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MPPT control for Wind Turbines with Battery Storage system

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Nibras Hazim Abbas

DEDICATION

I would like to dedicate this work to my teacher, my mother, my supporter role model, my father and my companion throughout journey. Without you, this dream would never come true and to my brother and my sister who stood with me in achieve my dream.

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MPPT control for Wind Turbines with Battery Storage system

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ABSTRACT

In wind energy conversation systems (WECS), power quality and energy conversion efficiency are crucial aims of control algorithms. These two points are self-contradictory and difficult to trade off where enhancing the efficiency of conversion may also enhance instability of output signal as well. In current work, we develop a wind turbines control scheme to ensure regular power and achieve variable load requests in Battery based variable speed Permanent Magnet Generators PMGs system. In the submitted scheme, Model Predictive Control (MPC) is joint with Fuzzy logic to achieve the advantages of these two diverse approaches. The suggested controller could enhance the power reliability performance of the wind turbine. According to obtained results, the proposed topology overcomes the traditional PI model by achieving profits in the context of step-overshoot response and the measure of total harmonic-distortion of nearly 1.1% and 1.13%, respectively.

Keywords: Perturb & Observing, Cost Function, Fuzzy Logic, Battery Storage, Model Predictive Control

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LIST OF ABBREVIATIONS

MPC : Model Predictive Controller.

FLC : Fuzzy Logic Controller.

PI : Proportional Integrator.

WT : Wind Turbine.

BESS : Battery energy-storage system .

MPPT : Maximum Power Point Tracking .

WECS : wind energy conversation systems.

THD : Total Harmonic Distortion.

BA : Blade Angle.

DFIG : Doubly Fed Induction Generator.

HAWT : Horizontal Axis Wind Turbine.

VAWT : Variable Axis Wind Turbine.

DC : Direct Current.

MW : Megawatt.

β : Pitch angle of WT rotor blades.

θ : Phase angle of space vector.

ρ : Air density.

FSFP : Fixed Speed _ Fixed Pitch.

PMGs: Permanent Magnet Generators

FSVP : Fixed Speed_ Variable Pitch.

VSFP : Variable Speed_ Fixed Pitch.

VSVP : Variable Speed_ Variable Pitch.

R : Rotor Blade Radius.

V_{DC} : ratio rectifier output voltage.

V_g : Voltage Phase.

P : Positive.

D : Ratio Duty Cycle.

N : Negative.

Z : Zero.

AC : Alternating Current.

MI : Multi Input.

MO : Multi Output.

GSC : Grid Side Converter.

HRES : Hybrid Renewable Energy Source.

1. Introduction

1.1 General Background

Wind turbine (WT) is a device that is able to use wind energy to convert it into mechanical power. From this process, it encourages various human activities, such as pumping water to irrigate rice fields or grinding grains, which require large quantities of energy. Modern windmills, also called wind turbines, are devices used to generate electrical energy. (WT) are mostly found in Europe and North America [1].

At the beginning of the industrial revolution, the stages of the development of the electrical plant, in terms of the timing of replacing and using unstable wind energy due to a decrease in the output of electricity as well as the oscillating exchange of fossil fuels were even for the launch of machines to produce electrical energy equipment, which provided an adjustable, more consistent power source at a price similar to acceptable and high efficiency.

Fossil fuel sources cover large quantities at a rate of about (80%) of energy absorption in the world as well as depletion of them at a faster rate than can be renewed. In general, in terms of fossil fuel consumption it has an impact on the atmosphere in terms of and the Earth's surface such as significant climate change and global warming, which is associated with the release of large quantities of tons of carbon dioxide (co_2) each year. Because it causes pollution on the ground and affects people, animals and plants, and very high fuel cost in generation.

To overcome this problem that the solution is to use, the more reliable Renewable energy is better in terms of work. There is no environmental pollution and Cost-effective is very less like the wind energy that was applied in the developed countries and it was traded commercially in many developing countries. Production in terms of high efficiency with higher advantages, less maintenance of renewable energy, has increased rapidly over the past decade, worries about restricted fossil resources, and related bio problems.

Increasing the very rapid evolution of wind power production in the electric power store, many issues increase regarding the stability of the system in environmental security or ease of maintenance and operation in terms of developing protection and control devices in the electric wind energy system as well as the stability of voltage and frequency. Nowadays, important symbols of the grid may be a critical point for its acquisition in many provinces that contain large-scale (WT) connected to the grid, that operate immediately in wide scale fields of turbine [2]. The request for green resources has increased in the world through (2014), and then provided an estimated value of (19.2%), which was a good percentage of overworld consuming of energy [3]. Different classes are used with various kind of generators with several figures of merit and disadvantages in performance, work and maintenance. By using modern devices such as controlling with high accuracy, reducing the error rate, frequency is constant, and voltages, the stability of commercial electric electronics in the design of (WT) since the start of the grid, in terms of changes in technology in a large range over the past six decades [4].

Recently, there are different applications of wind generators, as well as electronic energy devices in the case of wind turbines, as well as control units so that the system will be in a state when it will decide when the wind speed varies. In order to obtain a high efficiency to improve the system to convert wind energy also raise the rank of the introduced network energy. The wind energy transformer and the power controlling procedure are critical to the Operation of the Variable Speed (WT)

In practical, widely employed turbine systems apply electric machines with permanent magnetic (synchronous machinery) because of several figures of merit like the obtaining of very high wind energy density, higher production efficiency, higher performance reliability, low cost in maintenance as well as operation at a little speed of rotation [6]. Moreover, there is a big variety in terms of controlling the produced power, Voltage, Current and Frequency in all parts of system.

In general, there are many ways to control different variables such as the voltage and current of the generator, also in the Blade Angle (BA) of the wind turbine (WT), the (DC) Current Voltage, and grid side variables such as frequency, active and reactive energy in addition to the output voltage and currents injected into the grid. Various kind and technologies have been used to fulfill the requirements of control approaches and to achieve them in real world using appropriate hardware equipment [5].

Moreover, classical high-level controlling technologies were used as well as the use of modern simple equipment and devices in small-scale generators covering many homes. Such techniques have a accepted efficiency when we have fluctuated speed of wind, and continuous assuming linear scheme parameters. In terms to discussing many issues' in research instead of practice such as change of (WT) rotation, the system non linearity, scheme behavior through malfunctions or impairment, and major issues of the grid, system stability analysis, as well as voltage and frequency stability [7].

The running of the plan under steady frequency as well as voltage is a key in order not to have an effect on the grid side. We use a smart scheme like the Fuzzy Logic Control, dented by (FLC), in integration with another control system, which is a Model Predictive Controller (MPC) in terms of capturing the best advantages of these two change methods. Through the use of the proposed control (F_MPC) with the traditional comparison model (PI) improvement in work and energy reliability performance of wind turbines, simulation results provide that to obtain good results by reducing (over shoot) and frequency deviation (FD) and total harmonic distortion (THD).

1.1.1. Advantages and Disadvantages Of Wind Energy

Wind energy has many advantages for offer which explains why wind energy has the fastest growth of all the energy sources. Though there are many advantages there are also lot of challenges that it has to overcome. The advantages of wind energy are as follows [10]:

- Renewable and sustainable: The (WT) itself is renewable and we never run out of wind unlike fossil fuel, so the price of wind energy does not fluctuate as much as the fossil fuels making it an ideal sustainable power source.
- Eco_ friendly: wind energy is considered one of most environmental friendly energy source. There is very little to emission of harmful substances or greenhouse gases into atmosphere or the surrounding environment after the manufacturing and installation of the (WT). Though there is noise pollution but it considered as environmental effect but there is no negative effect on the earth. Water or the air we breathe.
- Wind energy is cheap: We can never run out of wind so there is an uninterrupted supply of wind and it only costs us for wind turbine, the site for the turbine and maintenance which is very less compared to the uninterrupted supply of the power we can tap from the wind energy. At times wind energy was sold at price as low as 2.5 cents/KWH.

- Remote Power Solution: For the remote areas we do not need to generate energy elsewhere and transmit energy to remote areas form there through the lines.
- Job creation: wind energy industry has boomed ever since the wind turbines are available on the market. This has helped create jobs all over the world. There are many job created for manufacturing, maintained and installing the wind turbine and also in wind energy consulting, where specialist consultant will help in determining a wind turbine installment will generate a return on investment.

The challenges that the wind energy is facing are clearly outweighed by the advantages but let's just have a look at the challenges:

- Wind is Intermittent: The wind does not always blow in the same way at any location. This is a serious problem for wind turbine developers who often invest a lot of time and money investigating whether a site is suitable for wind generation. That's why we often see wind turbines built on top of hills at the sea where there is no is obstruction by land masses.
- Manufacturing and Installation is very expensive: Although costs of designing, producing, and installation of a turbine is costing a lot, site survey need to be conducted at multiple locations for a significant amount of time and if deemed adequate the cost of laying foundation, transporting a huge turbine and erecting it at the site, the overall cost is huge. If it is an off_ shore wind turbine the cost for installing it is even higher.
- Threat to Wind Life: There have been many cases in Europe where a lot of birds and bats die. However, the threat due to the wind turbine is much less compared to the cell towers and radio towers and radio towers. Nevertheless, (WT) are contributing to the mortality rate of birds or bats population.
- Noise and Visual Pollution: There is loads of noise when the wind turbine is operating, which is around 45 dB if the turbine is a mile away, then the noise effect is negligible. Also the wind turbines when erected upon a hill the scenery might not always look nice.
- Radar Noise: When the wind turbine is installed near an air force or military base. The noise due to the turbine creates an interference due to which radar tracking becomes less efficient.

1.1.2 Wind Energy Developments

The wind energy is fastest growing in the energy sources because a lot of nations are their governments are investing in the wind energy a lot earth and every year. It is understandable why wind energy is growing at an enormous rate looking at the advantages stated earlier in this chapter. The recent statistics of new installations and the cumulative wind energy after Dec 2015 installed across the world can be seen in the graphs as shown in figures 1.1 and 1.2 and table 1.1 [8]:

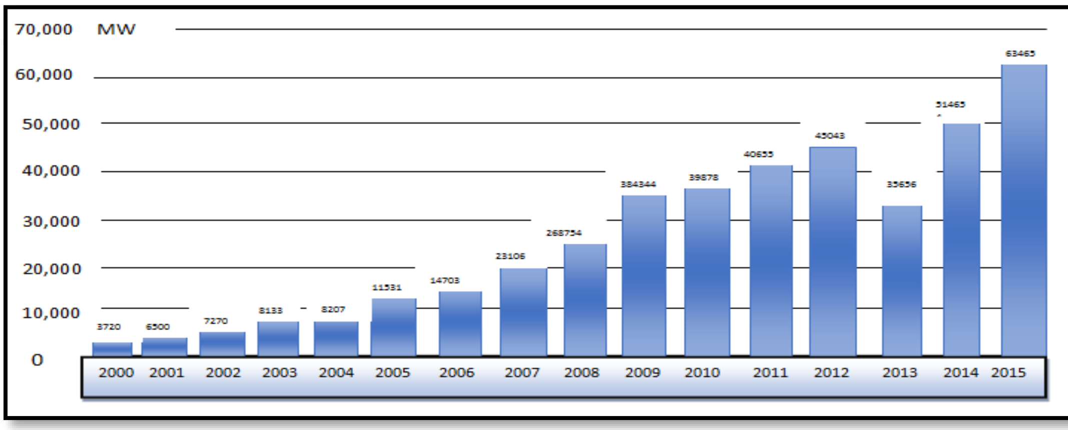

Figure 1.1: Global Annual Installed Wind Capacity 2000_2015 [8].

