WECS) have been constructed globally in recent years. By rectifying the DC output voltage, the brushless permanent magnet DC generator (PMBLDCG), which has a power density greater than 15% greater than PMSM machines (, should lessen ripple to trapezoidal EMF.

Compared to traditional synchronous and asynchronous machines, this results in a smaller machine with a given power rating. These characteristics offer PMBLDCG and may even suggest wind power conversion systems (WECS). The application of PMBLDCG for force transformation has been mentioned in several scholarly papers [32]. Offline WECS is, however, only partially attempted using PMBLDCG. Thus, the usage of PMBLDCG for standalone WECS is the main emphasis of this work. This relates to an off-grid wind energy conversion system's voltage and frequency regulator (VFC) for a permanent magnet brushless DC generator (SWECS). A single-phase voltage source inverter (VSI), buck-boost converter, and battery storage system are used to accomplish VFC.

A PMBLDCG-based WECS setup system is depicted in block diagram form in the figure. 2.1.

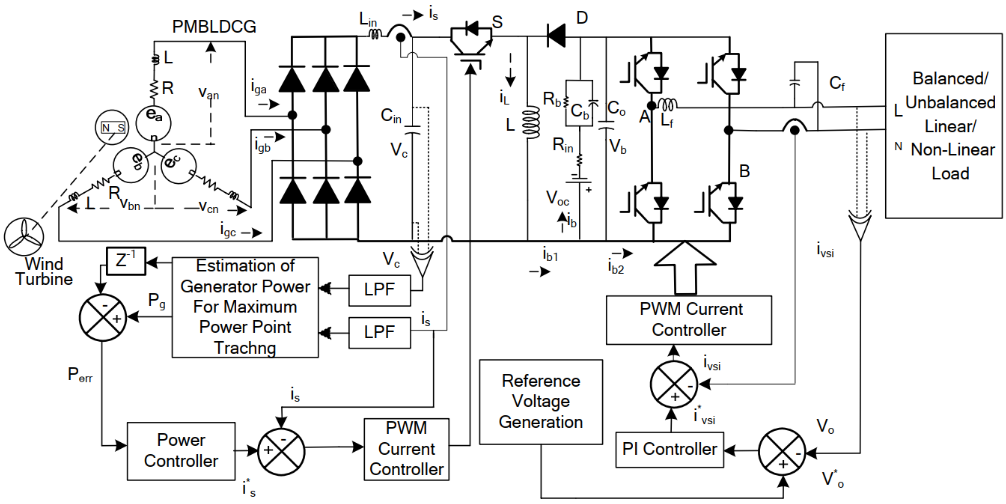

Figure 2.1: WECS Configuration Block Diagram Based On PMBLDCG [25].

The three-phase diode bridge rectifier, low-pass LC filter, DC boost-buck converter, battery-powered storage system, vector-controlled pulse width, pulse-width modulation (PWM), and four-arm stand-alone voltage inverter (VSI) are all components of the proposed WECS system. The output voltage of the PMBLDCG is trapezoidal, and its frequency likewise fluctuates as a function of alternator speeds to extract the most power from the wind turbine [25].

For wind turbines, the electronic brake becomes important. The high-power thyristors used in the derivative circuits are matched to the high-power outputs of current wind turbines. To get the most power out of the wind turbine, the PMBLDCG's output voltage is trapezoidal, and its frequency fluctuates in response to alternator speeds [25]. This BLDC generator is the subject of investigation. Simulations have demonstrated the operation's fundamental premise. The suggested electric brake is located on the frequency conversion's DC side. The voltage or current should be steady or fluctuate little after rectification. A block schematic of the electric brake position with illustrative values for the DC side shown in Figure 2.2.

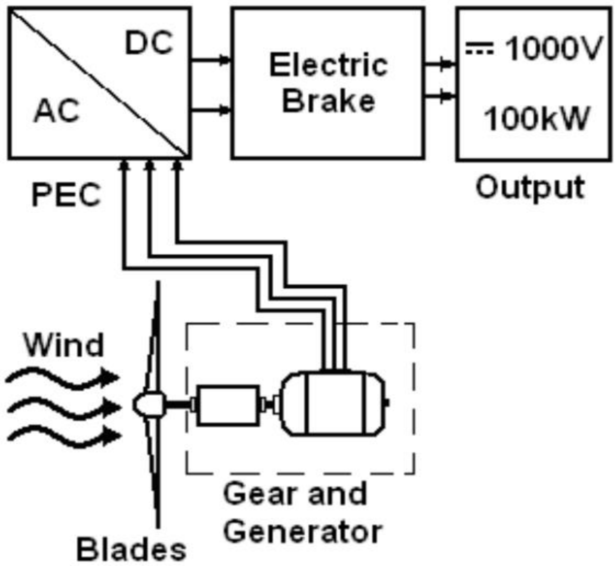

Figure 2.2: Location of the Proposed Brake Circuit of The System On The Block Diagram (approximate values) [26].

Power electronic converters referred to by the acronym PEC (in this case a rectifier). Additionally, the PM generator can be installed without a gear. Due to the elimination of the gearbox, direct-drive wind turbines offer higher overall efficiencies [26].

An induction-based wind generator modelled mathematically. A mathematical model of wind turbines with various parts displays the simulation and the outcome (Figure. 2.3) [27].

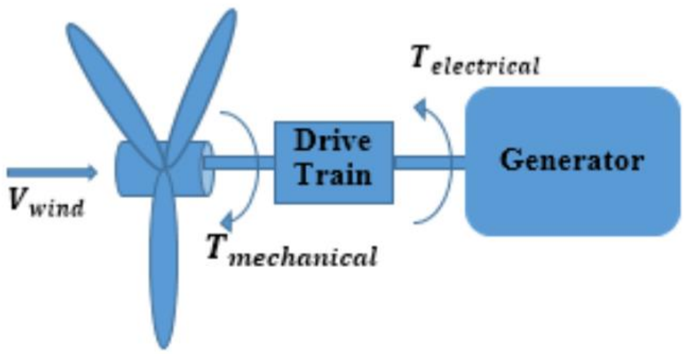

Figure 2.3: Wind Power Scheme [27].

Creating, analysing, and putting into use a novel current-generation algorithm for a BLDC generator. The created algorithm may be set up to regulate DC voltage or to extract the most power possible. The suggested technology may be employed for turbine power supply systems, WECS, and vehicle regenerative braking systems, as shown in the figure.2.4 [28].

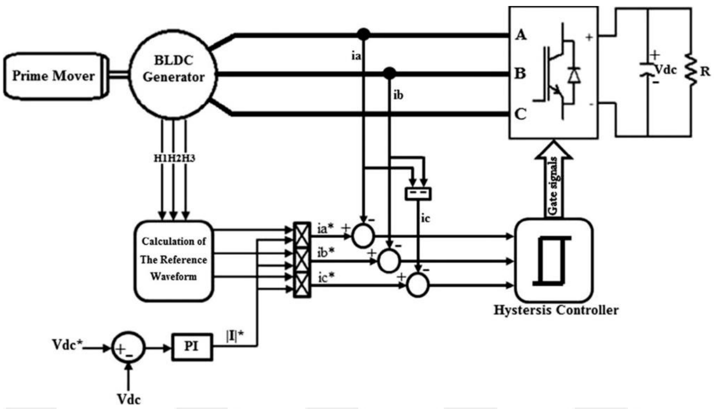

Figure 2.4: BLDC Generator System With Active Rectifier To Regulate The Voltage Of The DC Link With Maximum Power [28].

Wind energy conversion systems' modelling and simulation of BLDC generator-based power production. The MATLAB/SIMULINK modelling program is used to simulate the suggested system [36]. With the use of theories relating to rectifiers and a condensed analogy of a DC machine created from observations, the simulation is run on a conventional AC machine. Here, a three-phase star with an outer rotor, radial flux, permanent magnet, and BLDC generator being investigated. An uncontrolled rectifier at the generator's output taken into consideration to simulate the experimental machine-like behaviour of direct current. Small wind power conversion systems, as seen in figure 2.5, frequently employ such designs [29].

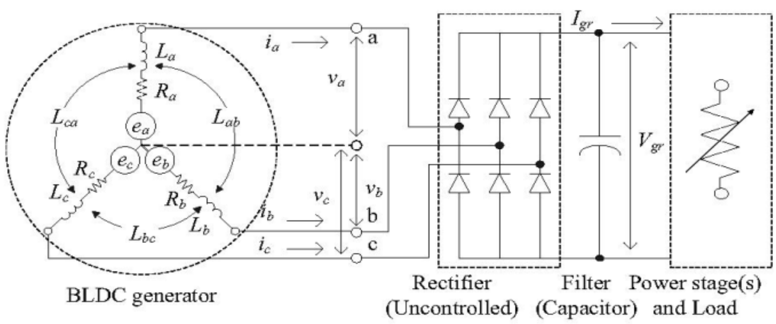

Figure 2.5: Rectifier Connected To BLDC Generator [29].

As a stand-alone WECS, the usage of a permanent magnet synchronous generator (PMSG) powered by a gear-driven wind turbine recommended. A VF controller, which consists of an IGBT (Insulated Gate Bipolar Transistor) VSC with a Battery Energy Storage System (BESS) on its DC link, regulates voltage and frequency. PMSG used to construct a 3-phase, 4-wire distribution system.

The regulator can control frequency and system voltage utilizing a bidirectional flow of active and reactive power under various consumer loads and wind speeds. In a three-phase, four-wire distribution system, the neutral terminal built locally using the zigzag transformer shown in Figure 2.6 [30].

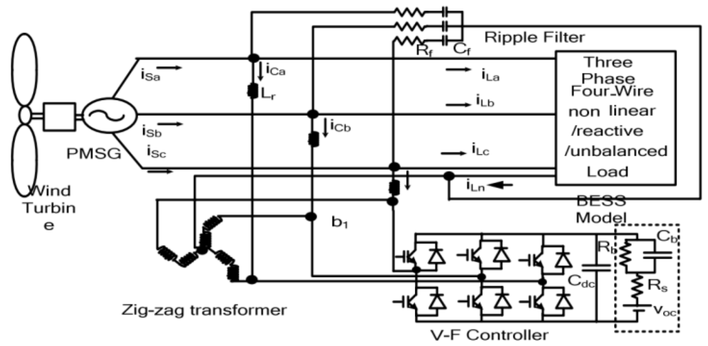

Figure 2.6: Schematic Diagram of WECS [30].

Utilizing a battery as a storage medium, an autonomous power supply system based on wind energy is built. An inverter linked to the load rod regulates the output AC voltage's frequency and magnitude. To reduce variations in AC output voltage brought on by variations in wind speed and load, a control method has designed. Under the unequal load conditions depicted in Figure 2.7, the PWM inverter control utilized to balance the line voltages at the common connection (PCC) stage [31].

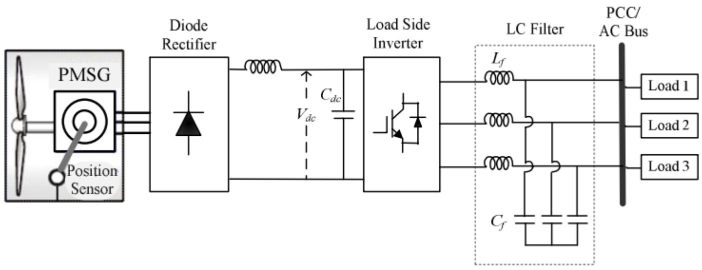

Figure 2.7: Wind Power System [31].

The fundamental issue with autonomous wind power systems, which is caused by their low inertia, is their brittleness and sensitivity to any abrupt changes in operating circumstances [32]. The key benefits of three-level converters over two-level typologies are the decrease in voltage on each semiconductor and, subsequently, the cost decrease, the decrease in harmonic distortion of the output voltage, and the decrease in converter losses [33]. To regulate a three-level converter in the sector of wind energy, the study suggests a PI-Fuzzy logic controller. The fuzzy logic approach has not yet been used to analyses a three-level converter, as far as the authors are aware. The next sections give an overview of the general autonomous system WECS that this study has suggested as well as the accompanying controllers [34].

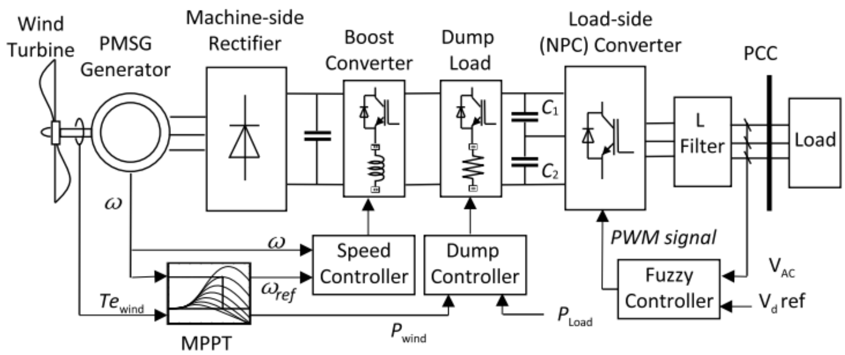

Figure 2.8: Structural Diagram of A Controlled Wind Power System [34].

A modular converter system connected to a six-phase synchronous machine is shown in Figure 2.9. The use of SGs with electrically and magnetically independent three-phase winding sets solves the problem of circulating currents that would occur if the converter modular structure were coupled to an SG with a single set of three-phase windings. The two converter modules have independent control units on the machine and network sides, as well as their own distinct sub-controllers for switching the switches [34].

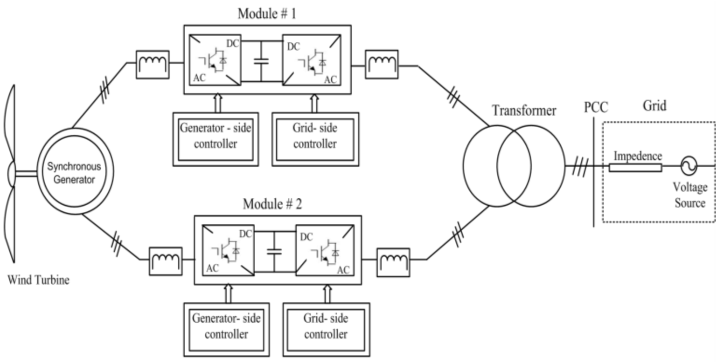

Figure 2.9: Multi-Phase PMSG Connected To The Network Using Modular Converters [34].

Based on changes in battery SOC, use a load power management approach. Depending on the instantaneous change in SOC and its value, some loads are connected or disconnected using this approach. Consumers are given regulated load voltage in terms of frequency and amplitude using a voltage source inverter controller. The architecture of the power circuit for a variable-speed autonomous wind power supply is depicted in Figure 2.10 [35].