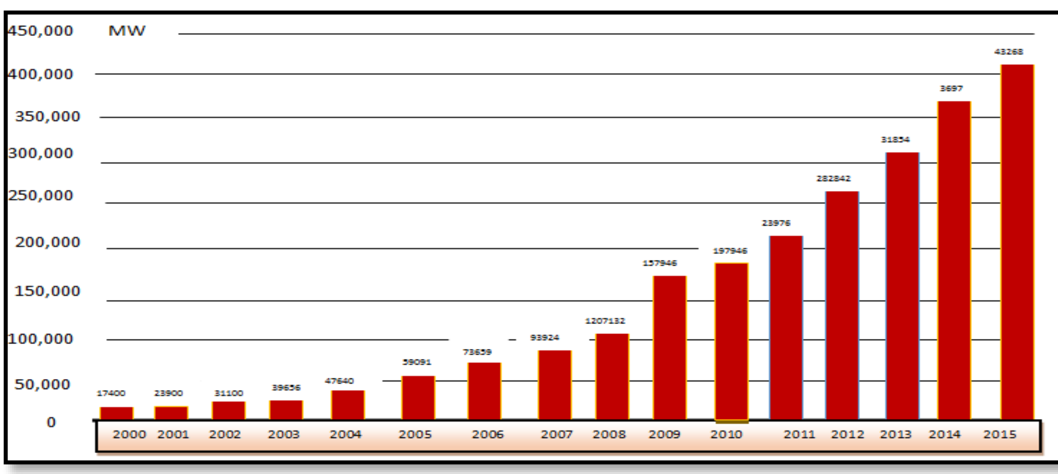

Figure 1.2: Global Cumulative Installed Wind Capacity 2000_2015 [8]

Figure 1.2 shows the cumulative wind energy generated across the world and the country wise share of the wind energy production can be seen in the pie chart shown in figure 1.3, by the end of the year 2015. In the pie chart of figure 1.3, from the overall wind energy of 432,883MW, each country share is as shown in table 1.1.

Table 1.1: Wind Energy in each Country 2015 [8].

Wind Energy Each Country	Values (WM)
PR China	33.61 %
USA	17.23 %
Germany	10.44 %
India	5.81 %
Spain	5.34 %
United Kingdom	3.17 %
Canada	2.65 %
Italy	2.12 %
Brazil	2 %
Rest of the world	15.5 %

In the recent years where since 2011 a lot of money has been invested in wind energy production by China where the energy is booming.

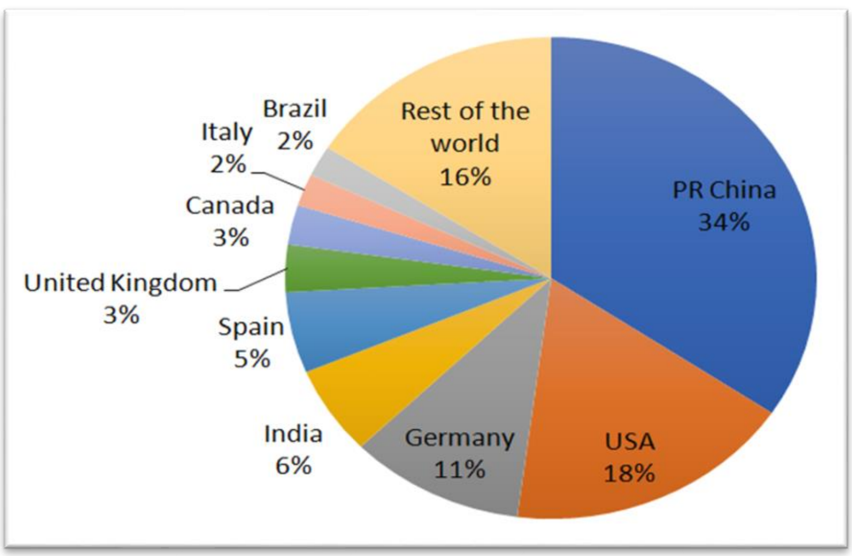

Figure 1.3: Cumulative capacity by country 2015 [8].

The growth in United States has been steady, and USA aims to reach a target of (20 %) wind energy of total power needs by the end of (2025) which is currently (3.6 %) of the total power requirements. Also there have been a lot of developments to the design of (WT). There are so many new models of wind turbines that have been invented to improve the effeciency of the (WT) and there is still a lot of researches still going on.

1.2 Basic principle of operation and control of the (WECS).

The overall details of the operation and concepts of the WECS is illustrated by discussing the basic component of the grid applied WECS scheme through the use of Mechanical and electrical parts and control as shown in the figure 1.4.

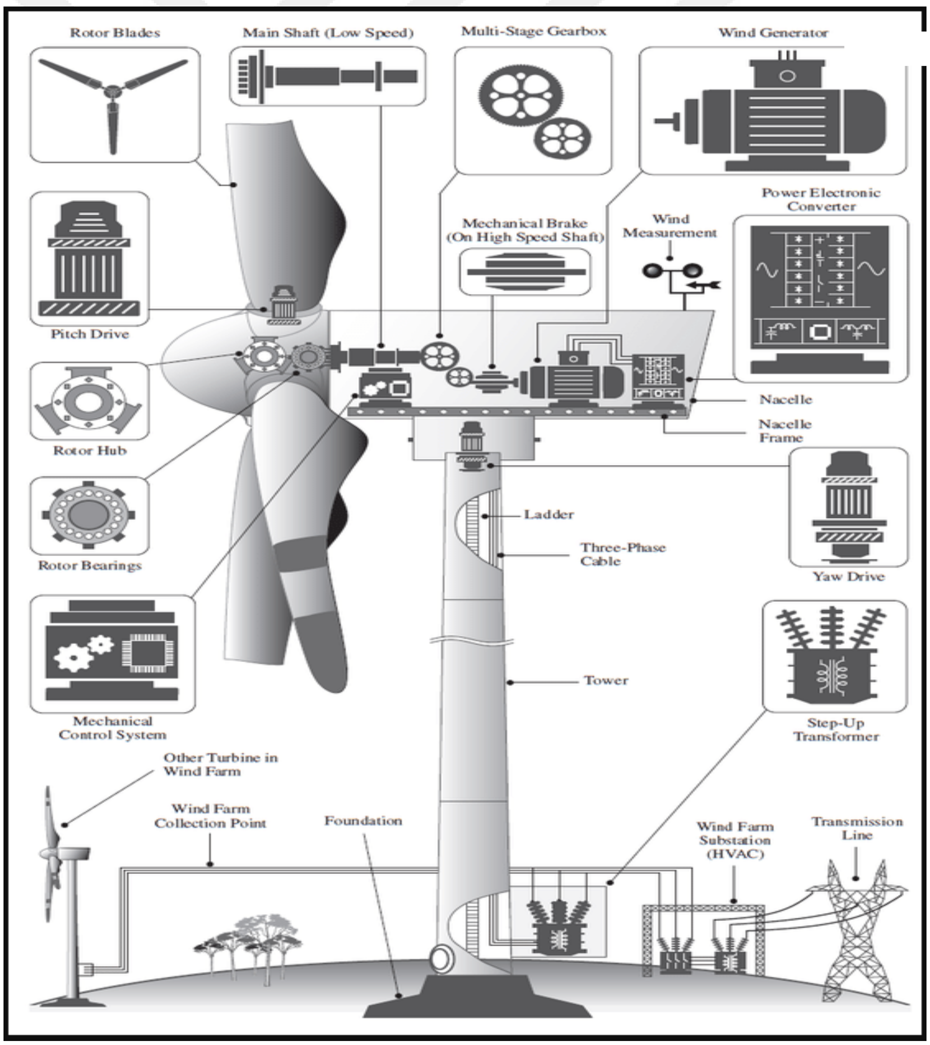

Figure 1.4: Parts Of a Wind Turbine [9].

1.2.1 Different Subsystems Of (WECS)

There are various physical parts in the wind turbine; they are organized as different sub-systems which are inter_ connected to each other to complete the (WECS). They are divided into subsystems wind respect to energy conversion flow [9]. The different subsystem in the WECS are as follows as shown in the figure 1.4 aerodynamic sub-system:

1. Aerodynamic Sub_ System: It is used to transform the active energy of the wind into mechanical energy. This sub_ system consists of blades. Hob and pitching devices used to change the alignment of the blades. When the wind cuts though the blades surface of the turbine it creates a lift force. Due to which the blades connected to the hob start rotating the rotor in the hob. The pitching devices are used to adjust the amount of lift force that acts upon the blades, so that the speed of rotor can be varied, in this manner the rotor speed is controlled through the pitching system. The rotor in the hub is connected on the drive Train sub_ system delivering the Mechanical Torque Generated (MTG) from the kinetic energy on the Wind.
2. Drive -Train Sub_ System: It is like a transmission system which takes energy provided by the aerodynamic system and modifies it as the needs of the generator. The drive train sub_ system has a gear mechanism which converts the high torque low speed provided by the aerodynamic sub_ system into low torque high speed to the generator which is required by the generator.
3. Generator: Is an electromechanical transducer which transfer the mechanical energy into electric energy. The power output from the (WT) mainly depends on the generator. So, generator is one of the most impotent components of the (WT). There are many different kinds of generators like squirrel cage indention generator. Doubly Fed Induction Generator (DFIG). And permanent magnet induction generator (PFIG). depending on the design the power generated by generators can be flow to the consumers directly.
4. Other subsystem: Other than the above mentioned three sub_ systems, there might be many other important sub_ system like the control system block which guide how to change the settings of the pitch system and direction of the facing of turbine etc. yaw (using to change the direction of the rotor). Brakes wind vane (to know the direction of the wind) tower etc.

1.2.2 **Different types of (WECS)**

(WECS) have been improved a lot from the past century and now there are many different types of WECS that exist today. A lot of advancements have been made in the design and performance of the (WECS). Starting from the small and simple to large and complex with respect to the size, efficiency, power generated and control system. There are many different classifications of WECS [11] that exist today. The classification may based on the location of the turbine, connectivity, and many more types of classifications.

1. Depending on wind rotor axis [14] there are two different types of (WT) as shown in figure 1.5:

- Horizontal axis wind turbine (HAWT): Through the rotation of the axis to the rotor horizontally with respect to the ground and is a common condition in the use of electricity generation with ease and simpler in the (WT) generator at the top of the tower, it must be pointed to the wind. The small turbine is indicated by a simple square wind vine with a rotor (blades). Through the large size turbines generally use the presence of a wind sensor along with a servo motor to convert the turbine to the wind. Since the zodiac results in turbulence behind it. The turbines are usually directed against the tower.
- VAWT wind turbine: Vertically through the main rotor shaft. The main adveantage of this arrangement in terms of (WT) these types do not need to indicate the wind. This is an advance on sites where the direction of the wind is highly variable or has turbulent winds. With vertical axis, alternator and other primary components.