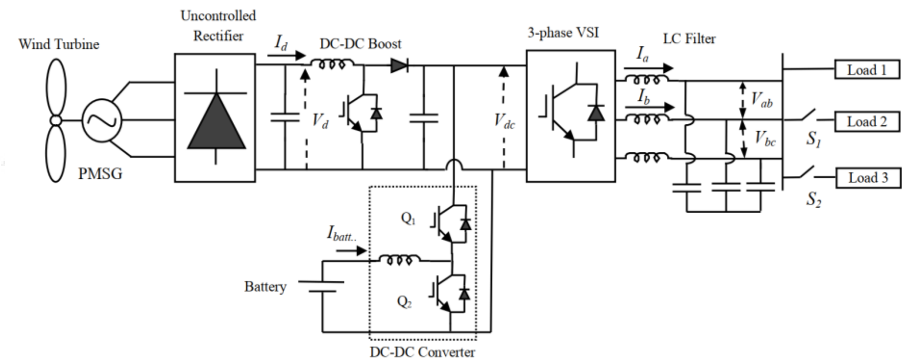

Figure 2.10: Topology of The Power Circuit of An Autonomous Wind Energy System With Variable Speed [35].

For an autonomous system to convert wind energy at the present control's maximum tracking power, an algorithm has been created and put into practice. The method combines characteristics for maximum power tracking and operation with a unity power factor [35].

Based on PMBLDCG, a new sensor less VFC control approach is presented for autonomous WECS. Without monitoring the brushless permanent magnet DC generator's speed, its currents, or its induced voltage, the Maximum Power Maintenance (MPPT) mode is accomplished. To keep the slope speed ratio (turbine angular speed/wind speed) constant for MPPT control, the duty cycle of the active switch of the DCDC boost converter is tracked for the turbine speed as the wind speed varies. An uncontrolled three-phase diode bridge rectifier coupled to the PMBLDCG stator powers the boost converter. The output (DC bridging) of the boost converter uses the battery energy storage system (BESS). A three-phase, four-wire consumer load is powered by an IGBT, a four-terminal voltage source inverter (VSI), at the necessary voltage and frequency. A schematic of the proposed variable rate autonomous WECS PMBLDCG is shown in Figure 2.11 [36].

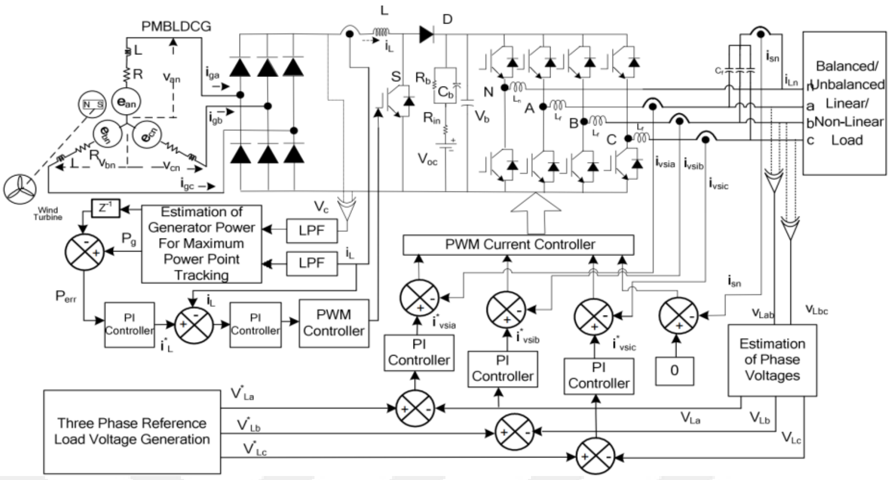

Figure 2.11: Control Block Diagram of An Autonomous Wind Power Conversion System Based On PMBLDCG [36].

An uncontrolled three-phase diode bridge rectifier coupled to the PMBLDCG stator powers the boost converter. The output (DC bridging) of the boost converter uses the battery energy storage system (BESS). A three-phase, four-wire consumer load is powered by an IGBT, a four-terminal voltage source inverter (VSI), at the necessary voltage and frequency. A schematic of the proposed variable rate autonomous WECS PMBLDCG. [36] The finite element approach is used to construct both generator simulation models. We compare the new generator's efficiency and attributes like torque ripple and DC voltage ripple. Additionally, the two machines' prices and weights are contrasted. Results indicate that 6-phase BLDCG is superior to PMSG in terms of benefits [37].

A novel approach to managing the PMSG wind turbine system in the IFSA microgrid was examined in the paper [38]. As a result, using sinusoidal voltage references synced to all CBGs, its grid-side converter (GSC) regulates the PCC voltages' magnitude and phase angle. Additionally, the generator's machine-side converter (MSC), when used in conjunction with a control system, regulates the real power balance of the generator by modifying the rotor speed to achieve maximum power point tracking (MPPT). The MSC also controls the voltage of the DC connection. This goes against the norm for a PMSG wind turbine system's control strategy [38].

The BLDC generator's advantageous qualities enable the adoption of compact wind energy conversion devices (WECS). Calculating the maximum possible power from the wind turbine is the foundation of the maximum power point tracking (MPPT) control of the BLDC wind turbine. The BLDC wind turbine's output terminals are connected to a PWM-regulated rectifier. The DC capacitor enables you to separate the PWM rectifier from the PWM inverter used to connect to the grid in addition to maintaining a consistent voltage in the DC circuit. The proposed system is modelled using the MATLAB/SIMULINK software to simulate a distributed power generation system based on a three-phase BLDC generator that is driven directly by a wind turbine WECS based on a BLDC generator. Its dynamic behaviour is simulated by an environment of various wind speed conditions and consumer loads, as shown in Fig 2.12 [39].

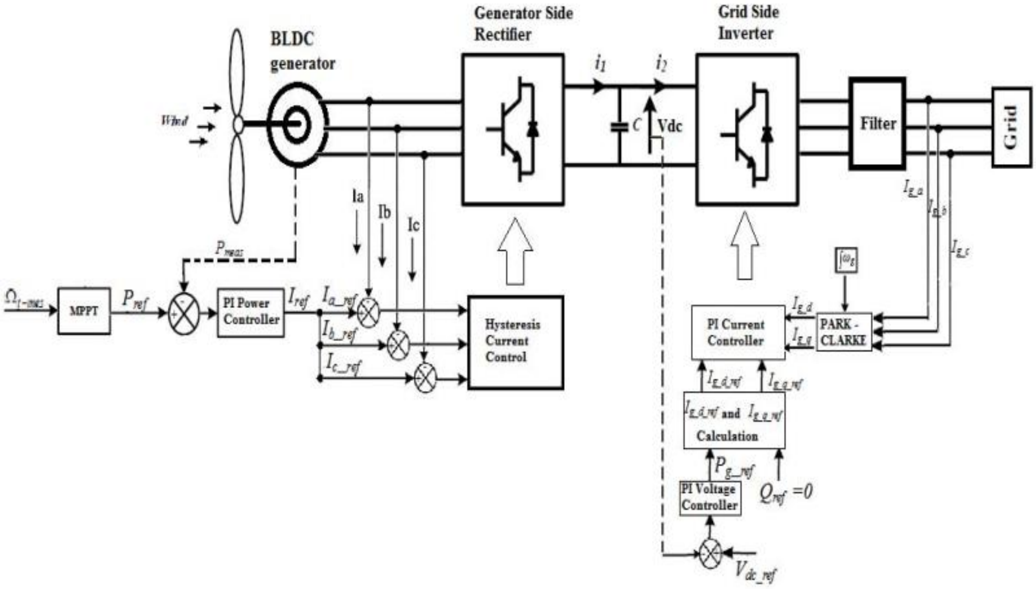

Figure 2.12: Schematic representation of the WECS under study based on a direct drive BLDC generator [39].

From the sources mentioned in the review, we conclude that wind turbines operate at maximum depending on the angle of attack as well as controlling the tracking system or increasing the efficiency of the electronic system by using a PI controller, where we do a mathematical analysis of integrated wind systems with the design of a control circuit for the system and the design of a plan or a way to control the angle of attack.

Physically, the lower the angle of attack, the greater the energy produced, depending on the wind speed and the power factor, as it reaches the highest energy.

A wind turbine generator's response to turbulent winds when it is running at a variable speed and with pitch control is the subject of this study, which aims to propose and build a mathematical model of a novel control technique and augmentation of the pitch angle of wind turbines. Moreover, the essential differences between a constant-speed and a variable-speed wind turbine will be covered. A wind turbine running at constant speed is a great place to start. The variable-speed method was chosen based on the steady-state limit and maximum energy of the wind turbine. The steady-state limit is established using the C_P-TSR curve. Thus, wind gusts and wind shear are not considered in the steady state calculation. Using the steady-state limit is an accurate approximation in the lower wind speeds, as shown by the performance ratio and energy collected by the wind turbine. Eventually, BLDC generator speed control unit creation utilizing PI controller and Simulink analysis of independent system employing wind generator-based BLDC machine.

3. METHODOLOGY

3.1 PROJECT ASSIGNMENT

It is unprofitable to include sparsely populated areas remote from large cities in a single energy system. Traditionally, their autonomous power supply is carried out using diesel power plants, and coal/oil boilers.

In this case, the supply of fuel occurs intermittently and is accompanied by an increase in the cost of transporting fuel by land or water, and sometimes by helicopter.

The traditional energy resources, especially fossil energy, will decrease someday, so clean energy was directed to solving this problem. As this energy is easy to use and cannot be depleted for example wind energy [40].

All environmental issues support the idea of developing an independent, isolated network to generate electric power using various generators for example induction or synchronous machines and PMSM /BLDC. So, one of the advantages of the BLDC has highly efficient and reliable in work and can be used with the mechanical turbine without the need for a gearbox [36].

Recently, the turbines designed with control of pitch angle have become famous. To regulate the pitch angle, where it was necessary to maintain the speed turbine by increasing the wind speed. Where are, any slight change in the pitch angle β greatly affects the generation efficiency and the amount of energy produced to reach the highest output power [41].

Three categories can be used to classify wind turbine simulators. Power electronic simulations, simulations based on programs, and electrical-mechanical simulations [42] [43] [44]. The electrical-mechanical simulation of a wind turbine system, which combines a generator and a motor, is the most popular. In terms of the motor, depending on the control system, it may be utilized with a DC motor [45], an induction motor with a speed drive control [46], an induction motor with frequency control [47] [48] [49] or an induction motor with torque control.[50] A three-phase synchronous generator [51], a permanent magnet synchronous generator (PMSG) [52], or a DC motor can all be used on the generator side.

The researchers decided to use computer software to imitate electrical equipment and run them.

This research aims to present and develop a mathematical model of a new control method and enhancement of the pitch angle β of a wind turbine, speed control BLDC generator using PI controller, and investigation of standalone system wind generator-based BLDC machine using Simulink shown in the figure. 3.1 Designation and analysis of existing power converters for wind turbines.

An important part of the wind power plant, which is part of an autonomous energy complex, is an intelligent converter (controller). This converter converts the primary power supply voltage from the generator to DC voltage. An inverter and a charger (battery) are connected to the output of such a device.

When the batteries are fully charged, the controller switches to a ballast rheostat so as not to spoil the operation of the batteries, as shown in Figure 3.1.

When the batteries are partially discharged, the power converter with the control system is reconnected to the DC bus. It is assumed that the smart converter will be able to work as AC / DC, that is, it will convert alternating voltage to direct voltage.

The structure of the conversion system of wind energy has a Wind turbine of 6 kW, a BLDC generator of 5kw, and a control unit of the pitch angle of the wind turbine shown in figure 3.1.

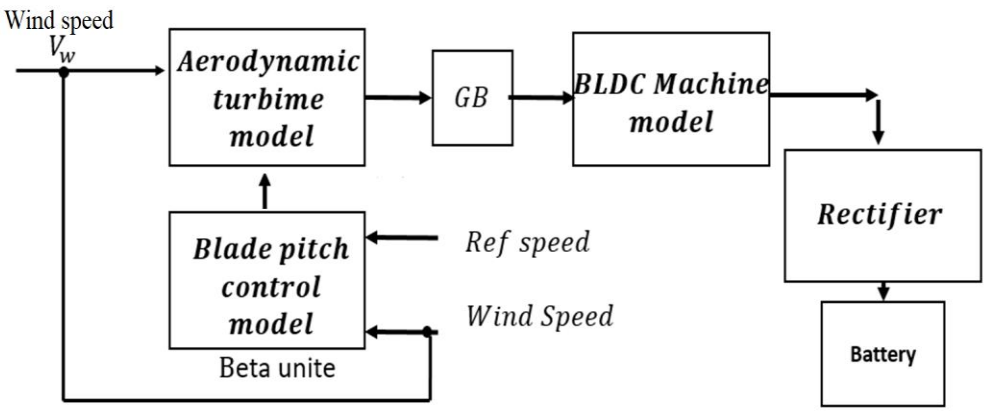

Figure 3.1: Scheme Development Control Method and Enhancement of The Pitch Angle B of The Wind Generator System.

In this work, assumptions were made for the work of the mechanical system of the gearbox and the electrical system of the inverter, where energy loss was not considered. But consider only the energy loss due to a jet of air exploding at the outlet of the turbine that is not involved in creating the torque.

3.2 MATHEMATICAL DESCRIPTION OF THE SYSTEM

For a horizontal wind energy conversion system three mathematical models, including the aerodynamic, mechanical (turbine), and electrical models, may be used to represent (generator + voltage source inverter). The process of energy conversion using three mathematical models and their corresponding subsystems (parts) is shown in Figure 3.2 [53]. Formulation of requirements for the converter, including its automation capabilities.

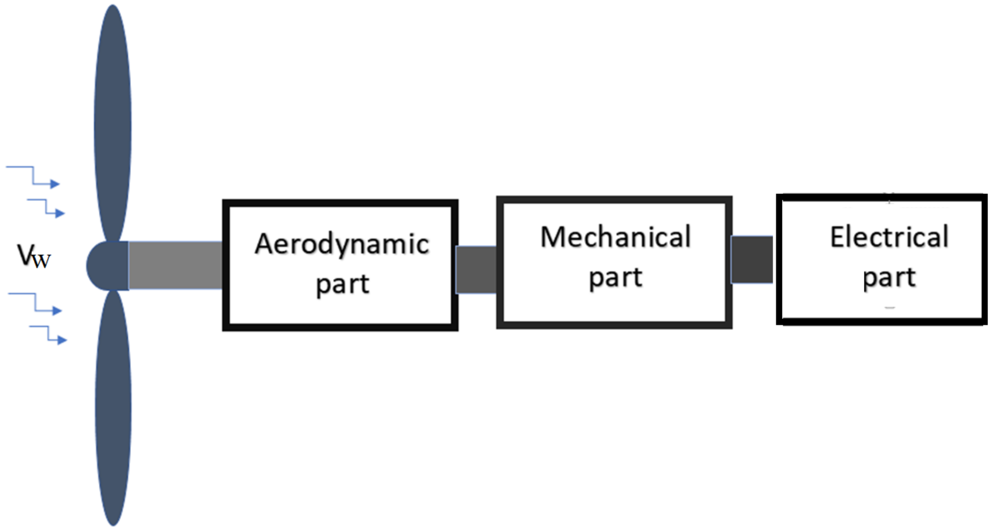

Figure 3.2: The Conversion Energy in A Wind Generator [53] [54].

The aerodynamic model oversees depicting how energy from moving air mass, which generates a turbine's rotational speed, is converted into mechanical energy on the generator's shaft. The gearbox's gear ratio and the shafts' elasticity are taken into consideration in the mechanical model when describing how the speed and torque of the generator shaft are dependent on the mechanical power of the turbine. The mechanical torque imparted to the generator shaft is converted into electrical energy at the generator's output according to the electrical model.

3.2.1 Mathematic Description of The Wind Turbine's Aerodynamics

The mechanical energy equation of power P_T extracted by wind turbines from wind energy P_W, shown in the equation below, could be used to obtain a description of the aerodynamics of wind turbines [53] [55] [56] [57]:

$$P_T = \frac{1}{2}\rho \cdot A_t \cdot v_w^3 \cdot C_p \quad , \tag{3.1}$$

where $A_t = \pi R^2$.

For accurate and correct calculations of *Cp*, *Cp* requires a complex mathematical description, so we can use the approximate polynomials derived in [53] [55] [56] [57] [58] according to empirical measurements, for the above values of tip speed ratio λ and angle of attack (pitch angle) β:

$$C_p(\lambda,\beta) = C_1(C_2/\lambda_i - C_3\beta - C_4)^{C_5/\lambda_i} - C_6\lambda \ , \tag{3.2}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + C_7\beta} - \frac{C_8}{\beta^3 + 1}, \tag{3.3}$$

Where the C_1, C_2, …, C_8 – It considers the coefficients on which the turbine's aerodynamic properties are dependent. The data presented may be considered as an example [58] [57]because each wind turbine has a unique value for these coefficients:

C_1 = 0.5, C_2 = 116, C_3 = 0.4, C_4 = 0, C_5 = 5, C_6 = 21.

The power coefficient of turbine *Cp* depends on the speed of rotation of the turbine blades and the wind speed as well, as it varies accordingly. It also depends on the important value of the peripheral speed ratio λ where the turbine torque coefficient C_t can be determined and calculated through it as in the equation below [55]:

$$C_t = \frac{C_p}{\lambda}. \tag{3.4}$$

The estimation of mechanical torque in the shaft generator determined [55]:

$$T_m = P_t / \omega_t . \tag{3.5}$$

When the equation is substituted into equation (3.5), the torque produced by the turbine is expressed.

To calculate the torque of the wind turbine we substitute equation (3.1) using equation (3.5) which gives the torque of the wind turbine [55]:

$$T_m = \frac{\rho\pi R^2 v_w{}^3 C_p}{2\omega_t} \tag{3.6}$$

The optimum value of angular turbine speed can be calculated by the equation below.

$$\omega_{t-otp} = \frac{v_w \lambda_{opt}}{R} . \tag{3.7}$$

The optimum torque value can be calculated using the equation [55]:

$$T_{opt} = P_{opt} / \omega_{t\_opt} \tag{3.8}$$

Here it is necessary to substitute the value of $C_p = C_{p\,max}$ from equation (3.1) and then we substitute it to express the turbine power in equation (3.8) we get the optimum torque value that can give the highest value for the turbine efficiency:

$$T_{opt} = \frac{\rho \pi R^2 v_w{}^3 C_{p\max}}{2\omega_{t-opt}} \tag{3.9}$$

To determine the dynamics of mechanical motion used the expression [55]:

$$\omega_t = \frac{1}{J} \int (T_{opt} - T_m) dt \tag{3.10}$$

Equation (3.10) represents the method for calculating the angular velocity of a wind turbine by calculating the optimum torque and the effective torque of the wind turbine.

3.2.2 Mathematical Model of BLDC Generator

The mathematical model of BLDC generator star connected [59]:

$$V_{ab} = R(i_a - i_b) + (L - M) \cdot \frac{d(i_a - i_b)}{dt} + e_a - e_b \tag{3.11}$$

$$V_{bc} = R(i_b - i_c) + (L - M) \cdot \frac{d(i_b - i_c)}{dt} + e_b - e_c \tag{3.12}$$

$$i_a + i_b + i_c = 0 \tag{3.13}$$

When the equation of motion defined by (3.10)

$$T_e = T_L + J\frac{d\omega_r}{dt} + B \cdot \omega_r \tag{3.14}$$

Where given by the wind turbine, $E = K_e \cdot \omega_r$.

The shape of EMF (trapezoidal) because back-EMF is a function of rotor position and has the amplitude.

The equation of electromagnetic torque for the BLDC generator is defined by the equation below:

$$T_e = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_r} \tag{3.15}$$

Whereas, for each of the phases, there is a phase difference of 120 electrical degrees, shifting the phase from the other two phases. We get the magnetic torque of the electric generator by the following equation (3.15).

3.3 MODELLING OF WIND ENERGY CONVERSION SYSTEM

3.3.1 Modelling OF Wind Turbine

For the simulation data, the technical characteristics of a three-bladed small-scale horizontal axis of rotation of a wind turbine with, manufactured under the brand name, were used Scirocco E5.6-6 by the French company Eoltec. Shown in table 4.1 [60]:

Table 3.1: Wind Turbine Characteristic Used Scirocco E5.6-6 By The French Company Eoltec [60].

Data	**Value**
Rated power of Turbine P_{nom}, KW	6
The number of blades of a wind turbine	2
The value for the wind's nominal speed is v_{nom}, m/s.	12
D the turbine's diameter by the (m)	5.6
J_{Tg}, $\kappa g.m^2$ is the total moment of inertia (turbine and generator).	6.8
Maximum wind speed V_{max}, m/s	20
Minimum wind speed $V\ max$, m/s	3.5
Air density, ρ, by the $\kappa g/m^3$	1.225
Gearbox ratio, (GB)	10
Height of Mast, m	18/24/30

The model of the BLDC generator supported with wind turbine and enhanced with control pitch angle β and speed control method by BLDC generator (wind energy conversion system) implemented, as shown in the figure 3.3 below. The structure of the conversion system of wind energy has a Wind turbine 6 Kw, BLDC generator, and control unit of the pitch angle of the wind turbine shown in figure 3.5.

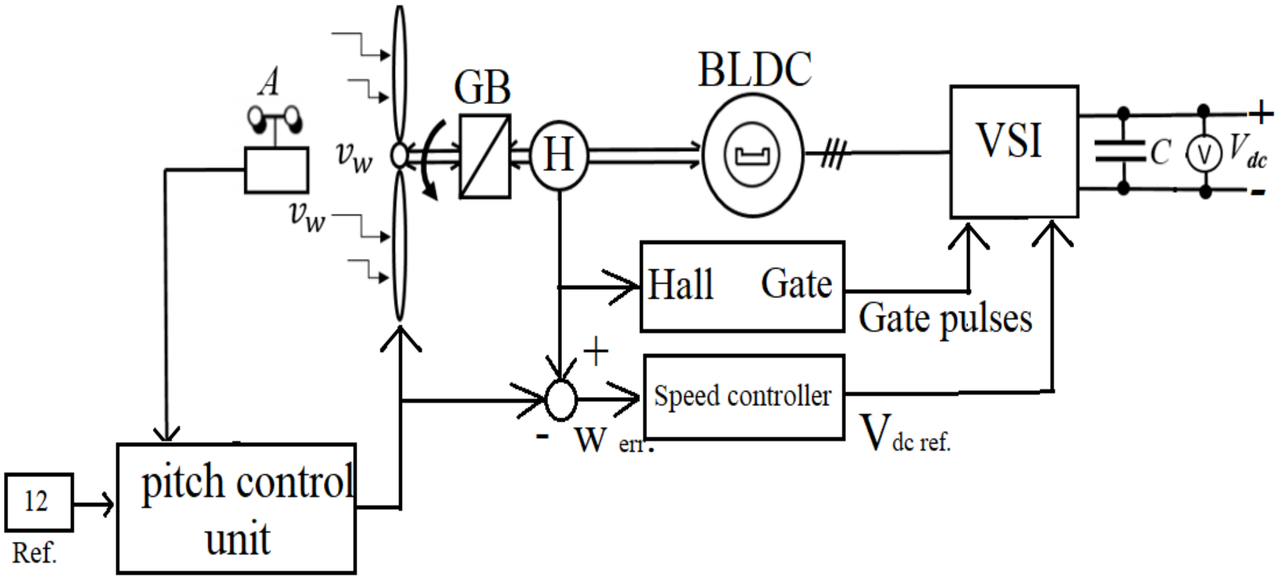

Figure 3.3: Wind Energy Conversion System Control-Based BLDC Generator By Simulink.

3.3.2 Modelling of BLDC Generator

The model of the wind energy conversion system consists of four blocks: A block of mathematical model for a wind turbine 6 kW, a block circuit to control the pitch angle β, a block of voltage source inverter VSI and a block of a BLDC generator 5kw have the parameters shown in Table 4.2.

Table 3.2 The Parameter of BLDC 5 Kw [61].

parameter	**Quantity**
Resistance, ohm	1.43
Inductance, H	$9.4e^{-3}$
Rotor Flux, [wb]	0.2158
Rated power	5 Kw
Moment of inertia	$5.5e^{-3}$
No of pole	4
Friction Coefficient -B	$2e^{-3}$

The novel work represents two methods of control, the first method by pitch angle β to the controlled speed and the second by speed control feedback.

3.3.3 Modelling of Voltage Source Inverter VSI

The mathematical description of the dynamic switching processes in the power semiconductor switches of the was obtained based on the equivalent circuit given in [62]. The system of voltage equations between the emitter and the collector was used in the model (for an insulated gate bipolar transistor):

$$V_a = \left[S_a - \frac{1}{3}\left(S_a + S_b + S_c \right) \right] V_{dc}, \tag{3.16}$$

$$V_b = \left[S_b - \frac{1}{3}\left(S_a + S_b + S_c \right) \right] V_{dc}, \tag{3.17}$$

$$V_b = \left[S_c - \frac{1}{3}\left(S_a + S_b + S_c \right) \right] V_{dc}, \tag{3.18}$$

where, S_k (k= a, b, c) is the switching function. S_k=1 means that the high-side switch is closed, and the low-side switch is open, whereas S_k=0, S_k=1 means that the low-side switch is closed, and the high-side switch is open, and Vdc is the voltage DC link. The method of pulse-width modulation in the traditional three-phase coordinate system (a, b, c), used to control power transistors, is described by the following system of equations [62].

$$L\frac{di_a}{dt} = \left[V_a - R_s i_a + \frac{1}{3}\left(S_b + S_c - 2S_a \right) V_{dc} \right], \tag{3.19}$$

$$L\frac{di_b}{dt} = \left[V_b - R_s i_b + \frac{1}{3}\left(S_a + S_c - 2S_b \right) V_{dc} \right], \tag{3.20}$$

$$L\frac{di_b}{dt} = \left[V_c - R_s i_c + \frac{1}{3}\left(S_a + S_b - 2S_c \right) V_{dc} \right], \tag{3.21}$$

$$C\frac{dV_{dc}}{dt} = \left[S_a i_a + S_b i_b + S_c i_c - \frac{V_{dc}}{R_L} \right] \tag{3.22}$$

where, R_s - is the resistance of the coils of the equivalent circuit, L_s is the inductance, C is the smoothing capacitor on the DC bus, (I_a, I_b, I_c) and (V_a, V_b, V_c) are the phase currents and voltages. It is worth noting that the model described above is an IGBT model.

3.4 CONTROL METHODS

Block sub-system of speed controller of BLDC generator when the setting of the width of the hysteresis loop for the relay controller, as well as the proportional and integral coefficients for the PI controller, is carried out by experimental selection. The coefficient of the proportional part is Kp1=41 for the first loop, and Kp2= 10 the second loop, and the coefficient of an integral part is Ki=345.32, shown in figure (3.4).

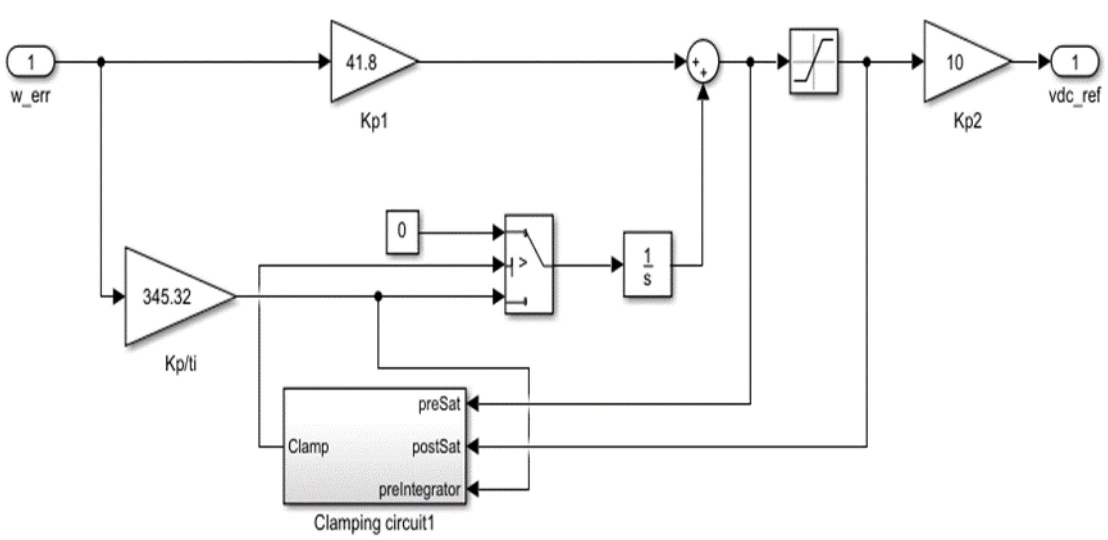

Figure 3.4: Sub-System Speed Controller of BLDC Generator By MATLAB Simulink.