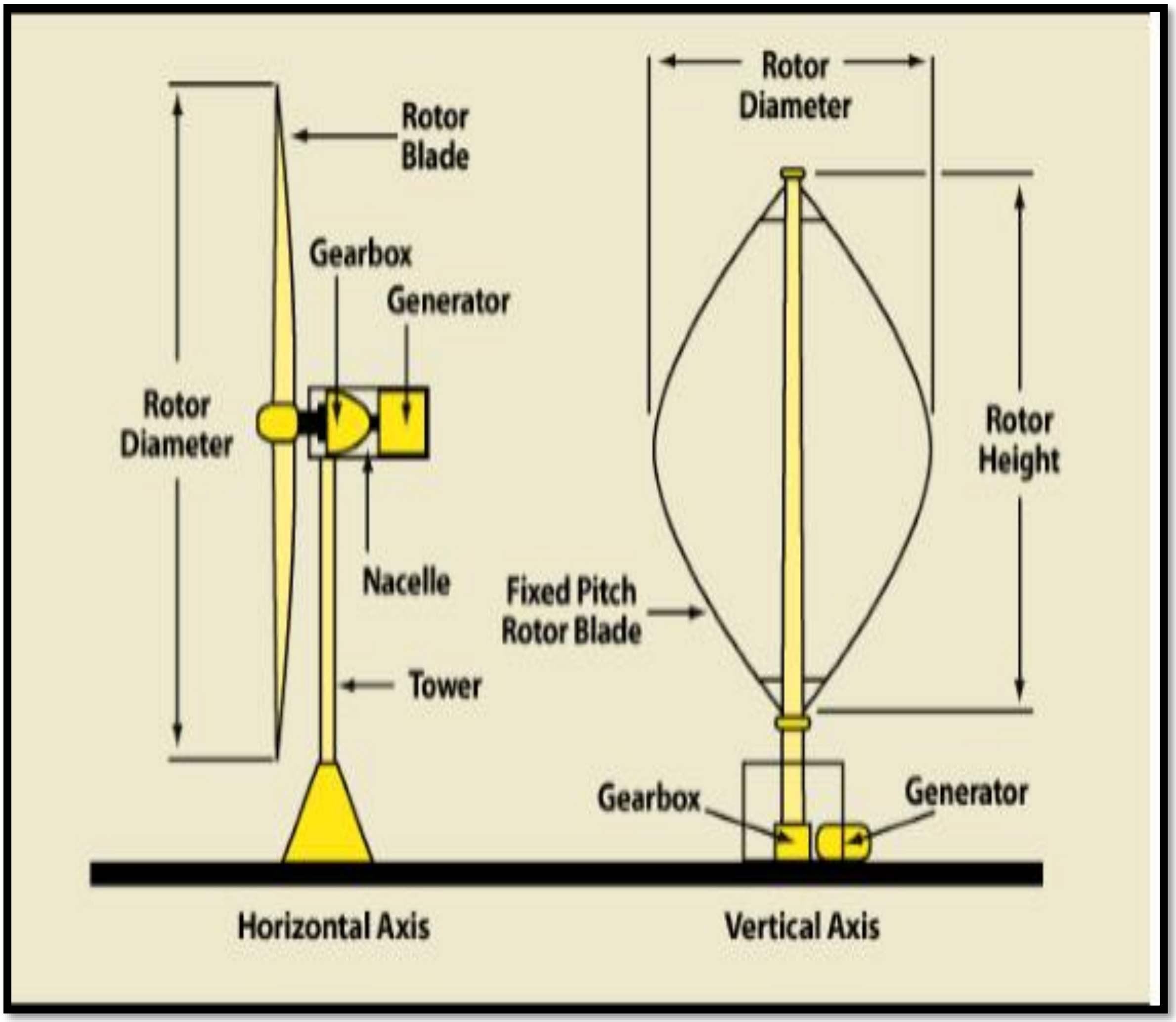

Figure 1.5 : The HAWT and VAWT [11].

2. Depending on the location there are two different types of the (WT):
   - On_ shore wind turbines: on-shore (WTs) are land-based wind turbines which are set up on land, which consume a huge land area and It causes a great deal of noise pollution, visual pollution and bird harm [11]. There are, however, also several coastal advantages of onshore (WT) control that influence the environment by extension. Onshore (WT) also has the advantage of being near to existing electric grids, reducing the environmental effects associated with the development of new electric grids.
3. Off_ shore wind turbine (WT): Off_ shore (WT) installed right off the coast or little further away from the coasts in sea. The advantages are huge as it does not require any

land resources and there will be no noise pollution or environmental effect to the birds. Wind turbine are from where the pads are placed through concrete located extending for the undermost to the sea water, and move to the sea water using floating platforms, these increase the high costs through materials that are additional to it and for the installation of the dedicated electricity grid (EG). The short payback period is one of the most significant environmental aspects of wind power. The payback time is (0.39) years for a (40.5 m) (WT) based on a (40 percent) projected high performance, less than (2 percent) of the (20) year life cycle of an offshore wind farm [11]. There are two types of wind farms with respect to their connectivity:

- Standalone wind farms: Power through the power grid is not available in some rural and isolated regions, in such cases the power to places like those are provided by wind turbine, farms or hybrid system. Their power is only limited to the local grid.
- Grid connected wind farms: To diversify the power sources and to get cheaper electric power; wind farms are integrated to the existing power grid. This kind of installation is more dominant these days.

4. There are four different types of (WT) depending on the control point of view: Using the fundamental control techniques. Either the speed can be controller or the output power generated by the turbine can be controlled. Depending on the design of the generator and wind turbine, the speed can be controlled by two methods, which namely; (Fixed_ Speed) and (Variable_ Speed). Speed control can be used to maximize the power conversion by control the aerodynamic efficiency to control the converted power, when the wind speed is large and above the rated capacity of the (WT). Controlling the aerodynamic efficiency can be achieved by controlling the orientation of the pitch angle of the blades of turbine, so that the effect of the wind on the blades can vary, this type of control is called active power control or variable_ pitch power control. There is also a simpler way called passive or fixed_ pitch power control, which is implemented by special design of blades such that they can be stalled at high wind speed to reduce the aerodynamic effect. However, the fixed_ pitch technique has a drawback that it produces an immense stress on the wind turbine which might reduce the life time of a turbine and increasing the maintenance costs of it. Now by combining both the control technologies together; four different types of wind turbine can be designed:

- Fixed speed fixed pitch wind turbine (FSFP).
- Variable speed fixed pitch wind turbine (VSFP).
- Fixed speed variable pitch (FSVP)wind turbine (FSVP).
- Variable speed variable pitch wind turbine (VSVP).

1.2.3 Categories of WECS plants

Different types of (WT) generators that could be used in the power system applications to the past decade. These kinds are classified into four types that are described in the following sections [12] and [13]. There are various types of (WT) generators currently in use and it is categorized with regards to the types of their components and the converted energy [14].

Type1: Fixed Rotation Speed WTs

Fig.1.6 predicts an example of such type with induction machine, which is the simplest type in (WECS) without power converter interface. As shown in the in the figure, the configuration step up transformer and starting device are employed for grid connection [15]. This method is the legacy approach that represents the wind turbine scheme. In large power plant of WECS, the unpretentious kinds of SCIG, i.e., Squirrel-cage induction generator includes of 6 or 4 poles to achieve better operation at 60 or 50 Hz operating frequency.

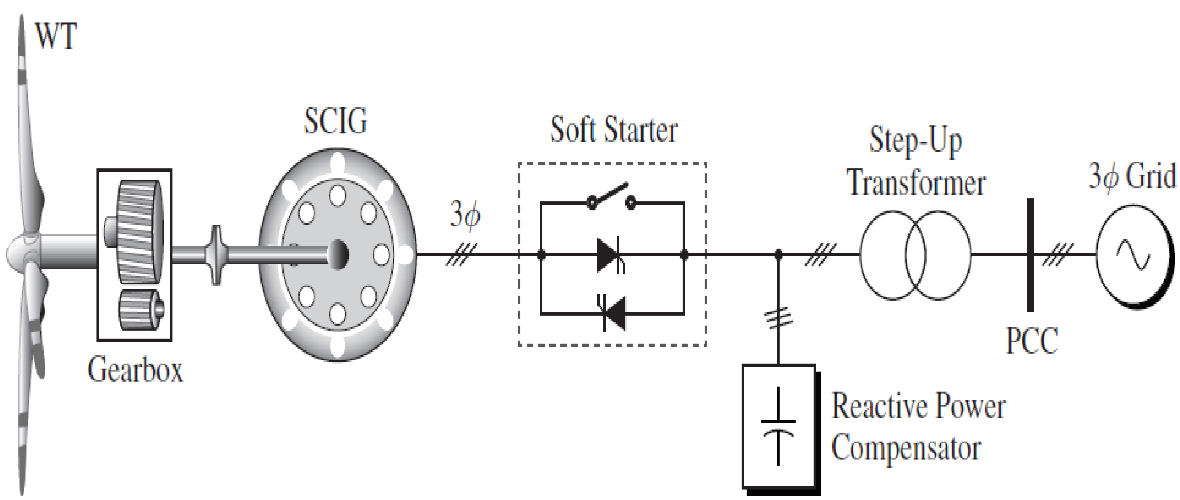

Figure 1.6 : The schematic diagram of WECS employing SCIG [15].

The different in the speed of rotation of the machine, is sometimes restricted to a value of approximately (1%) of speed values of WT (with changes of wind speed values). Consequently, this kind of energy conversion systems is defined as fixed_ speed system [15]. Specifically, the speed error between the (WT) and the generator can be balanced using a gearbox. After starting with a switch, the starter device can be bypassed, where the system operates effectively without the converter device being needed. This extracts a valuable amount of reactive electricity from the grid. kind of generator configuration. Usually, three-phase capacitor banks act as a compensator system to remedy this condition. The benefits of this type are:

- Very simple setup, high reliability and high accuracy
- Lower efficiency than any other type of energy conversion.
- A change in wind speed or some turbulence will transfer to the side grid
- Any disturbances in the grid side will affect the WT side equipment.

This WECS configuration is operated with auxiliary equipment, such as the STATCOM i.e., static compensator, in order to increase the efficiency of the activity and eventually meet the requirements of the grid code [14].

Type 2: WTs with Variable Rotor speed

Application of the mutable speed of WT machine arrangement, will raise the efficiency and improve it's work and reduce the losses of the conversion process, as well as reduce the disturbances that present in the mechanical parts, which affected by wind storms with different speeds, that will affect the system in terms of the nedd to use of some speed control, and finally reduce friction The bearing is present in maintenance, which ultimately increases the life of the wind turbine (WT) at all. Also uses wind energy for the semi-mutable speed of the wound rotor kind (IG) and a partially reaches about (10%) of the wind energy conversion estimated in figure (1.7). In terms of Variable Rotor speed, it employs the concept of the resistance of the rotor, which influences torque, generator rotation, and variable speed wind energy operation. This kind of rotor resistance can be adjusted by using a transducer containing of a mixing of a miniature circuit and a diode rectifier. This arrangement is usually called optic_ slip controller [16]. The speed adjustment limits, that reaches about (10%) of the speed is limited normally, in terms of a different speed of capturing wind energy with acceptable efficiency, as well as a loss of energy in the resistance of the generator.