Also, the novel work represents two methods of control, the first method by pitch angle β to the controlled speed of wind turbine shown in figure (3.5), and the second by speed control feedback of BLDC generator by PI controller shown in figure (3.4). The pitch angle control unit block of shown in figure below:

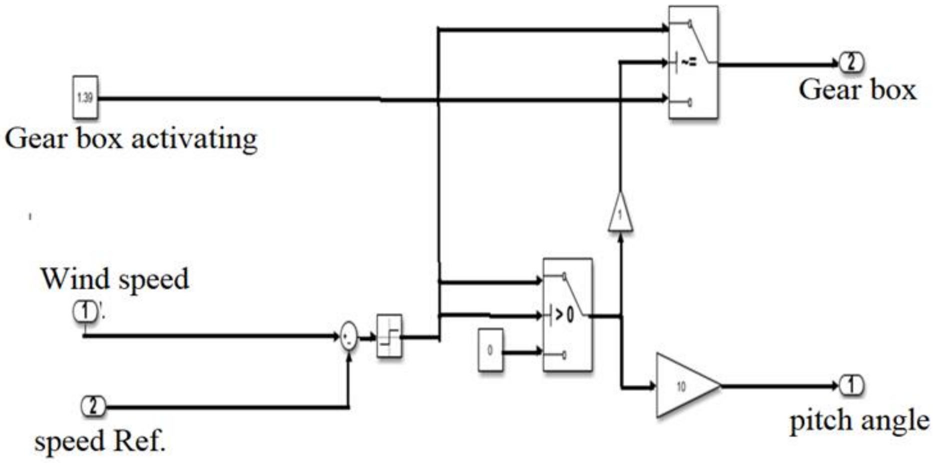

Figure 3.5: Pitch Angle B Control Scheme.

The variable pitch angle β system control compares the wind speed and reference speed value (12 m/s) to determine the level speed over or underdrawings speed, When the wind speed is greater than the reference speed (12 m/s), the system control of pitch angle gives a negative error signal to minimize positive glitched in speed values. Another hand if the signal is positive, it is mean the wind speed is more than the reference speed, it will enter directly and multiply by a value of 10 degree, which is the pitch angle β magnified to illustrate the clear behaviour of speed behaviour for the researchers.

For a relatively low wind speed, the system converts it directly to the optimized speed of the turbine, to show good clarity in the control signal, which is obtained from the potential energy of the air. These amplifications are compensated in the practical results, as the gearbox, which in turn doubles the rotational speed of the turbine shaft in the second stage converts the power to match the speed of the generator, which has a constant synchronous speed to be suitable for electrical generation.

4. SIMULATION AND RESULTES

4.1 SIMULATION OF WIND ENERGY CONVERSION SYSTEM-BASED BLDC GENERATOR

Each component of a wind turbine has a mathematical description. Equations (3.1) - (3.10) were utilized to create a visual depiction of the wind turbine mathematical model created in Simulink shown in figures 4.1, 4.2, 4.3, and 4.4. Using the above equations, A mathematical model of the BLDC electric generator has been developed using Equations 3.11, 3.12, 3.13, and 3.14 shown in Figures 4.5 below:

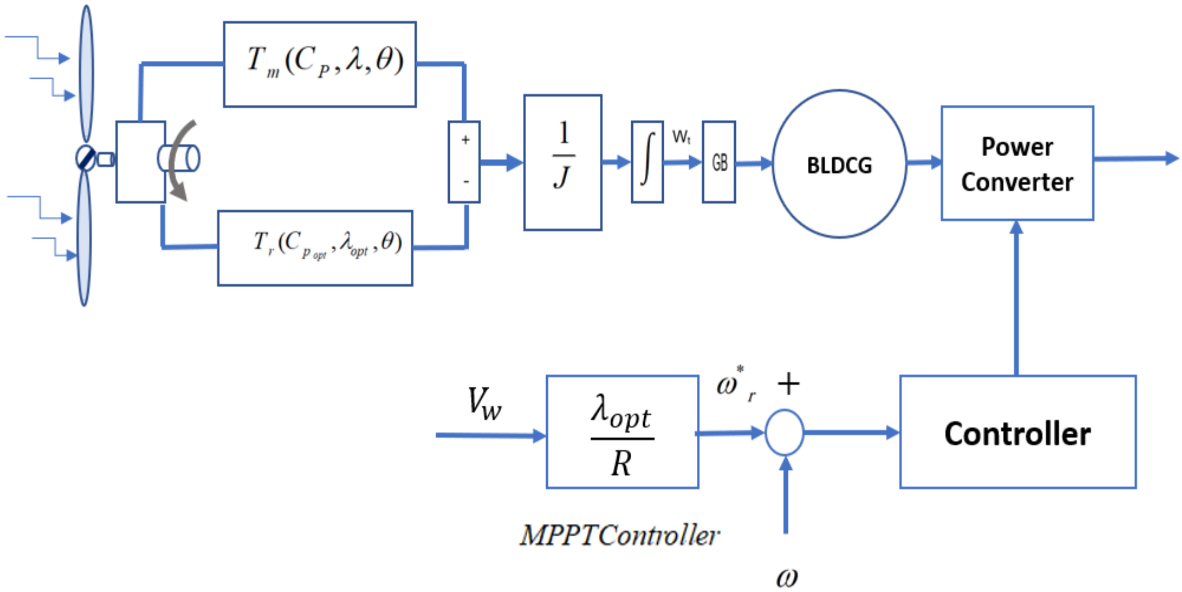

Figure 4.1: Schemes of WECS.

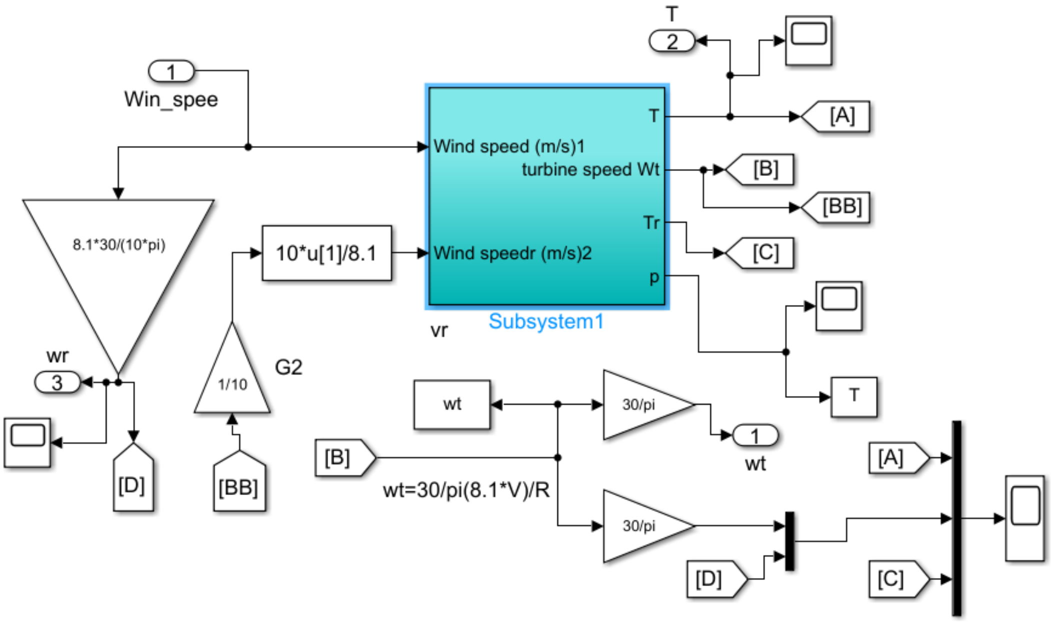

Figure 4.2: Schemes of the Mathematical Model WECS In Simulink.

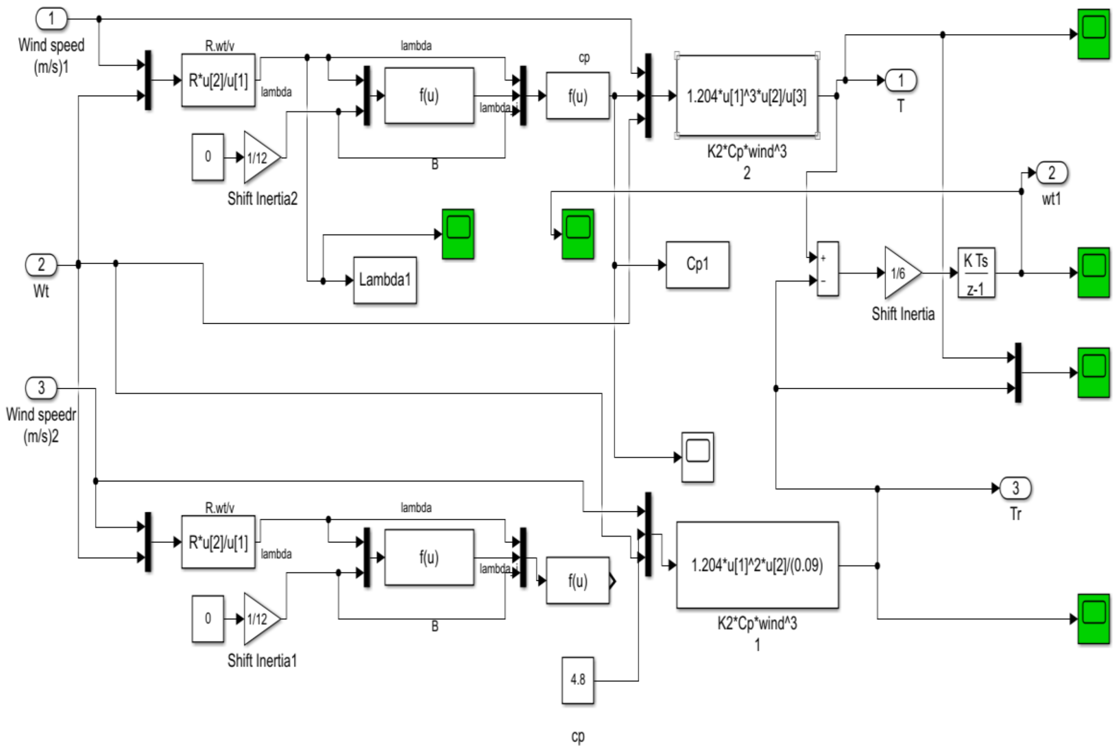

Figure 4.3: Schemes of The Mathematical Model WT In Simulink.

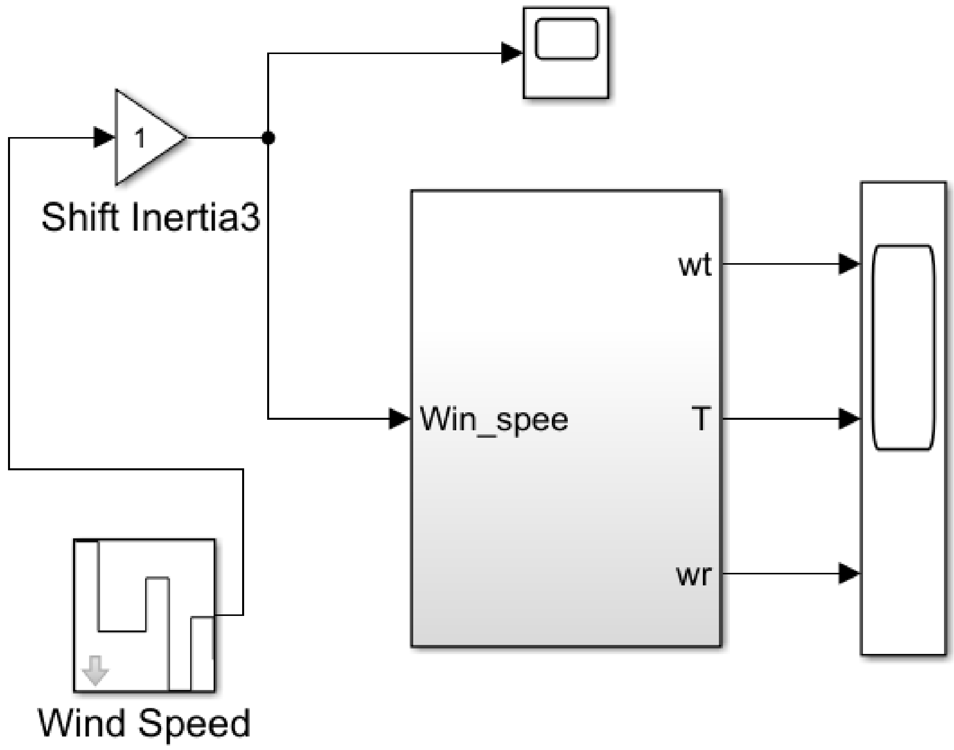

Figure 4.4: Schemes of the Mathematical Model WT in Simulink.

Thus, in the course of the work done, a simulation model of a wind turbine with a horizontal axis of rotation was implemented according to its mathematical description, using the MATLAB package.

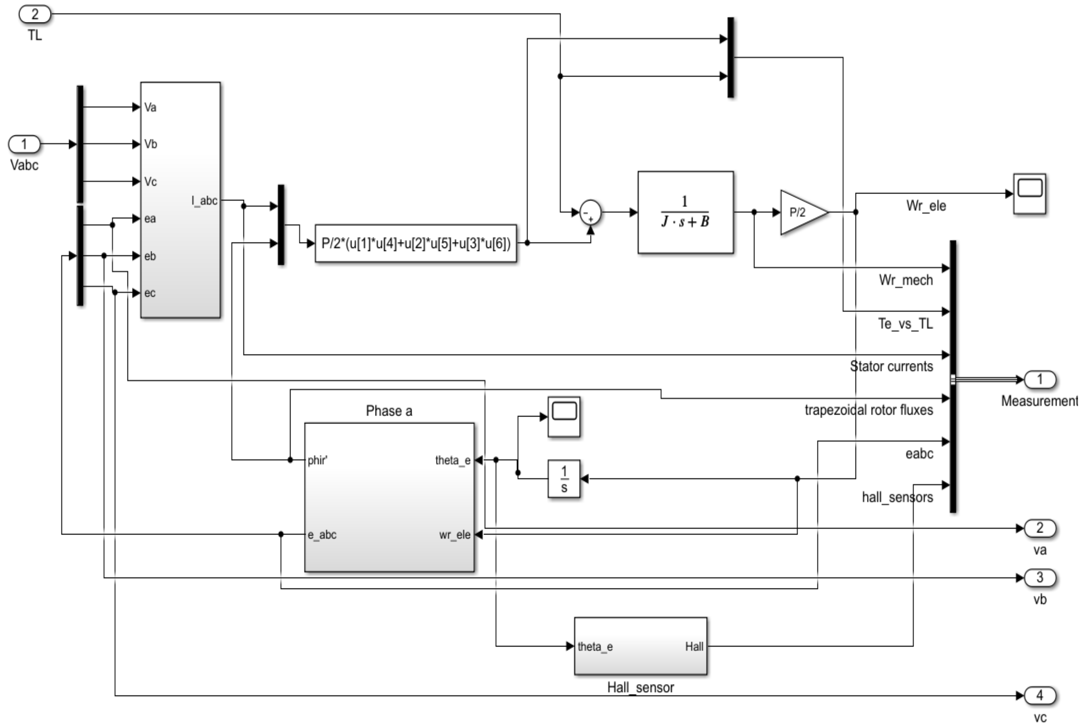

Figure 4.5: The mathematical model of the BLDC generator.

Figure 4.6 represented the mathematical model of a subsystem of the electrical equation to calculate the three-phase electrical current of the BLDC generator.

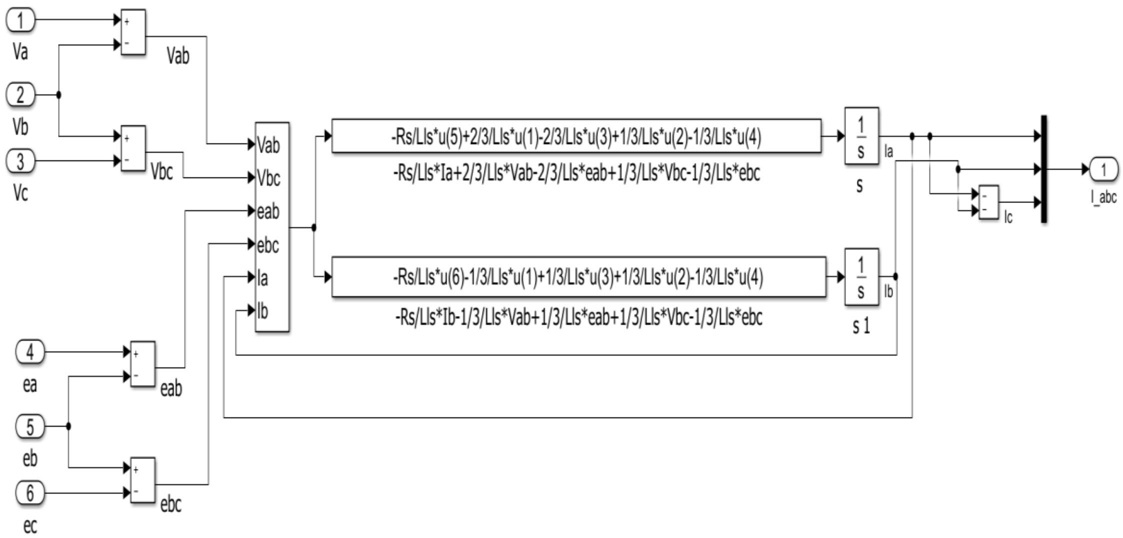

Figure 4.6: The Sub-System of BLDC Generator Electrical Part (Viewed Under Mask).

Figure 4.7 shows the mathematical model for calculating the value of the electric motive force of the electric generator BLDC.

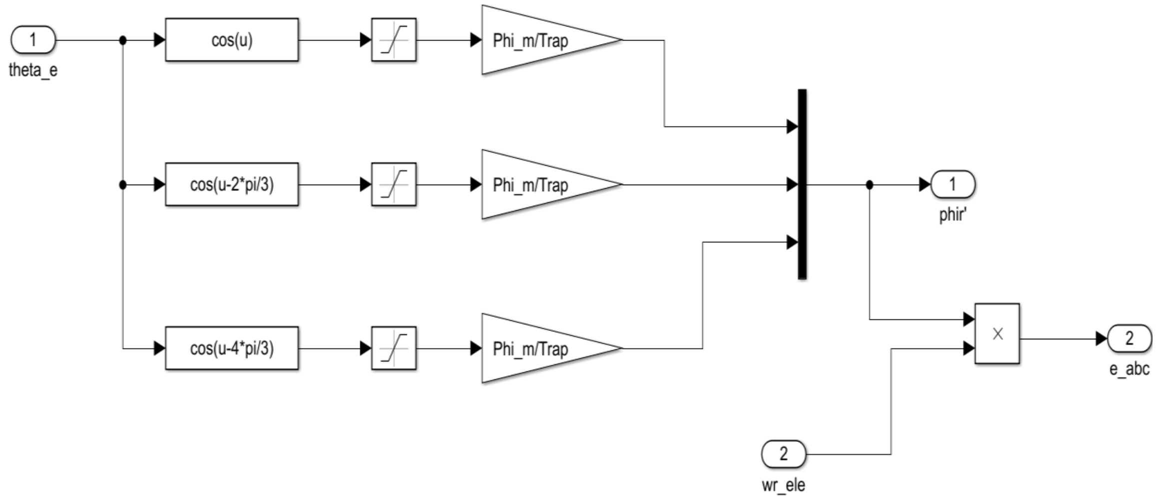

Figure 4.7: Mathematical Model For Calculating The Value of The Electric Motive Force of The BLDC Generator By The Simulink.

The sub-system for calculating the location of the rotor position sensor (Hall sensor) of the BLDC generator is shown in figure 4.8 below.

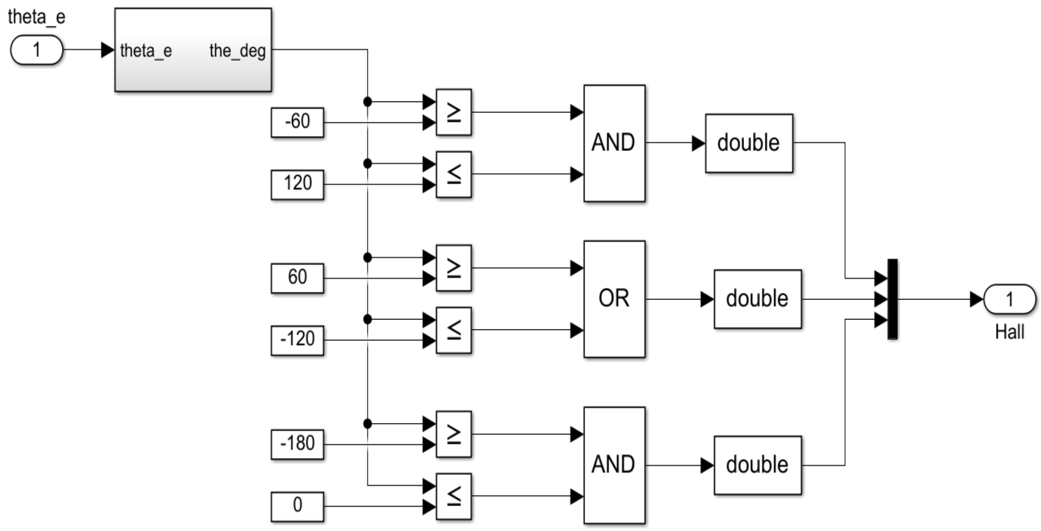

Figure 4.8: The Mathematical Model of The Hall Sensor.

The mathematical subsystem of the voltage source inverter VSI is represented in figure 4.9 by using equations 3.16, 3.17, 3.18, 3.19, 3.20, and 3.21 in Chapter three above.

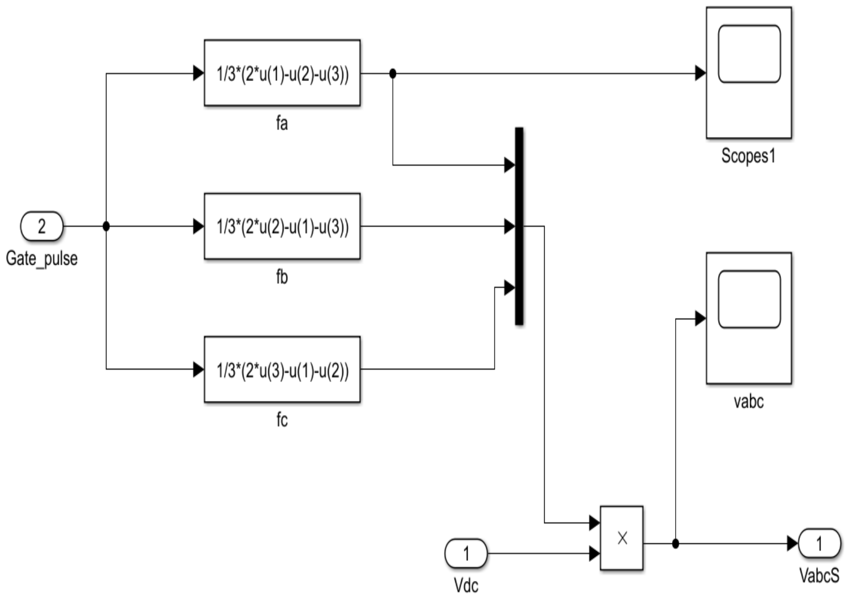

Figure 4.9: A mathematical model of voltage source inverter VSI by Simulink.

4.2 SIMULATION RESULTS OF WIND ENERGY CONVERSION SYSTEM-BASED BLDC GENERATOR

The turbine starts to work when the wind speed exceeds the speed of the side wind. The power captured by the turbine increases as the wind speed increases. At a given point, the wind speed generating power reaches the rated power of the turbine. If the wind speed continues to increase, the generator output remains constant at the design limit. For safety reasons, the turbine is switched off at speeds exceeding the wind speed with the shutdown. Figure 4.10. We consider the wind power plant and the method of operating the wind power plant.

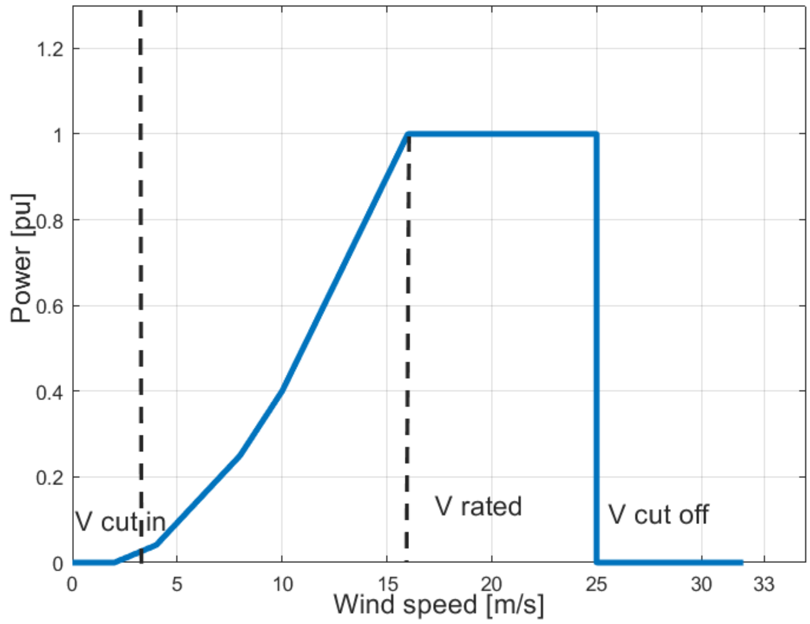

Figure 4.10: Variable Speed Pitch-Controlled Wind Turbine [55].

A gearbox of the appropriate ratio of teeth (N) is required to match low turbine speeds with higher performance per Table 4.1. Table 4.1 A gearbox of the appropriate ratio of teeth

Table 4.1: Gearboxes of the appropriate ratio of teeth

V_W(m/s)	N^*(rev/min)
6	600
7	700
8	800
9	900

Figure 4.11 show the wind speed here the intensity of the wind ranges from 4 to 16 meter per second, for example. In Figure 4.12, the diagram shows Otherwise errors may occur between T_{opt} and T_m. They can be driven to zero as in the stationary ones shown in Figure (4.12).

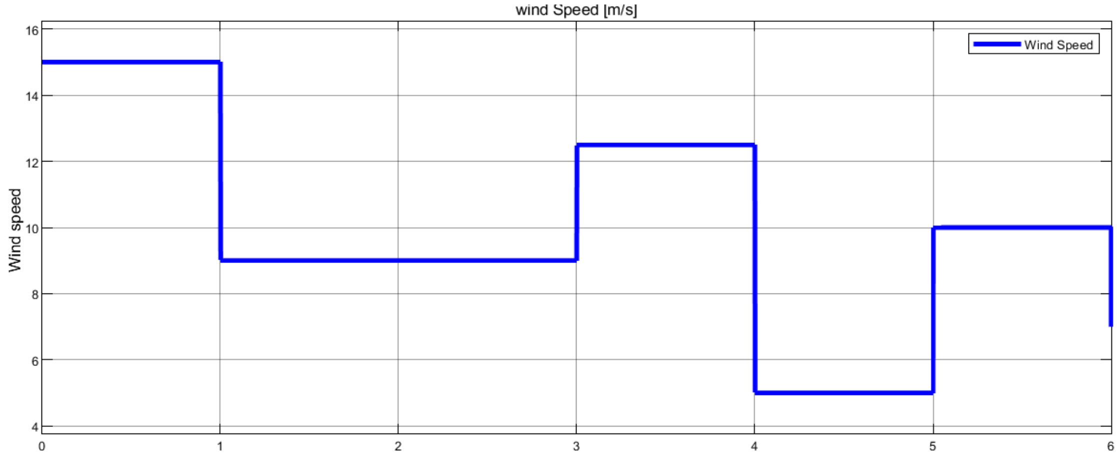

Figure 4.11 : Variable Speed of Wind Speed.