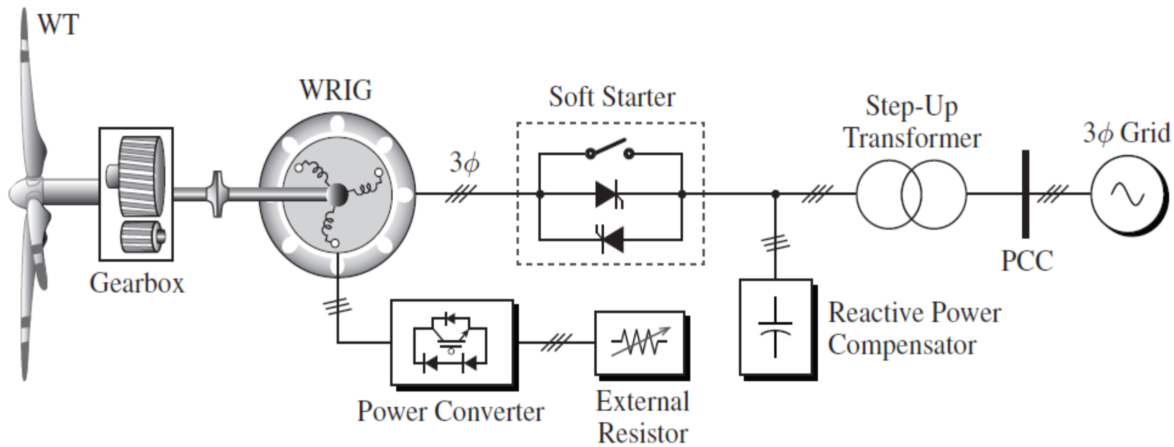

Figure.1 7 : The Schematic Diagram Of WRIG WECS [16]

Type 3: WTs employing Doubly_ Fed Induction Machines

Figure (1.8) illustrates the variable speed configuration (WECS) applied (DFIG). By using the operation of these types, the generator power is more saving to the grid than the use of two windings, and the use of rotating fixed parts in terms of using the lowest part of the transformed energy in a response circuit sliding value that ranges from (30%) of the relative value of the amount of generated power.. The Power transfer is used to allow the penetration of bidirectional power of the rotor parts and raises the domain of machine speed. The overall efficiency of power transformation can be enhanced through this feature to achieve maximal power [18], and an growth in speed of approximately up to a value of (30%), the work can enhance dynamic features and improve the durability versus the sheme energy.

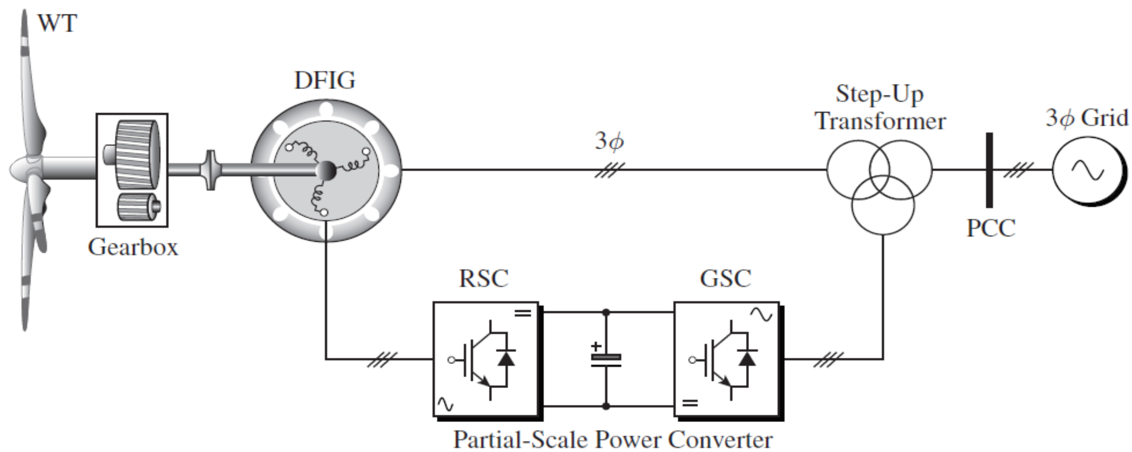

Figure 1.8: The schematic diagram of DFIG WECS

These advantages allowed this kind of induction generator and may be key or dominant technologies on the electrical market. This market shares approximately the value of (50%) [19].

Type 4: WTs employ Full_ Scale Converter (Variable Speed)

The use of full-size power transformers (100%), that will significantly improve the achievements of WT (see figure (1.9)). There is some application of the use of this kind of transformers in (SCIG) and (PMSG). However, it also separates the generator and transformers entirely from the grid, fully estimated wind power generation through a wide range of rotor speed operations from 0 to 100% as well as power and electricity transformers to offset reactive energy and obtain smooth seamless energy [21]. In terms of obtaining efficiency (WECS) is higher efficiency in wind turbines than other kinds [23]. It also improves the FRT compliance work and obtains it without external equipment. Electric power transformers, although a bit expensive, will be a fraction as much as 7% - 12% of the total cost of the equipment. When use a large number of electrodes of all kinds (PMSG), the turbo gearbox can be deleted [22]. This type of WECS system was stronger in the face of energy system disturbances than three aforementioned kinds. In addition, applying the idea of scattered transmission in the large wind energy system in terms of developing type 4. Although this application (WRSG and SCIG) existed in this principle, in terms of presence (PMSG) showed good operational performance in addition to removing slip rings as well as brush-technique which supplies a very practical approach [31]. Gearbox is an auxiliary tool accomplished the running of different generators at a higher speed, and a high energy density can also be achieved via spreading power and multiple machines. Some configurations show efficient fault tolerance for different operating conditions. In terms of using the other three adapters, the power grid can be connected in case of any failure of one of the transformers [24]. The application of the use of a multi-wind transformer in grid side reduces the value of the current in circulation as well and reduces the harmonics. The designers use a multi pole generator to maintain the value of frequency of (50HZ), improve performance, increase angular efficiency within the rated value and eliminate many of restrictions.

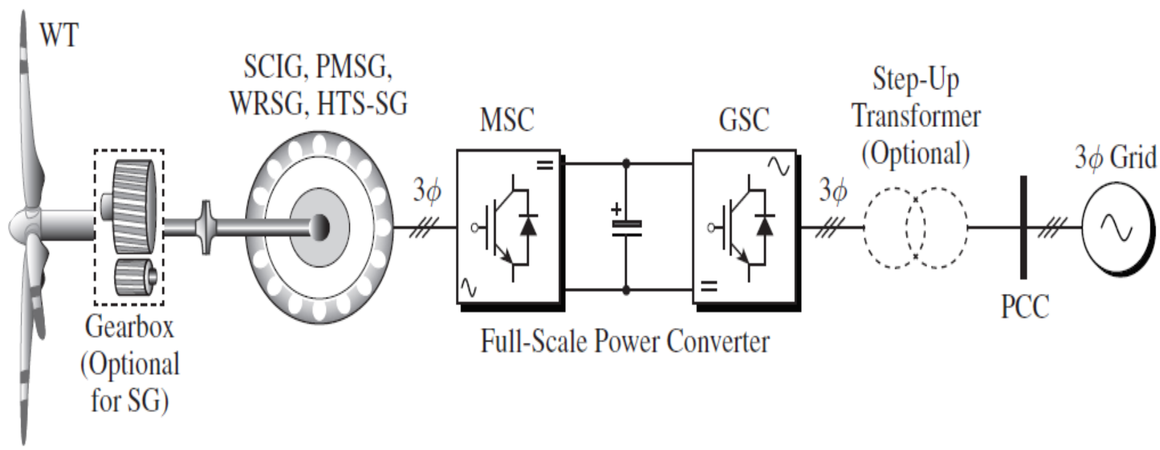

Figure 1.9: Type 4 grid-connected variable speed WECS

1.3 Controlling Schemes Overview

Recently, several researchers have published their work on WECS and control systems. [36] the authors describe different kind the (WT) controllers, as well as different kind of generators and rotor speeds. The authors in [32] analyzed system work in terms of stability, reliability, and efficiency of the (WT) system, high quality energy, as well as transport and storage systems, etc. The authors have described in [25] the WECS control diagrams that consist of (MI) and (MO) and a comparison with another system.

Some studies focus on wind turbine control schemes in case of battery charge and discharge ratio [26]. The authors reviewed the control process through frequency control until the system was in a state of (WT) stability and wind energy saturation. Other surveys focus on current. Future and Past tries to control producing of wind energy via applying horizontal axis (WT) [24].

In comparison with other generator kinds, the researches in [26] Investigated for the optimum energy recovery and high efficiency in wind turbine system, also making a comparison between the synchronous machines and the DFIG that employed in WTs.

Moreover, in [25], the authors were reviewed the controlling of wind energy in terms of electronic units in WECS, (PI) and (FLC) and (MPC). The system would be stable. Some authors have investigated and focused on modeling WTs based on WECS-PMSG, to demonstrate system performance using network approaches [20]. It appears through the features in the control stability of the system, which systematically solves many current problems and noticeable development in outputs using advanced WECS control technologies based on change development configurations of (WT) generators [17].

1.3.1 Fuzzy Logic Controlling Scheme

Fuzzy logic controlling Scheme, is one of the forms of mystery that puzzled scientists, but it is not necessary now full explanation of the fuzzy logic, but just define and clarify its uses in 1969 When working at the University of California, Lutfi Zada discovered the fuzzy logic where he noted that correctness and error are not adequate to represent all the logical types we are currently facing. Classical logic is based exclusively on 0 or 1, and this is what many relationships depend on, although there are other relationships in which the situation is considered at the same time to be partly accurate or partly incorrect [27].

The adjustment between the two situations is incremental in the fuzzy logic, so that we can consider the scenario bringing both cases together at this point as a minor shift in the amount of income induces an improvement in the shift, not a total change.

1.3.1.1 Advantages of fuzzy logic controller

It has certain advantages which make it preferable to the other controllers. They are: [36]

- The ease of understanding as it depends on a satisfied understanding.
- Fuzzy logic can work even when there are noise inputs.
- The return to the point of departure; flexibility in terms of the integrity of the amendment and change without it.
- The representation of unverified dada.

- It is not difficult in an uncomplicated mathematical analysis and therefore a very simple design.

1.3.2 Proportional Integrator Controller

We suggested using the Proportional Integration Controller (PI) for improved performance to increase efficiency as well as ease of operation with the wind turbine system. It is also used in devices that control modern power transformers, as well as using the control unit in the equipment of the control system that works to replace the transformers that are placed between the wind turbine generator and the common collection point [27]. However, using (PI) processing to collect the error signal between the already established reference value and the actual output power, which can be measured through the load to obtain the best value from the system's error reduction. In some studies, the authors focused on using the (PI) to control the generated power according to pitch angle in the generator side and this reflected on the grid side. The use of (PI) was controlled and adjusted to get the best values [29]. In addition, some authors have suggested using a non-linear dynamic (WT) PI model with a comparison between the system, another choice, and the best response with the PI controller. Particle swarm and radial base function algorithms in the neural network, however, have much better performance than traditional PI controllers [27].

1.3.3 Model Predictive Controller (MPC)

We suggest using the Model Predictive Control Unit (MPC) to apply charge and discharge of a battery by increasing the rate of ignition of the switch. We benefit from battery charging and an increase in direct transformation to the side of the grid. In most studies, MPC uses wind power according for variety of working circumstances through which the (WT) is tested. These researches can be further divided into groups according to control system [20-22].

This kind of control has been developed to solve many problems of wind energy conversion system (WECS), in addition to controlling individual (WT). [29] The use of (MPC) is applied analyzes to a distribution in the Power production aspect that contains wind fields formation. Reference [31] discusses use some simple techniques (MPC) is to integrate with the fuzzy logic controller (FLC) system to get the best WECS with battery storage. Non-linear problems can be controlled through predictive controlling policy with reasonable restrictions. There are some studies that employ predictive control approach for WT systems that apply DFIG machines connected to the electricity grid [32]. Likewise, the authors [29] considered that these Non-Linear predictive technique for grid based DFIG with high accuracy, ease of use, and correction change and had good work performance.

2. Literature review

2.1 Introduction

Nowadays, wind power has become one of the world's fastest rising energy sources. Wind power incorporation into the grid brings difficulties for power systems due to the inherent instability and uncertainty. This energy production is in full growth, and the various means are now at the disposal of scientists to explore it to the maximum extent**.**

In (2017) [25] In terms of the use of three controllers, model predictive control applied for (PV wind hybrid) system has a strong steady stare efficiency, faster and accurate transient response. The first control was designed (PV) (BOOST) controller, the second part of the wind speed control changes the time through Proportional Integrator (PI) controller and in terms of controlling the internal current based on the model predictive control (MPC) current controller. The use of the parts to control the grid side conversion where the (dc_ link voltage) control is in terms of the use of (PI) controller. It also contains internal currents that were dependent on current control which is based on the (MPC) current controller.

The effect of the grid integration of wind energy conversion systems (WECS) on the grid frequency in the presence of load disruption was investigated in (2015) [26]. The output power of the (WECS) is also uncontrollable, because of the uncontrollable existence of wind energy. When a system disruption occurs, this uncontrollability renders the (WECS) unable to respond to the difference in load frequency. The instability of a power system like this leads to the failure of the system. For the help of load frequency control (LFC) in a DFIG-based WECS under the variation of wind speed, a model predictive control (MPC) is used. (MPC) is shown to be able to tolerate more feedback signals, such as a Proportional Integral Derivate (PID), than any other traditional controller. The model predictive control (MPC) approach for the permanent magnet synchronous generator (PMSG) based variable speed wind energy conversion system (VS-WECS) was suggested in (2018) [27]. For the optimum operation of a (PMSG) wind turbine (WT), predictive control is applied. Via a three-phase back-to-back (BTB) converter, the (PMSG) is tied to the power grid. By applying the control algorithm to the machine side converter (MSC), the maximum power available from the (WECS) is harvested. Using the grid side converter (GSC), the DC link voltage control is accomplished. Using the MATLAB /

SIMULINK environment, a directly controlled (PMSG) variable speed (WECE) model is generated and imitated. With a large variance in wind speed, the MPC provides good dynamic efficiency.

In (2014) [28] In recent years, with the rapid developments in technology of the processing of many digital signals, through the use of A Model Predictive Control (MPC) approach as a simple and promising digital control instrument in both power electronics and speed-changing engines as well as in the energy transfer system. (MPC) with non-linear control and provide a more convenient approach to controlling WECS power transformers. In this method, there are some technical and operational defects associated with the method of simple classic control techniques, by maintaining the frequency value from a decrease during variables of switching from one level to another one.

Digital controller friendliness, finite number of optimizations, removal of Proportional Integral (PI) controllers, pulse width free structure, pulse width free structure, due to a basic and intuitive definition, form the advantage of a very fast dynamic response, and it is more stable in performance in all operating conditions, as well as the ability to compensate the disturbances and loss time of the power conversion system, as well as the ease of incorporating non-linear constraints into the design, by improving and addressing multivariate control problems with separation . Over the past decade, many books have been published on power transformers, wind power systems and (MPC).

The use of renewable energy , such as wind, solar energy and fuel cells, is attractive for power generation in (2017)[30] because of its high performance, easy maintenance and friendly climate. It deals with device integration and fuzzy logic-based console control for grid-connected hybrid renewable energy source (HRES) power management. The combination of a fuel cell (WT) and battery storage through a typical multi-input transformer (DC DC) is a hybrid system. Via this, the converter is used to connect the supply of renewable energy with the power grid. A two-tier control system comprising (FLC) has been introduced, ensuring power management between intermittent enervation (RE), energy and grid storage, as well as local PV module control units. In MATLAB / Simulink, simulation is done. In (2018) [32] using the fuzzy _ PI controller to get the best results through the use of a fuzzy and proportional integral (PI) controller for improving the work and increasing the energy transfer of the independent wind energy conversion system

(WECS). The fuzzy _ PI controller, which was more responsive to achieve results, is applied to (WECS) for (MPPT). Through the improve of the work; results in improve the performance with high efficiency in the system comparison with the classical (PI) controller. Indeed, using the suggested console in terms of getting the most responses to the system. This was good by adjusting the rotor speed of the permanent magnet synchronous generator's (PMSG) rotor speed under the change of the wind speed. The computer simulation results in Matlab/Simulink environment, by proving the efficiency and quality of the system in performing the system designed in a very good way.

In (2018) [33] the authors, uses the fuzzy logic control (FLC), to control the battery energy storage system (BESS) by stabilizing the system to maintain the voltage and frequency of the searing micro grid. For the study presented in determining the effectiveness of the control unit (BESS) in light and fluctuations or changes in wind speed and other light amounts to maintain these (frequency / voltage) that are subject to disturbance occurring in the small island grid. In the Mae searing system, electricity is produced from two renewable energy sources, Hydro, Wind and Solar PV. Even the most beneficial through the production energy, as well as the most efficient in the work system, control the quantities of storage and the rest is transferred to the grid. Moreover, in terms of energy uncertainty there are some problems with this energy quality that causes a blackout. In order to overcome these problems, the proposed Fuzzy Logic Control (FLC) approach is applied to the BESS controller to improve and multiply its work Efficiency stability of the terrifying Mae partial grid. The proposed FLC aims to provide BESS with features of a dynamic disorder response, which is analyzed by model predictive controller (MPC). The proposed FLC has been valedated and compared to the robust control method, by analyzing a mathematecal model by using systim identification technilogy, by using accurate grid system models using (BESS) and verifying them on the DIGSILENT power plant program. The simulation result shows that both control Methods allow the dynamec stability of the microscopic grid and maintain the acceptable value of voltage and frequency. However, BESS is less likely to be in doubt than BESS. Moreover, in the proposed Fuzzy Logic Control (BESS), the precise grid frequency and normal voltage accelerate to their normal stable state and the size (BESS) is smaller than the strong BESS control.

3. Theoretical Analysis

3.1 Introduction

The diagram of the complete wind energy scheme is illustrated in Fig.3.1. This model proposes the employing of various types of algorithms for machine side/ load side inverter, while the scheme employs uncontrolled-rectifier for the purpose of simplicity.

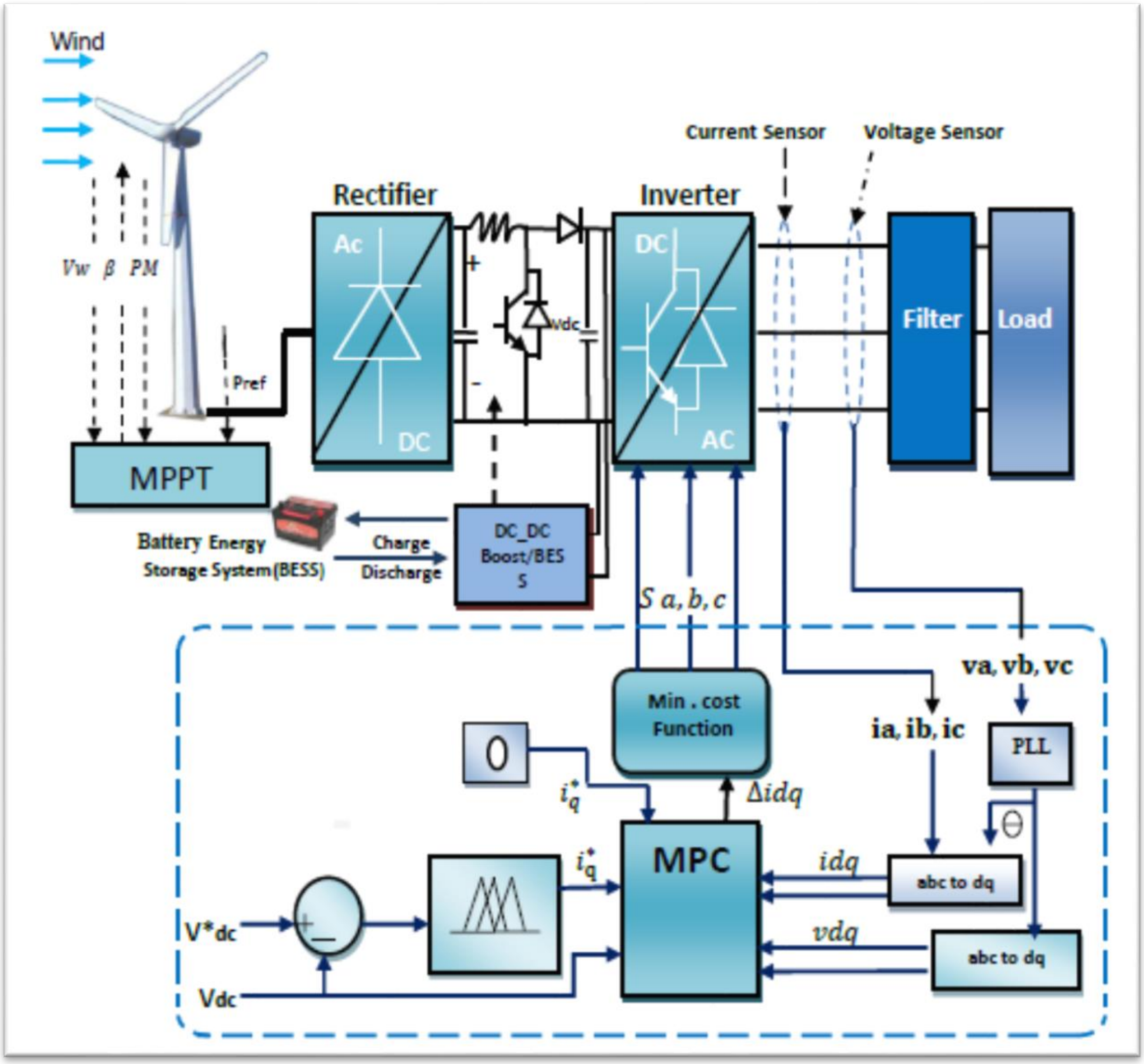

Figure 3.1: The proposed Control scheme for the WT and Battery system.

3.2 Wind turbine model using control Proportional_ Integral (PI)

The benefit of MPPT techniques is to improve wind turbine efficiency. For this purpose, different approaches for optimal power have been created and applied like the Incremental Conductance method, Perturb/Observe, and hill climbing approach. Hill climbing schemes or P&O approaches are the commonly utilized tracking algorithms for the MPPT purpose in the wind turbines, [34]. In the current work, we employ conventional Proportional/Integral (PI) approach to adjust the blades pitch-angle of Figure 3.2.