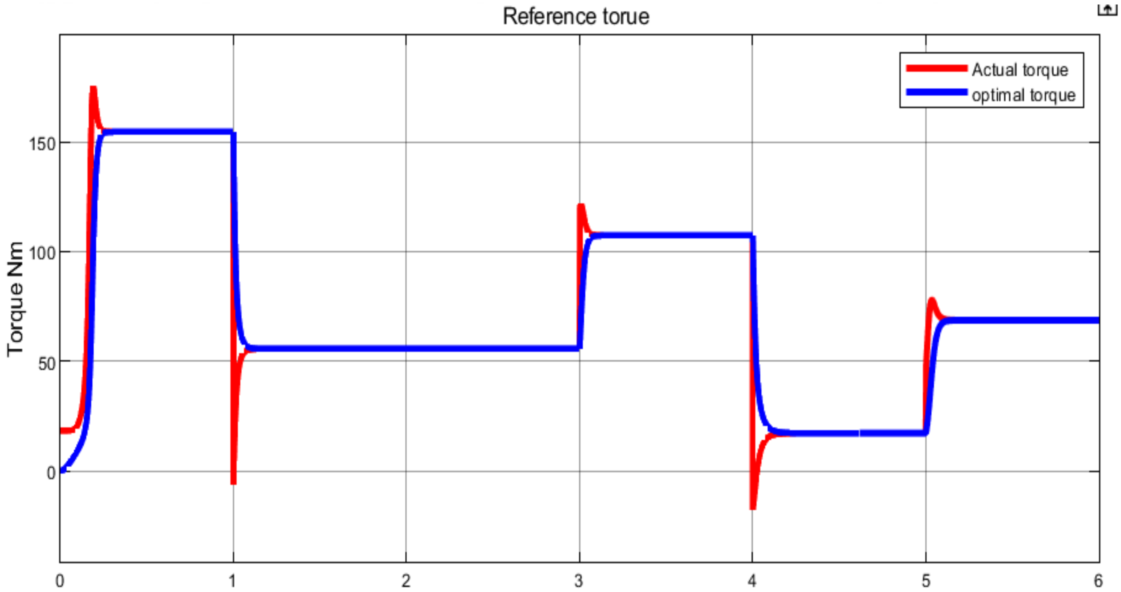

Figure 4.12: Torque of Wind Turbine.

In Figure 4.13. The diagram shows otherwise errors may occur between the optimal speed of the wind turbine ω_{opt} and the actual speed of the wind turbine ω_m. figure 4.14 represented the tip speed ratio with time.

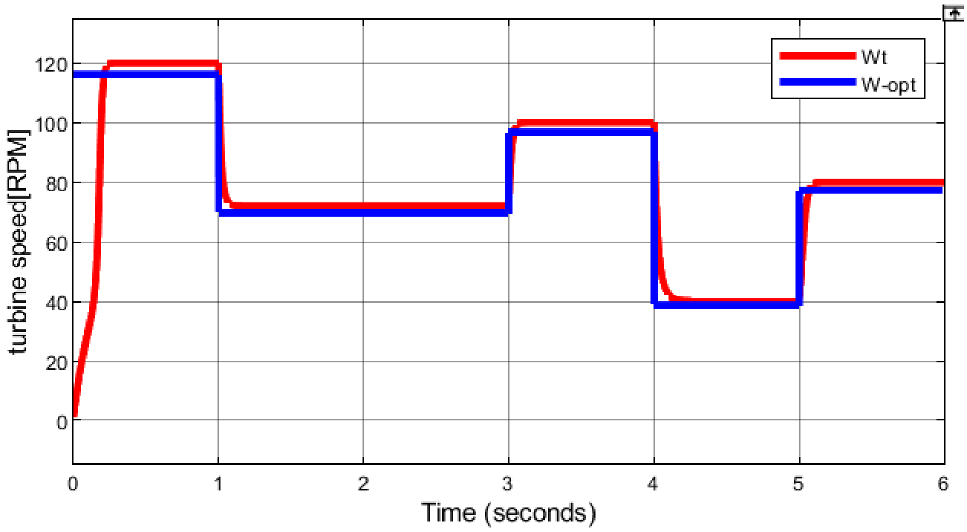

Figure 4.13: Variable Wind Speed.

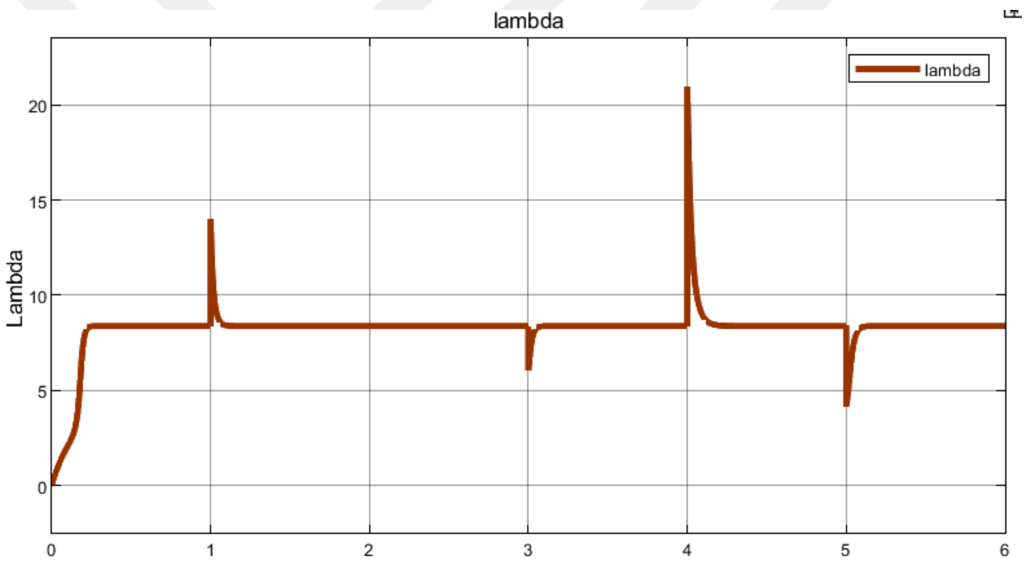

Figure 4.14: Tip Speed Ratio.

In figure 4.15 Different wind speed values (5 to 13 m/s) represented by mechanical characteristics

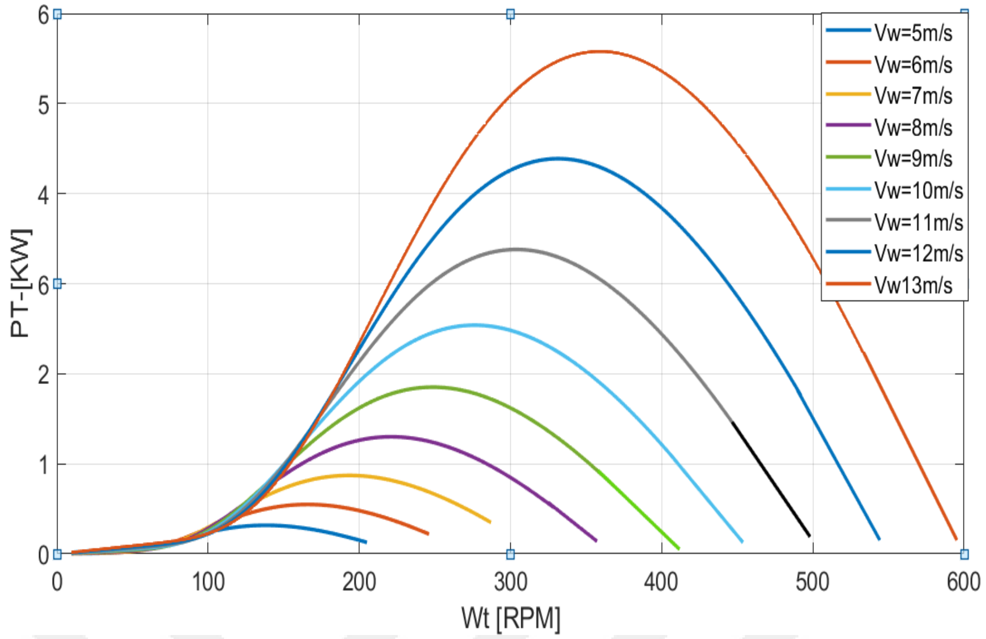

Figure 4.15: Dependence Between Mechanical Power and Angular Speed of Turbine.

When the wind speed changes, the value of the mechanical characteristics changes as well as the turbine rotation speed also changes by fixing the angle of the blades β = 0. We obtain a maximum power of the turbine at the outlets of 5.6 kW at a wind speed of V_w = 13 m / s. Where the mechanical properties of the wind turbine were obtained depending on the power coefficient of the turbine C_P and the tip speed ratio λ as in Figure 4.16.

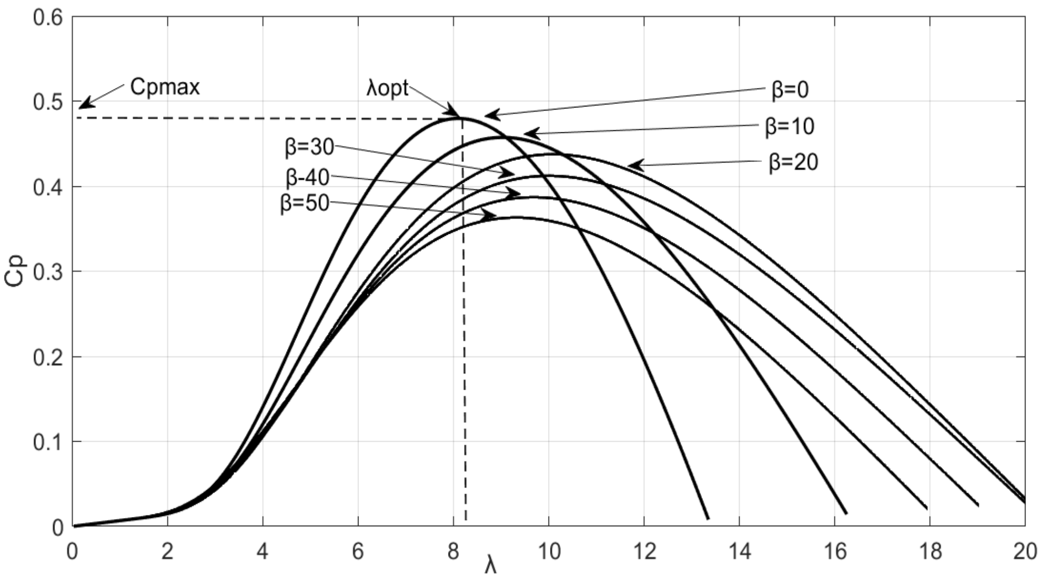

Figure 4.16: Aerodynamic Characteristics.

In Figure 4.16 it is shown that the maximum value of the power coefficient of turbine Cp-max is 0.48 with the pitch angle of the blades of the turbine can be constant (β = 0) and the optimal value of tip speed ratio λ is 8.1. Figure (4.17) shows a relationship between of coefficient of torque and tip speed ratio.

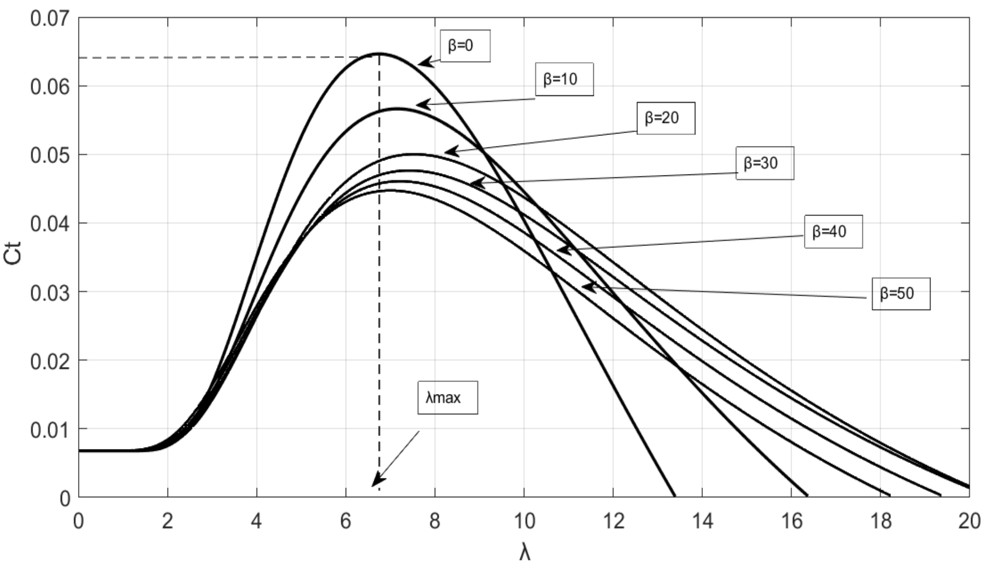

Figure 4.17: Aerodynamic Performances.

The figure above shows the relationship between the coefficient of torque and tip speed ratio with the change of pitch angle β (0-50 deg.). As result, the maximum value of coefficient torque is shown 0.065 when the angle of attack is equal to zero, and from that obtain the maximum value of tip speed ratio λ_{max}=6.2.

Table 4.2: Actual Results Shown in Aerodynamic Performance.

B Degree	Cp MAX	Ct MAX
0	0.48	0.065
10	0.44	0.058
20	0.42	0.05
30	0.41	0.048
40	0.38	0.046
50	0.34	0.044

This table shows the actual results when changing the pitch control angle from (0-50) degrees and the change in aerodynamic performance, including Ct, Cp, and tip speed ratio.

The selected group of wind speeds input of turbine to simulate this model, shown in figure (4.18).

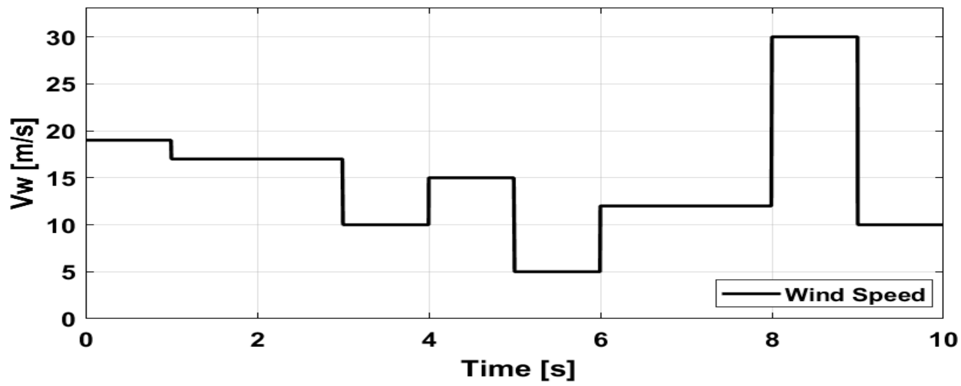

Figure 4.18: Wind Speed With Time.

The following figure (4.19) shows the work of the control circuit in the pitch angle β and discusses how to control the speed of the wind generator. This means that the difference between the rotation speed of the turbine before Enhancement and after Enhancement.