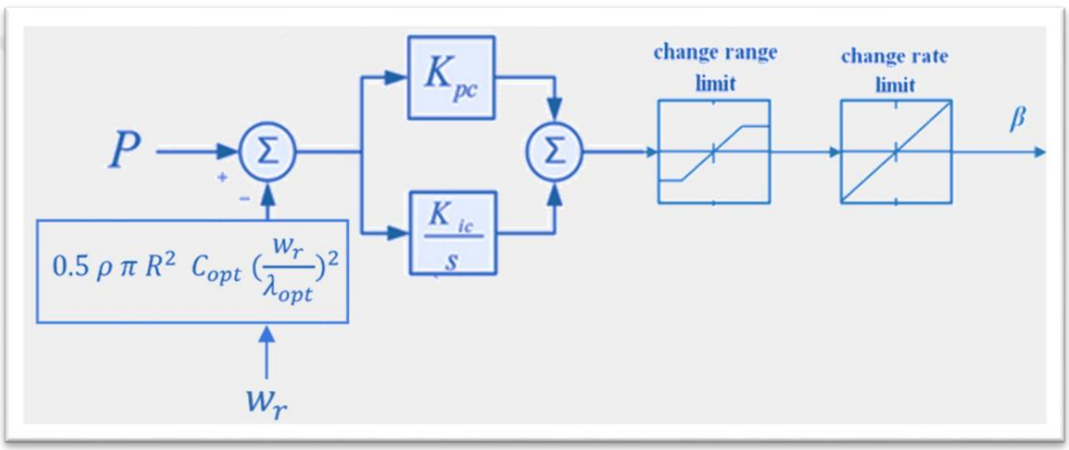

Figure 3.2 Pitch angle control block diagram.

According to e [37], the captured power, i.e., mechanical power P_m, from the wind can be determined as,

$$P_m = 0.5\,\rho\,\pi\,R^2\;C_p\,(\lambda,\beta)\;V_w^3 \qquad (1)$$

where, P_m is the extracted wind power, R is the rotor blade radius, ρ = density of the air, V_w is speed of the wind, β is pitch angle, λ is the tip speed ratio, and $C_p\,(\lambda,\beta)$ is the power conversion coefficient and according to our turbine model, can be modeled with the following generic equation [32].

$$P_{wind} = \frac{1}{2}\,\rho A v_w^3 \qquad (2)$$

Cp, power coefficient is defined as the ratio of turbine power to the extracted wind power.

$$Cp = \frac{Turbine\ Power\ (P_{turbine})}{Power\ obtained\ from\ wind\ (P_{wind})} \quad (3)$$

Hence the turbine--power is given by:

$$P_{turbine} = P_{wind}\ Cp = \frac{1}{2}\ pAv_w^3\ Cp \quad (4)$$

The turbine--power w.r.t wind transients is given by:

$$P_{turbine} = P_{wind}\ Cp = \frac{1}{2}\ pAv_w^3\ Cp\ (\lambda, \beta) \quad (5)$$

Where λ is the tip_ speed ratio of the turbine:

$$\lambda = \frac{\text{Rotational speed of rotor } (\mathrm{w_r}) * \text{radius } (\mathrm{r})}{\text{Wind velocity } (\mathrm{v_w})} \quad (6)$$

Where

$$Cp(\lambda, \beta) = C_1\ \left(\frac{C_2}{\lambda_i} - C_3\,\beta - C_4\right) e^{\frac{-C_5}{\lambda_i}} + C_6\ \lambda \quad (7)$$

$$Cp(\lambda, \beta) = 0.5\ \left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{\frac{-21}{\lambda_i}} + 0.0068\lambda \quad (8)$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda_i + 0.08\beta} - \frac{0.035}{\beta^3} \quad (9)$$

Where β stands for the blade pitch angle .

The coefficient C_1 to C_6 are: $C_1 = 0.5$, $C_2 = 116$, $C_3 = 0.4$, $C_4 = 5$, $C_5 = 21$, $C_6 = 0.0068$.

Figure (3.3) show the relationship between the power coefficient C_P and tip speed ratio λ.

Consequently, the maximum power point tracking can be determined using the following equation [37]

$$P_{mppt} = 0.5\,\rho\,\pi\,R^2\ C_{opt} \quad (10)$$

here, C_{opt} is optimal value of tip speed ratio at which the power and the power conversion coefficient are maximums.

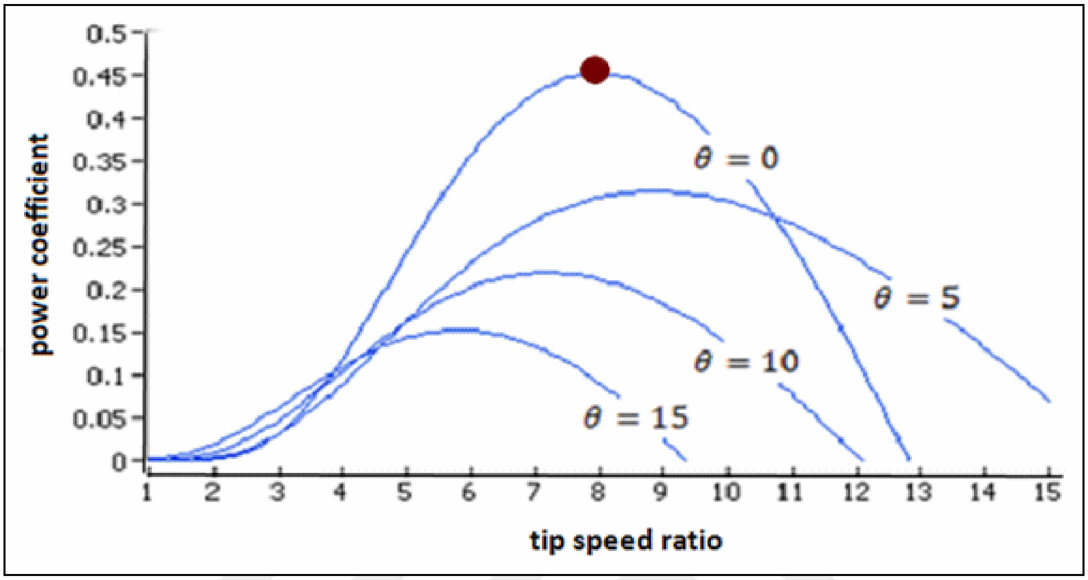

Figure 3.3: Power coefficient Cp(λ, β) vs tip speed ratio λ.

3.3 Battery energy-storage system (BESS) controller

A battery storage device can be utilised to store the excess produced-energy. This storage can be used to supply the load if additional energy is needed. Consequently, a bi--directional controller is needed to discharge/or charge the battery storage device if there is an overflow/shortage of energy, respectively. The state of battery charging (SOC) percentage information (percentage of the device capacity) can be used to express the quantity of electrochemical energy remained in a battery storage device [39]. A buck-boost operation mode of bi-directional DC controller can be employed for charging/or discharging purpose. In the proposed approach, a system of energy storage is applied to keep DC voltage at a stable level where a fuzzy controller is employed to accomplish this job. The output (DC) voltage (V_{DC}) of the rectifier is depends on the phase voltage as shown in equation 11 [36].

$$V_{DC} = \frac{3\sqrt{6}}{\pi} V_g \tag{11}$$

Where (V_{DC}) is the rectifier output voltage and (V_g) is the phase voltage.

As the (PMSG) voltage is variable with the wind speed, the (DC) output power of the rectifier is also change. This change in (DC) voltage is given as an input to the (MPPT) controlled boost conversion. The output voltage of the boost converter can be expressed as:

$$V_l = \frac{1}{1-D} V_{DC} \tag{12}$$

Where (V_L) is the output voltage of the boost converter and (D) is the ratio duty cycle.

3.4 Controller of Load-Side Inverter (LSI)

The LSI is a current_ regulated approach inverter in which current in the direct_ axis i_d is used to regulate the voltage of the dc bus while current in the quadrature _ axis i_q is applied to control the system reactive power see Fig, 3.1. The reactive power request is set to zero to confirm unity power factor condition. The Controller of Load-Side inverter is a hybrid scheme produced as a joint of fuzzy algorithm and MPC technique. The key point of the model predictive approach is using the plant model to forecast the future behavior for some variables within a definite horizon of the model. Figure 3.4 depicts the flowchart for MPC procedure in which cost function is given as,

$$g = \sum_j^J \lambda_j \left(x_j^* - x_j^P\right)^2 \tag{13}$$

Here, λ_j is the weighting factor, x_j^P is the prediction of the variable x_j, and x_j^* is the reference command. dq_load currents-prediction can be used to adjust the current of LSI and this quantity depends on the dq-converter-voltage components. The Park and Clarke voltage transformation can be expressed, respectively, as follows in equations (14) and (15)

$$\begin{bmatrix} V_d^j \\ V_q^j \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_\alpha^j \\ V_\beta^j \end{bmatrix} \tag{14}$$

$$\begin{bmatrix} V_\alpha^j \\ V_\beta^j \end{bmatrix} = V_{dc}^* \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \tag{15}$$

Here, V_{α}^{j} and V_{β}^{j} are the stationary vectors for voltage within the α and β axis, V_{d}^{j} and V_{q}^{j} are the dq_axis component vectors of voltage and S_{abc} are the controller switching signals. Euler formula is employed to determine the discrete dq _ currents as follows.

$$i_{gd}^{j}[\,k+\,1\,] = \frac{T_s}{L}\left[V_{gd}^{j}[\,k] - V_{d}^{j}[\,k\,]\right] \; + \; \left(1 - \frac{T_s}{L}\right) i_{gd}^{j}[\,k\,] \tag{16}$$

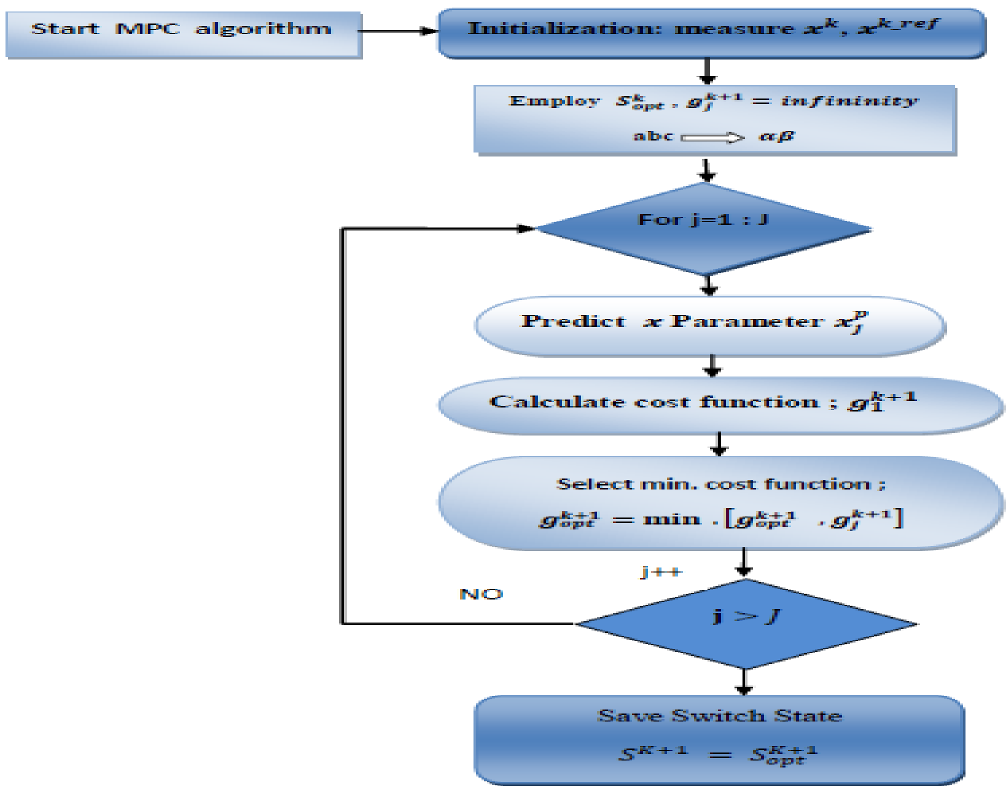

Figure 3.4: MPC algorithm flowchart

$$i_{gq}^{j}[\,k+\,1\,] = \frac{T_s}{L}\left[V_{gq}^{j}[\,k\,] - V_{q}^{j}[\,k\,]\right] \; + \; \left(1 - \frac{R\,T_s}{L}\right) i_{gq}^{j}[\,k\,] \tag{17}$$

Error signals dq-axis load currents $\Delta i_{gd}^{j}[k+1]$ and $\Delta i_{gq}^{j}[k+1]$ are determined as follows

$$\Delta i_{gd}^{j}[\,k\,+\,1\,] \;=\; \Delta i_{gd}^{*}[\,k\,] \;-\; \Delta i_{gd}^{j}[\,k\,+\,1\,] \tag{18}$$

$$\Delta i_{gq}^{j}[\,k\,+\,1\,] \;=\; \Delta i_{gq}^{*}[\,k\,] \;-\; \Delta i_{gq}^{j}[\,k\,+\,1\,] \tag{19}$$

The cost function in the prediction procedure can be determined as follows.

$$g^j = \left|\Delta i^j_{gd}[k+1]\right| + \left|\Delta i^j_{gq}[k+1]\right| \tag{20}$$

Now, this cost function could be minimized by choosing the optimum switching signals values. The input reference-current of the model predictive, i.e., i^*_q can be estimated through the inference of fuzzy logic (see fig.3.4) where the fuzzy logic for current control is given in figure 3.5, and the input/output membership-function given in figure 3.6.

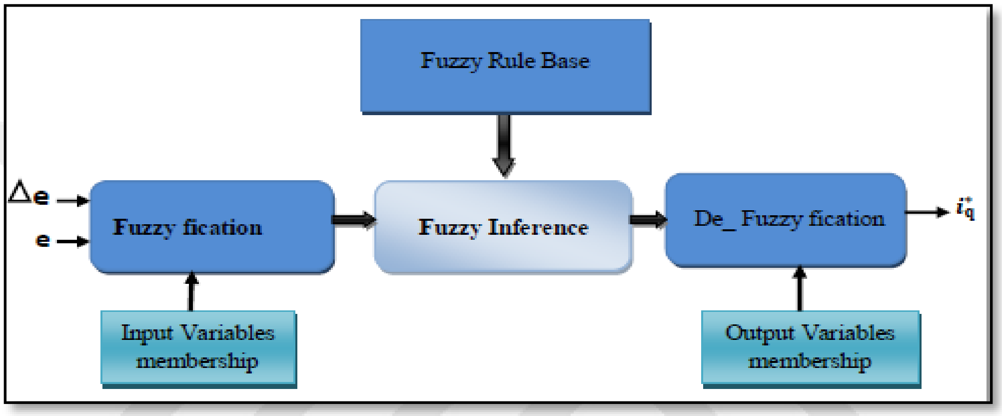

Figure 3.5: LSI reference-current prediction.

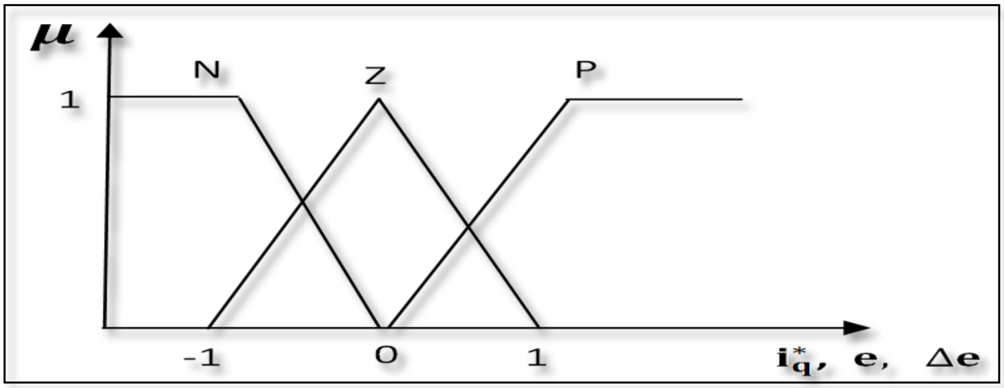

Figure 3.6 : Input/output membership_ function of fuzzy technique.

The associated Inference_Rule for the Fuzzy controller is presented in Table 3.1

Table 3.1: Fuzzy controller Inference_ Rule

e/Δ*e*	***N***	***Z***	***P***
N	N	N	Z
Z	Z	Z	P
P	Z	P	P

e and Δe are calculated and convertsion to the linguestic change during fuzzification. Table (3.1) shows the ratio between measured error and the linguistic term, such as negative (N) and zero (Z) and positive (P).. Lastly, the resulting fuzzy output is mapped to a crisp output using the membership functions during defuzzification.

4. Results of the Simulation

System components (the generator, battery, and turbine) are modelled using the Simulink environment of MATLAB package as shown in figure 4.1 to investigate the overall performance of the proposed approach.

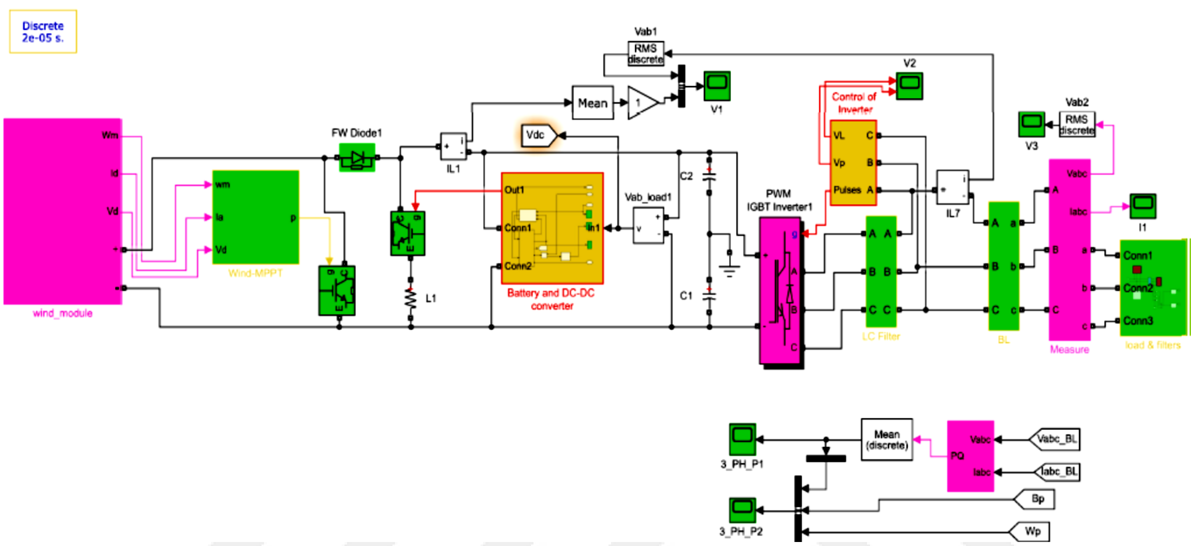

Figure 4.1 Proposed model block diagram.

In the simulation study, the parameters of the components for the scheme are set according to table 4.1 and the simulation is passed for 4 sec in each situation. The entire simulation results can be put in two parts. First, results for the variable wind-speed case. Second, results for different load case.

Table 4.1:System parameters setting

Parameters	**Values**
Wind Turbine	
frequency	50Hz
average power	25Kw
voltage	380v
average wind speed	12 m/sec

Direct, Quadrature-axis inductance L_d, L_q	0.435mH
Number of pole-pairs	4
Battery storage system	
Initial SoC	60%
battery capacity	6.5 Ah
nominal voltage	350v

4.1 Machine Side Controller Response

Four various levels of wind speeds are excited at system input in the time interval between 0 sec and 4 sec as shown in figure 4.2. The optimal power tracking (turbine rotor-speed response) for the imposed reference parameter is depicted in figure 4.3. After a tiny oscillation following the wind.

speed oscillation, the power-coefficient is kept at the optimum level fast, where it endures around 0.2sec to move amid two various stable levels.

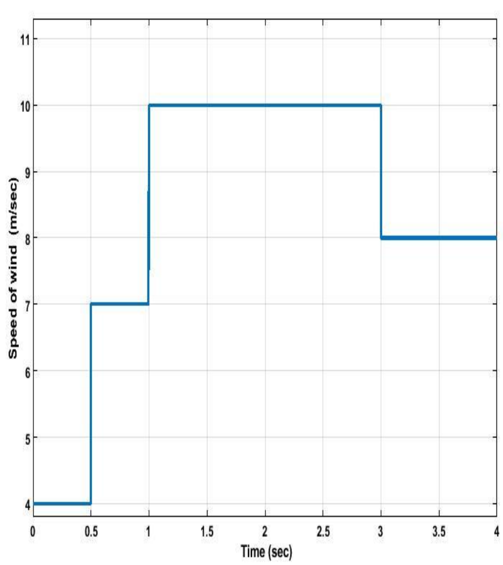

Figure 4.2: System input excitation (wind speed).

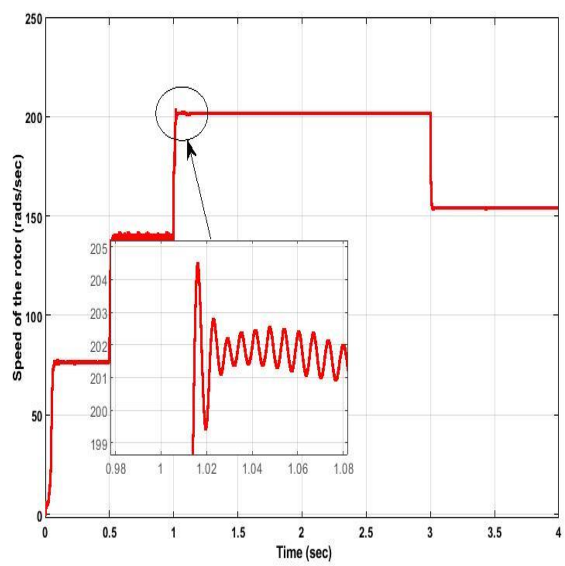

Figure 4.3: The response of Rotor speed for abrupt input excitation.

4.2 The Response of the DC line bi-directional control

DC_ bus voltage V_{dc} is wanted to be around a steady reference point V_{dc}^{*} (nearly 650v, as shown in figure 4.4) which will be adjusted to AC phase voltage of 230v /50Hz at load side via inverter cct. According to the load power demand the bi-directional controller will determine which process of charge or discharge to take place. As shown in figure 4.4, in the situation when the created wind power is high and the requested load-power is low, in this case the overflowing power is used to charge the storage device and vice versa. In addition, figure 4.5 shows the dc current through the battery circuit and figure 4.6 depicts the percentage variation of energy storage due to charge – discharge process where initial charging state percentage is 60%.