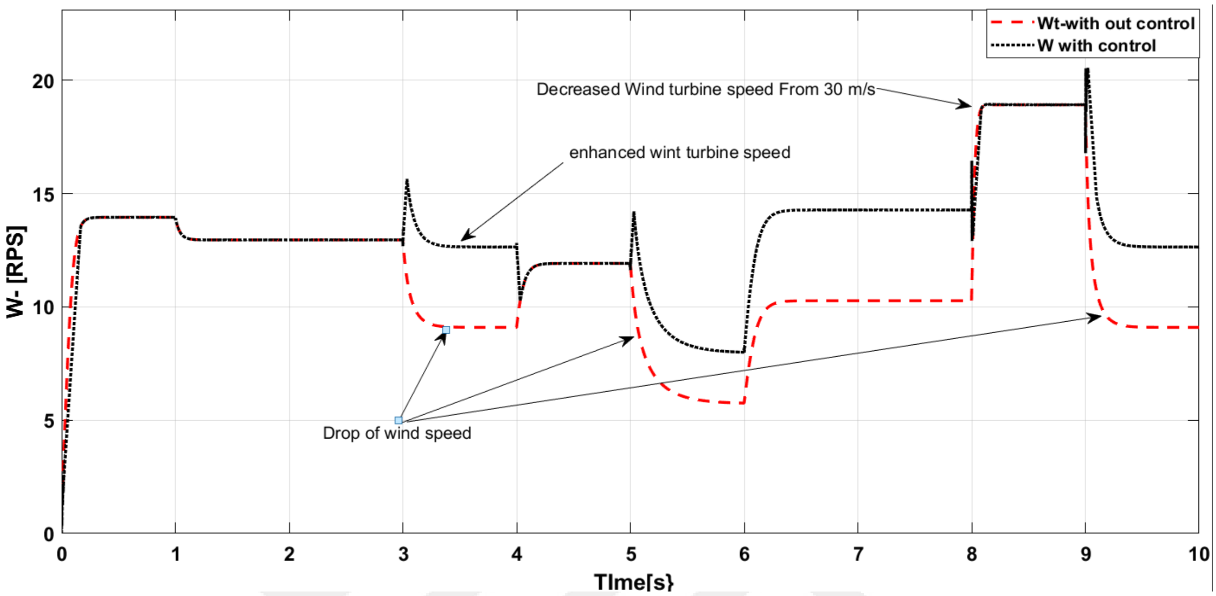

Figure 4.19: Enhancement of Wind Turbine Speed By Pitch Angle Control.

When the time 3 sec. can be seen in the drop in wind generator speed because the wind speed decreases. Finally, in this case, the wind speed is high from the input system 30 m/s means the wind speed is equal to the maximum value, see the speed response control of pitch angle to keep of system equipment by reducing the speed by method pitch angle control unite.

Wind generator-based BLDC generator characteristics performance is shown in figure (4.20).

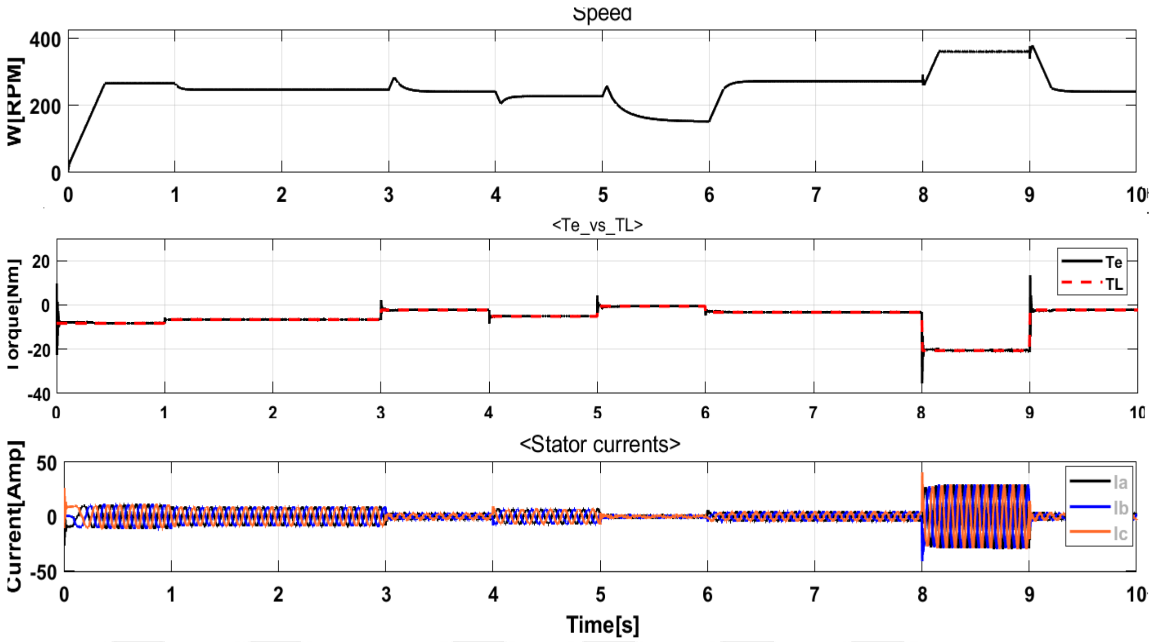

Figure 4.20: Performance Output BLDC Generator.

Figure 4.20 shows how the generator's rotational speed varies concerning wind speed, the electric and load torque of the generator, and the three-phase current (Ia, Ib, and Ic) induced in the stator portion, respectively. We observe that the voltage and the current increase with the increase in the speed of the air masses.

With an increase in the speed of air masses, the control system provides sufficient smoothing of current and voltage surges. The current now equal to 8 s is equal to 23 A.

The output performance of the BLDC generator-based wind turbine illustrates (rotor flux, EMF generator, and hall sensors respectively are shown in figure (4.21).

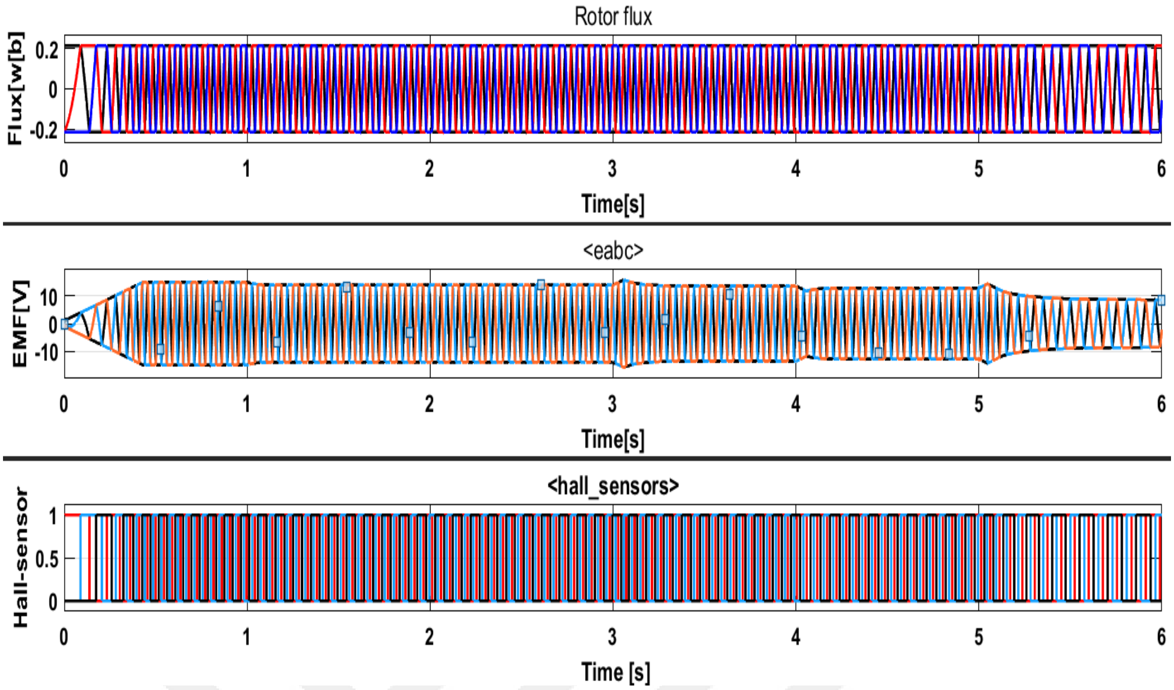

Figure 4.21: Rotor Flux, EMF ABC, Hall Sensor With Time.

Figure 4.22 consider the dependence of voltage and current on the speed of the rotor.

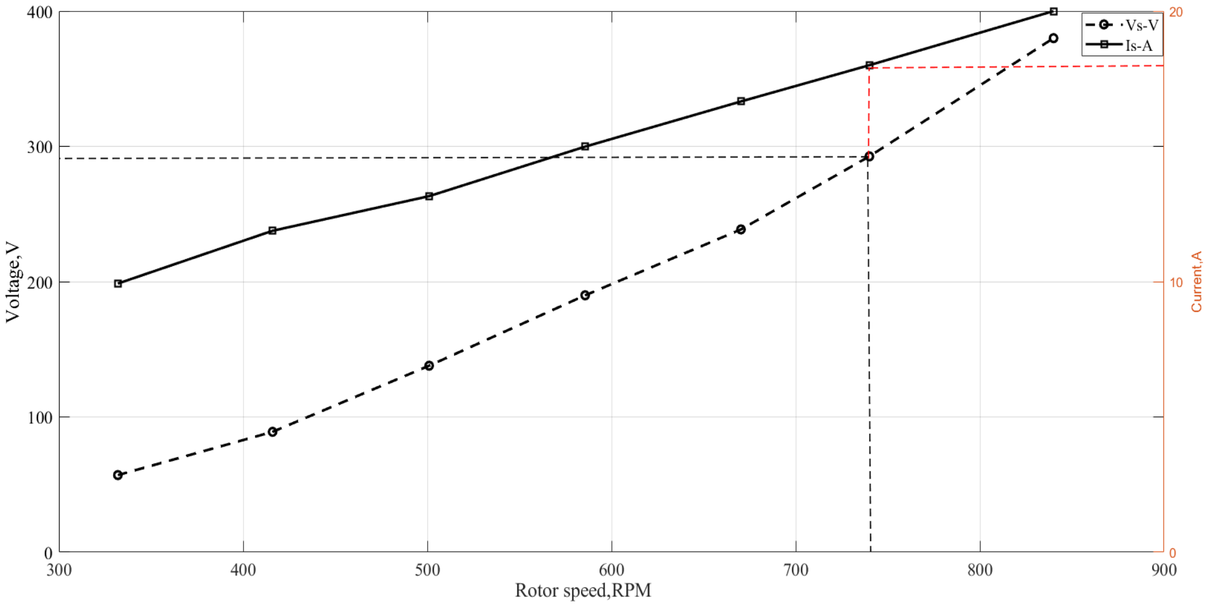

Figure 4.22: Dependence Between Voltage and Stator Current At Rotor Speed.

The model under consideration shows that the selected generator produces rated power at a wind speed of 9 m/s (rotor speed is 754 rpm). Under this condition, the phase current is 18.7 A and the voltage 298 V.

Table 4.3: Dependence Between Voltage and Stator Current at Rotor Speed.

W(rpm)	**V(volt)**	**I (ampere)**
400	80	12
500	150	14
600	200	15
700	280	18.7
800	350	21

Table 4.3 illustrates the results from the comparison of voltage and current at rotor speed as shown in the figure 4.22.

5. CONCLUSION

The objective of this research was to advance theoretical understanding in the field of professional work on the design and investigation of intelligent converters for wind generators of low-power autonomous energy complexes. A variety of tasks were completed during the thesis to get the intended outcome:

a. Revealed and researched the characteristics of the utilization of autonomous energy complexes globally, particularly on Iraqi land.

b. The turbine and machine were selected, its calculation was carried out, and requirements for it with the possibility of automation were formed.

c. A mathematical model wind turbine, electrical machine, and voltage source inverter was created by the Simulink software.

d. A mathematical model for a stand-alone wind energy conversion system WECS was proposed and designed,

where two control systems were developed, the first mechanical control unit (pitch angle control) to increase the efficiency of the turbine through the angle of attack as well as to protect the turbines from high wind speed from wind speed, and the second is an electrical control system (speed controller) for the generator speed through a new control of voltage and frequency, which contains Two loops of control using PI controller. High efficiency and good characteristics of the electric generator were obtained, which enables us to use it in the countryside or any remote and isolated areas where it works at different wind speeds.

A mathematical model for a standalone wind energy conversion system was proposed and designed in this study. Two control systems were created, the first of which was a mechanical pitch angle control unit that increased the efficiency of the turbine by controlling the angle of attack and shielding it from high wind speeds. Also, the outcome of the angle of attack (pitch angle) work control unit is that, in time 3 seconds, the turbine speed is increased from 10 RPM to 14 RPS, which is equivalent to 140 RPM, to compensate for the value of the wind speed decreasing for example, not this According to the system, the system is a strong wind that is more than 30 meters per second, in time 8 seconds, where the turbine speed was fixed and protected from the high wind. The second method is an electrical control system (speed controller) for the generator speed through a new control of voltage and frequency, which contains Two loops of control using a PI controller. Development of the mathematical model of the mechanical aerodynamic wind turbine was designed as an imitation electronic device wind energy conversion system in Simulink. The maximum amount of the coefficient of torque of the wind turbine is C_{tmax} (0.06). in result in the maximal value of the coefficient power of wind turbine *Cp* (48%) when the coefficient of tip speed ratio λ_{opt} = 8.2. The optimal torque of the wind turbine is provided at the maximum value of the *Cp* this means that the wind turbine operates at the highest possible efficiency obtained from the wind speed. High-efficiency wind turbine (48%) Compared to previous research by researchers, the efficiency does not reach more than 40%. The value of the coefficient of power Cp, according to the sources, is equivalent to the efficiency of the wind turbine, as the percentage between the outside capacity is divided into the ability to enter, for this in the event of a decrease in the external power of *Cp,* for example, if the value of the angle of the attack is 50 degrees the turbine efficiency is 35.

The BLDC's speed control system has been created structurally. The mathematical modelling of wind energy conversion system-based BLDC has been completed. The electric generator has good qualities that allow us to use it in rural or other isolated locations where there are varied wind speeds.

In conclusion, we can state that the findings from the end thesis offer the chance for more study into the creation of converters for wind turbines with the network, a topic that is now very promising in renewable energy.

REFRENCES

[1] K. Bassett, R. Carriveau, and D.-K. Ting, “3D printed wind turbines part 1: Design considerations and rapid manufacture potential,” *Sustainable Energy Technologies and Assessments*, vol. 11, pp. 186–193, 2015.

[2] A. Stan, S. Costinaș, and G. Ion, “Overview and assessment of HVDC current applications and future trends,” *Energies (Basel)*, vol. 15, no. 3, p. 1193, 2022.

[3] “Wind Power in the United States,” Mar. 2014, Accessed: Apr. 05, 2023. [Online]. Available: https://sites.psu.edu/egorivanov/2014/03/28/wind-power-in-the-united-states/

[4] A. M. El-Zafry, O. E. A. El-Hameed, M. S. Hassan, and M. M. Shaheen, “A review on the types of vertical axis wind turbines and the methods of their performance study,” *J Multidiscipl Eng Sci Technol*, vol. 6, no. 9, pp. 10633–10643, 2019.

[5] W. Fedak, S. Anweiler, R. Ulbrich, and B. Jarosz, “The concept of autonomous power supply system fed with renewable energy sources,” *Journal of Sustainable Development of Energy, Water and Environment Systems*, vol. 5, no. 4, pp. 579–589, 2017.

[6] M. Zemamou, M. Aggour, and A. Toumi, “Review of savonius wind turbine design and performance,” *Energy Procedia*, vol. 141, pp. 383–388, 2017.

[7] F. Castellani, D. Astolfi, M. Peppoloni, F. Natili, D. Buttà, and A. Hirschl, “Experimental vibration analysis of a small scale vertical wind energy system for residential use,” *Machines*, vol. 7, no. 2, p. 35, 2019.

[8] R. Usubamatov, A. Y. Qasim, and Z. M. Zain, “New Vane-Type Wind Turbine of High Efficiency,” *Pertanika J. Sci. & Technol*, vol. 20, no. 1, pp. 175–188, 2012.

[9] S. A. Burtsev and A. S. Komshin, “Challenges in development of wind energy in Russia,” in *2019 International conference on industrial engineering, applications and manufacturing (ICIEAM)*, IEEE, 2019, pp. 1–5.

[10] D. I. Muravyev, B. V Lukutin, and E. S. Daminova, “Stand-alone power supply DC system with distributed photo-diesel source,” in *AIP Conference Proceedings*, AIP Publishing LLC, 2019, p. 020040.

[11] N. Y. H. Ccallo and O. Chamorro-Atalaya, “Analysis of the Asynchronous Motor Controlled by Frequency Inverter Applied to Fatigue Test System,” *International Journal of Advanced Computer Science and Applications*, vol. 12, no. 10, 2021.

[12] N. Koshkin, *Handbook of elementary physics*. Mir publishers, 1968.

[13] Greg Whitburn, “How does wind energy work?”, Accessed: Apr. 05, 2023. [Online]. Available: https://exploringgreentechnology.com/wind-energy/how-does-wind-energy-work/

[14] Andreea-Adriana Laczko, “Brushless DC permanent magnet micro-wind generator modeling and optimization over long-term wind-speed cycle operation,” 2016.

[15] B. Wu, Y. Lang, N. Zargari, and S. Kouro, *Power conversion and control of wind energy systems*. John Wiley & Sons, 2011.

[16] H. Li and Z. Chen, “Overview of different wind generator systems and their comparisons,” *IET Renewable Power Generation*, vol. 2, no. 2, pp. 123–138, 2008.

[17] V. Yaramasu, B. Wu, P. C. Sen, S. Kouro, and M. Narimani, “High-power wind energy conversion systems: State-of-the-art and emerging technologies,” *Proceedings of the IEEE*, vol. 103, no. 5, pp. 740–788, 2015.

[18] Administrator, “Introduction to Brushless DC Motors (BLDC Motor),” Sep. 2010, Accessed: Apr. 05, 2023. [Online]. Available: https://www.electronicshub.org/brushless-dc-motor-bldc-motor/

[19] İ. Tarımer and C. Ocak, "Performance comparision of internal and external rotor structured wind generators mounted from same permanent magnets on same geometry," 2009.

[20] S. Z. Vijlee, A. Ouroua, L. N. Domaschk, and J. H. Beno, "Directly-coupled gas turbine permanent magnet generator sets for prime power generation on board electric ships," in *2007 IEEE Electric Ship Technologies Symposium*, IEEE, 2007, pp. 340–347.

[21] I. Schiemenz and M. Stiebler, "Control of a permanent magnet synchronous generator used in a variable speed wind energy system," in *IEMDC 2001. IEEE International Electric Machines and Drives Conference (Cat. No. 01EX485)*, IEEE, 2001, pp. 872–877.

[22] A. S. Nagorny, N. V Dravid, R. H. Jansen, and B. H. Kenny, "Design aspects of a high speed permanent magnet synchronous motor/generator for flywheel applications," in *IEEE International Conference on Electric Machines and Drives, 2005.*, IEEE, 2005, pp. 635–641.

[23] M. Yin, G. Li, M. Zhou, and C. Zhao, "Modeling of the wind turbine with a permanent magnet synchronous generator for integration," in *2007 IEEE Power Engineering Society General Meeting*, IEEE, 2007, pp. 1–6.

[24] S. R. Shankapal, P. Mallya, J. Shivkumar, and N. Venkateswaran, "design Analysis of Brushless direct current Generator," *Def Sci J*, vol. 67, no. 4, p. 437, 2017.

[25] B. Singh and S. Sharma, "PMBLDCG based stand-alone wind energy conversion system for small scale applications," *International Journal of Engineering, Science and Technology*, vol. 4, no. 1, pp. 65–73, 2012.

[26] P. V. Yankov, A. Van den Bossche, and V. C. Valchev, "Successive resistive braking circuit for permanent magnet wind turbine generators," in *Proceedings of 14th International Power Electronics and Motion Control Conference EPE-PEMC 2010*, IEEE, 2010, pp. T11-27.

[27] M. R. Sarkar, S. Julai, C. W. Tong, O. Z. Chao, and M. Rahman, “Mathematical modelling and simulation of induction generator based wind turbine in MATLAB/SIMULINK,” *power*, vol. 2, p. 7, 2006.

[28] V. Behjat and M. Hamrahi, “Dynamic modeling and performance evaluation of axial flux PMSG based wind turbine system with MPPT control,” *Ain Shams Engineering Journal*, vol. 5, no. 4, pp. 1157–1166, 2014.

[29] D. Vizireanu, S. Brisset, P. Brochet, Y. Milet, and D. Laloy, “Investigation on Brushless DC Appropriateness to Direct-Drive Generator Wind Turbine,” *Cedex, France*, 2005.

[30] V. Sheeja, P. Jayaprakash, B. Singh, and R. Uma, “Stand alone wind power generating system employing permanent magnet synchronous generator,” in *2008 IEEE International Conference on Sustainable Energy Technologies*, IEEE, 2008, pp. 616–621.

[31] M. M. Hussein, T. Senjyu, M. Orabi, M. A. A. Wahab, and M. M. Hamada, “Control of a stand-alone variable speed wind energy supply system,” *Applied Sciences*, vol. 3, no. 2, pp. 437–456, 2013.

[32] H. Sharma, S. Islam, C. V Nayar, and T. Pryor, “Dynamic response of a remote area power system to fluctuating wind speed,” in *2000 IEEE Power Engineering Society Winter Meeting. Conference Proceedings (Cat. No. 00CH37077)*, IEEE, 2000, pp. 499–504.

[33] A. M. El-Zafry, O. E. A. El-Hameed, M. S. Hassan, and M. M. Shaheen, “A review on the types of vertical axis wind turbines and the methods of their performance study,” *J Multidiscipl Eng Sci Technol*, vol. 6, no. 9, pp. 10633–10643, 2019.

[34] M. Zulqarnain, D. Xu, and B. Yuwen, “Multi modular converters with automatic interleaving for synchronous generator based wind energy system,” in *Proceedings of The 7th International Power Electronics and Motion Control Conference*, IEEE, 2012, pp. 2255–2261.

[35] M. M. Hussein, T. Senjyu, M. Orabi, M. A. A. Wahab, and M. M. Hamada, “Load power management control for a stand alone wind energy system based on the state of charge of the battery,” in *2012 IEEE International Conference on Power and Energy (PECon)*, IEEE, 2012, pp. 93–98.

[36] S. Sharma and B. Singh, “Permanent magnet brushless DC generator based stand-alone wind energy conversion system,” in *2013 4th IEEE International Symposium on Power Electronics for Distributed Generation Systems (PEDG)*, IEEE, 2013, pp. 1–6.

[37] Z. Chen, Z. Chen, and X. Liu, “A 2MW 6-phase BLDC generator developed from a PM synchronous generator for wind energy application,” in *2014 IEEE International Conference on Industrial Technology (ICIT)*, IEEE, 2014, pp. 110–114.

[38] J. I. Yoo, J. Kim, and J.-W. Park, “Converter control of PMSG wind turbine system for inertia-free stand-alone microgrid,” in *2016 IEEE Industry Applications Society Annual Meeting*, IEEE, 2016, pp. 1–8.

[39] A. A. Laczko, M. V Zaharia, M. M. Radulescu, and S. Brisset, “Modeling and simulation of a brushless DC permanent-magnet generator-based wind energy conversion system,” in *2015 Tenth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, IEEE, 2015, pp. 1–7.

[40] K. Prechanon, “Mathematical model of the PMSG based on wind energy conversion system,” *Int. Res. J. Innov. Eng*, vol. 1, no. 3, pp. 2395–2560, 2015.

[41] A. M. Abdulelah, B. Ouahid, and S. Youcef, “Control of a Stand-Alone Variable Speed Wind Turbine with a Permanent Magnet Synchronous Generator,” in *2021 18th International Multi-Conference on Systems, Signals & Devices (SSD)*, IEEE, 2021, pp. 546–550.

[42] A. Junyent-Ferré and O. Gomis-Bellmunt, “Wind turbine generation systems modeling for integration in power systems,” in *Handbook of renewable energy technology*, World Scientific, 2011, pp. 53–68.

[43] K. Ishibashi and H. Yamada, “Modular Multilevel Converter based Single-Phase Grid-Tied Wind Power Generation System With Multiple Wind Power Generators Under Different Wind Speeds,” in *2020 23rd International Conference on Electrical Machines and Systems (ICEMS)*, IEEE, 2020, pp. 1017–1021.

[44] Y. Ando, N. Yamamura, and M. Ishida, “Maximum Power Point Tracking Control Method for the Small Wind Power Generation System Corresponding to Wind Speed Variation,” in *2020 23rd International Conference on Electrical Machines and Systems (ICEMS)*, IEEE, 2020, pp. 1008–1011.

[45] J. Vaheeshan, V. Vihirthanath, S. G. Abeyaratne, A. Atputharajah, and G. Ramatharan, “Wind turbine emulator,” in *2011 6th International Conference on Industrial and Information Systems*, IEEE, 2011, pp. 511–516.

[46] L.-D. Dănuţ, D. Hulea, O. Cornea, N. Muntean, M. A. Iuoras, and N. Hinov, “Low Cost Implementation of a Wind Turbine Emulator,” in *2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*, IEEE, 2020, pp. 1–6.

[47] V. T. Ha, V. H. Phuong, N. T. Lam, and N. P. Quang, “A dead-beat current controller based wind turbine emulator,” in *2017 International Conference on System Science and Engineering (ICSSE)*, IEEE, 2017, pp. 169–174.

[48] A. K. R. Sombra, D. Sgrò, R. P. S. Leao, R. F. Sampaio, and F. C. Sampaio, “Modeling and simulation of an emulator of a wind turbine using vector speed control of a three-phase induction motor,” in *2018 Simposio Brasileiro de Sistemas Eletricos (SBSE)*, IEEE, 2018, pp. 1–6.

[49] E. Mousarezaee, A. Polat, and L. T. Ergene, “Wind turbine emulator based on small-scale PMSG by fuzzy FOC,” in *2020 21st international symposium on electrical apparatus & technologies (SIELA)*, IEEE, 2020, pp. 1–4.

[50] A. Mahdy, S. M. El-Hakim, and H. H. Hanafy, “Small wind turbine emulator with separately excited DC motor using analog electronic circuit,” 2011.

[51] S. Tammaruckwattana and K. Ohyama, “Experimental verification of variable speed wind power generation system using permanent magnet synchronous generator by wind turbine emulator,” in *IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society*, IEEE, 2012, pp. 5827–5832.

[52] S. Tammaruckwattana, “Modeling and simulation of wind power generation system using diode bridge rectification circuit for converter,” in *2015 15th International Conference on Control, Automation and Systems (ICCAS)*, IEEE, 2015, pp. 132–137.

[53] R. Lanzafame and M. Messina, “Horizontal axis wind turbine working at maximum power coefficient continuously,” *Renew Energy*, vol. 35, no. 1, pp. 301–306, 2010.

[54] V. Suresh, G. Emayavaramban, A. Amudha, K. Balachander, and D. Kavitha, “Modeling, design and implementation of a power conversion system for WECS by using fuzzy based MPPT.,” *Mathematical & Computational Forestry & Natural Resource Sciences*, vol. 11, no. 1, 2019.

[55] D. V Samokhvalov, A. I. Jaber, D. M. Filippov, A. N. Kazak, and M. S. Hasan, “Research of maximum power point tracking control for wind generator,” in *2020 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (EIConRus)*, IEEE, 2020, pp. 1301–1305.

[56] A. I. Jaber, D. V Samokhvalov, F. S. Al-Mahturi, D. M. Filippov, and A. N. Kazak, “Power Losses Calculation in Wind Power Plant based on a Vector-Controlled Permanent Magnet Synchronous Generator,” in *2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering (ElConRus)*, IEEE, 2021, pp. 917–921.

[57] J. G. Slootweg, H. Polinder, and W. L. Kling, “Representing wind turbine electrical generating systems in fundamental frequency simulations,” *IEEE Transactions on energy conversion*, vol. 18, no. 4, pp. 516–524, 2003.

[58] D. V Samokhvalov, A. I. Jaber, and F. S. Almahturi, “Maximum power point tracking of a wind-energy conversion system by vector control of a permanent

magnet synchronous generator," *Russian Electrical Engineering*, vol. 92, no. 3, pp. 163–168, 2021.

[59] D. V Samokhvalov and A. I. Jaber, "Estimation of the Maximum Efficiency and Mechanical Performance Output from Wind Turbine," in *2019 XXII International Conference on Soft Computing and Measurements (SCM))*, IEEE, 2019, pp. 81–84.

[60] D. Vizireanu, S. Brisset, P. Brochet, Y. Milet, and D. Laloy, "Investigation on Brushless DC Appropriateness to Direct-Drive Generator Wind Turbine," *Cedex, France*, 2005.

[61] S. KAZRAJI, S. KHANABDAL, M. HOLAKOOIE, and M. B. SHARIFIAN, "A PERMANENT MAGNET SYNCHRONOUS WIND GENERATOR FOR VEHICULAR APPLICATION," *IU-Journal of Electrical & Electronics Engineering*, vol. 14, no. 1, pp. 1745–1753.

[62] A. Carlsson, "The back-to-back converter," *Lund: Department of Industrial Electrical Engineering and Automation Lund Institute of Technology*, vol. 7, pp. 1002–1016, 1998.