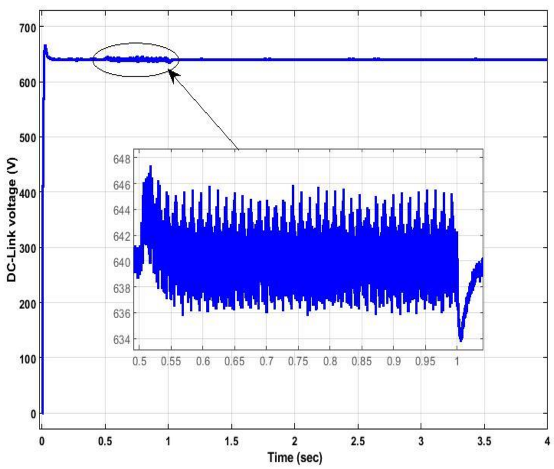

Figure 4.4. Boosted DC link voltage.

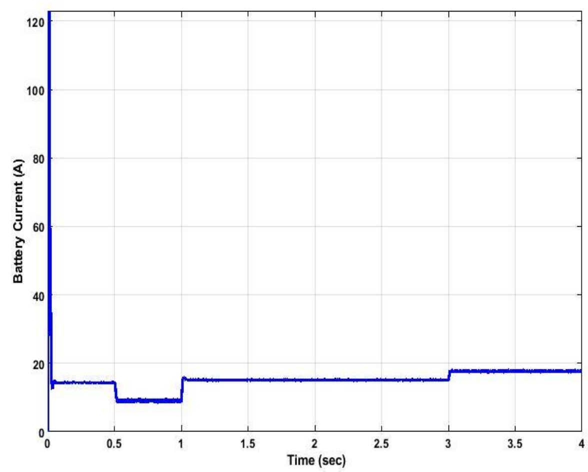

Figure 4. 5: Battery Charge/Discharge current.

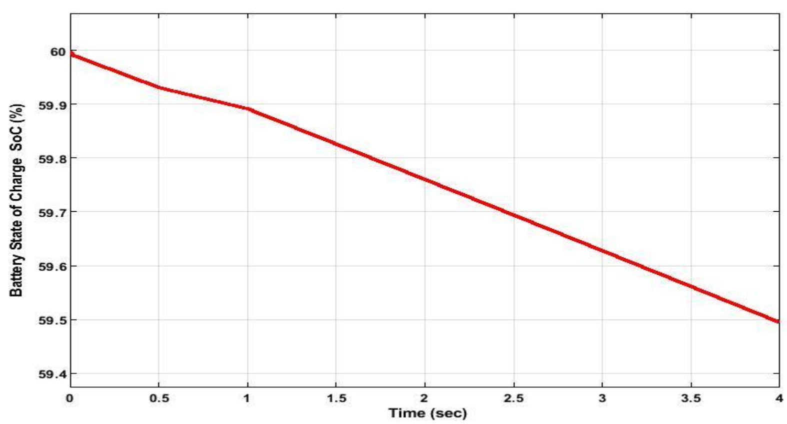

Figure 4.6 Battery charging State (Percentage)

4.3 Load Side Controller Response

Along with the previous step-change in wind speed level, the influence of abrupt load change (see figure 4.7 at second 3) is inspected simultaneously in order to show the stability of the scheme against environmental fluctuations. Figure 4.8 shows the change in DC-bus voltage due to this sudden variation in load current. The simulation is run through two various methods of load_side control, one is our proposed scheme and another one is the traditional PI scheme as a baseline to the proposed scheme performance.

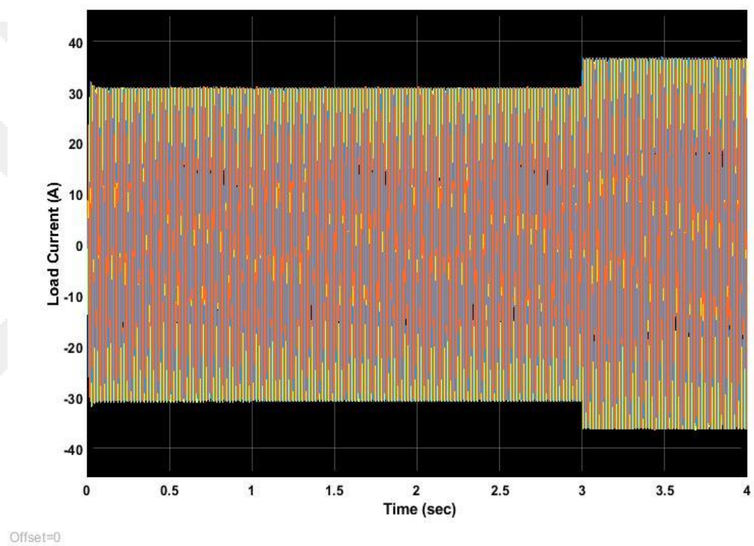

Figure 4. 7: Output load current.

Figure4.9 proves that both approaches have a good response versus sudden fluctuations in wind-speed. The figure presents voltage fluctuations w.r.t various wind-speed and load-current. Nevertheless, the proposed model has additional reliability and robustness than the benchmark classical scheme upon all operational region. Besides, our proposed scheme tracks faster at a steady voltage under load fluctuation. When the proposed system undergoes a step change, it provides a key decreasing in overshoot and settling time values (see table 4.2). Enhancement in the overshoot response is around 1.1% while the reduction in settling time is around 0.33 msec.

Table 4.2: Response to step input.

Metric/technique	Overshoot value (%)	Time of system settling (msec)
Proposed	1.41	0.21
Traditional PI	2.51	0.53

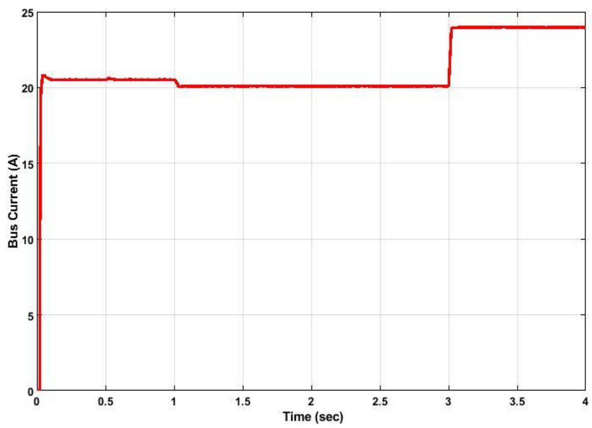

Figure 4.8: DC _ bus current

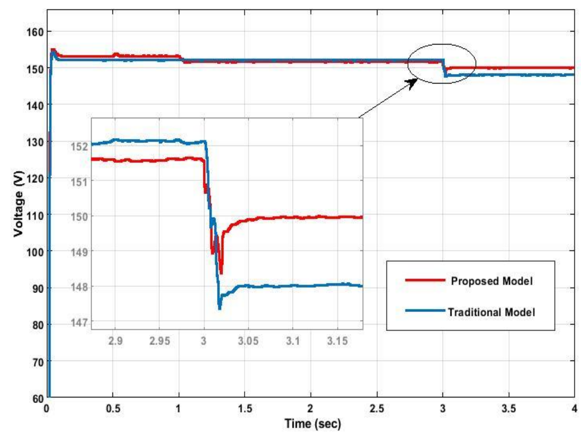

Figure 4.9: Comparison with the conventional PI approach.

Total harmonic _distortion (THD) of voltage or current signals, on the other hand, is a key quantity beneficial in qualifying the AC waveform quality and this important metric can be determined as follows,

$$THD_v = \frac{1}{V_1}\sqrt{\sum_{i=2}^{\infty} V_i^2} \times 100\% \tag{4.1}$$

here, i is the harmonic index and V_1 is the fundamental voltage bin. In this work, the THD measure (figure. 4.10) introduces a tiny volume of decreasing from 3.7% for the benchmark scheme to 2.55% for our proposed model at 50Hz frequency. It is worth mention here that these limits of THD are almost reasonable according to IEEE standards. In addition, the usage of uncontrolled-rectifier and the passive components in the topology of the proposed scheme results in some high harmonics limits. Consequently, there is a need for using a filter for the machine side to mitigate effects of high harmonics.

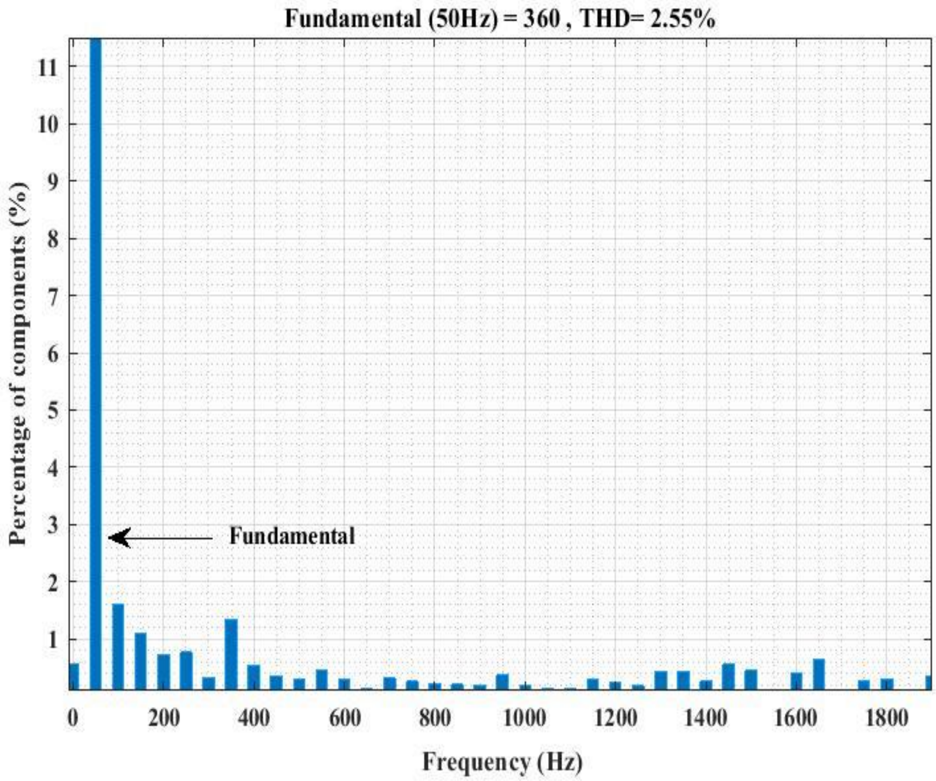

Figure 4.10: Harmonics performance at 50Hz frequency.

5. Conclusion

This work introduces a controlling approach that considers of joining of fuzzy technique with model predictive techniques in management of the battery-storage based turbine system. Where the MPC part predicts the model w.r.t to past-readings and determines future inputs and thus gives system robustness. Fuzzy logic, on the other hand, can deal with the non-linear behaviour of the model. Simulation output results verify the efficiency of the proposed approach in pursuing the required recommended metrics in terms of overshoot and settling time.

6. Future Work

a. Carry out the project on WT of DFIG type.

b. Study of performance of combining more type of inelegant controlling schemes on different stages of the system.

c. Extension of the current work to a more complicated network like grid-connected network.

d. Utilizing of some advanced optimization algorithms in both the turbine side and load side controllers.

e. Implementation of the proposed algorithms on hardware using a specific chips, microprocessor, or field programmable gate arrays chips e.g. Xilinx FPGA chips.

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