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Power Electronics Converters for Wind Turbine - An Analytical study

مبدلات إلكترونيات القدرة لتوربينات طاقة الرياح - دراسة تحليلية

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree of M.Sc. In Electrical Engineering (Power)

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الآيـة

قال تعالى:

(وَمِنْ آيَاتِهِ أَن يُرْسِلَ الرِّيَاحَ مُبَشِّرَاتٍ وَلِيُذِيقَكُم مِّن رَّحْمَتِهِ ..)

صدق الله العظيم

سورة الروم الاية (46)

DEDICATION

I owe my gratitude to my mother, my brother, my sisters, my friends and my family members for all their love and support during my personal and professional education.

ACKNOWLEDGMENT

I would like to express my deep and sincere gratitude to my supervisor **Dr. Othman Hassan Abdalla** for his excellent supervision and help during this work. It is a pleasure for me to take the opportunity to thank all my colleagues and friends also for support.

ABSTRACT

The steady growth of installed wind has pushed the research and development of power converters towards full scale power conversion, lowered cost per kW, and increased power density and the need for higher reliability.

Converters used today are power electronic devices, and as technology develops and the cost drops, the importance of power electronic devices in wind turbine systems increases rapidly.

In this research, power converter technologies are reviewed and applying to wind turbines with focus on two/multi-level (VSC), connected to a (DFIG).

Based on the analyses a comparison was made for the two/multi-level VSC with PSIM software, that are: the output voltage and current to be less distorted and THD is a lower, when the number of level is increase.

المستخلص

إن زيادة النمو في طاقة الرياح قد دفعت الباحثون إلى تطوير محولات الطاقة وذلك بتحويل القدرة الكاملة وخفض التكلفة لكل كيلوواط وزيادة كثافة القدرة للحصول على درجة أعلى من الموثوقية.

المحولات المستخدمة اليوم هي أجهزة كهربائية إلكترونية، ومع تطور التكنولوجيا وانخفاض التكلفة، تزداد أهمية الأجهزة الإلكترونية للطاقة في أنظمة توربينات الرياح بسرعة.

في هذا البحث، تتم مراجعة تقنيات تحويل الطاقة وتطبيقها على توربينات الرياح مع التركيز على محول مصدر جهد ثنائي / متعدد المستويات، عندما يعمل مع مولد ثنائي التغذية.

وبناءً على التحليلات، تم إجراء مقارنة لمحول مصدر الجهد ثنائي / متعدد المستويات عن طريق برنامج PSIM ,ووجد ان جهد الخرج والتيار أقل تشوهًا و التشوه التوافقي الكلي يقل كلما زادت عدد المستويات.

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LIST OF SYMBOLS

Symbol	Meaning
V	Volt
Ω	Ohm
A	Ampere
P	Real Power, Watt
V	Voltage, V
I	Current, A
M	Mass, Kg
Q	Reactive power, VAR
S	Apparent power, VA
V	Speed, m/s
R	Resistance, Ω
X	Reactance, Ω
Z	Impedance, Ω
$\mathbf{V_L}$	Line voltage, v
$\mathbf{I_L}$	Line current, A
P	Air density, kg/m^3
A	Cross-sectional area, m^2
$\boldsymbol{P_w}$	Power in the wind, W

LIST OF ABBSERVATION

HAWT	Horizontal Axis Wind Turbines
VAWT	Vertical Axis Wind Turbines
IGs	Induction Generators
SGs	Synchronous generators
SCIGs	Squirrel-Cage Induction Generators
DFIG	Doubly-Fed Induction Generator
PMSG	Permanent Magnet Synchronous Generator
WRSG	Wound-Rotor Synchronous Generator
AC	Alternating Current
DC	Direct Current
THM	Top Head Mass
WTG	Wind Turbine Generator
WECS	Wind Energy Conversion System
IGBT	Insulated-Gate Bipolar Transistor
IGCT	Integrated-Gate Commutated Thyristor
EMI	Energy Management Institute
PWM	Pulse Width Modulation
VSI	Voltage Source Inverter
THD	Total Harmonic Distortion
MV	Medium-Voltage
NPC	Neutral Point Clamped
CHB	Cascaded H-bridge
BTB	Back-To-Back

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 Background

Over the last twenty years, renewable energy sources have been attracting great attention due to the cost increase, limited reserves, and adverse environmental impact of fossil fuels. In the meantime, technological advancements, cost reduction, and governmental incentives have made some renewable energy sources more competitive in the market [1]. Renewables are climate-friendly forms of energy, due to the absence of emissions detrimental to the environment. The savings especially in carbon-dioxide and Sulphur dioxide emissions are a significant advantage over fossil power stations. Hence a main role is assigned to renewable energy in the proclaimed fight against climate change [2].

The major source of renewable energies is the sun, with some forms also attributed to the earth and the moon. Utilization of renewables is mostly with conversion into electrical energy [2]. Wind energy has been used for hundreds of years for milling grains, pumping water, and sailing the seas. The use of windmills to generate electricity can be traced back to the late nineteenth century with the development of a 12 kW DC windmill generator [3]. In the United States, the first wind-electric systems were built in the late 1890s, and by the 1930s and 1940s, hundreds of thousands of small-capacity, wind electric systems were in use in rural areas not yet served by the electricity grid. In 1941, a wind turbine comparable in size to the largest ones in operation at the turn of the century went into operation at Grandpa’s Knob in Vermont. Interest in wind power lagged, however, when cheap and plentiful petroleum products became available after World War two. The high capital costs and the uncertainty of the wind placed wind power at an economic disadvantage [2]. It is, however, only since the 1980s that the technology has become sufficiently mature to produce electricity efficiently and reliably. Over the past two decades, a variety of wind power technologies have been developed, which have improved the conversion efficiency of and reduced the costs for wind energy production. The size of wind turbines has increased from a few kilowatts to several megawatts each. In addition to on-land installations, larger wind turbines have been pushed to offshore locations to harvest more energy and reduce their impact on land use and landscape [4].

1.2 Problem Statement

The proposal will compare between tow-level VSC and three-level NPC voltage source converter, combined with a doubly fed induction generator, based on the PSIM software

1.3 Objective

A variety of power converter topologies used in wind energy conversion systems (WECS) will analyze in this project, including: two-level voltage source converters (VSC), three-level neutral point clamped (NPC) converters, Three-level H-bridge back-to-back topology, Five-level H-bridge back-to-back topology and Three-level Neutral Point diode Clamped topology for generator side and Five-level H-bridge topology for grid side. The operating principles and switching schemes of these converters will be discussed in detail.

1.4 Thesis Layout

Chapter two is the basic theory which includes definitions and mathematical relations of the wind energy systems.

Chapter three contains types of multilevel converters, advantages and disadvantages of multilevel converters, modulation techniques of multilevel converter, types of converters used in wind turbine.

Chapter four is decade to simulation of the all types of power electronics used in wind turbine will be obtained and compared, finally the conclusion and recommendations of the research in chapter five is.

CHAPTER TWO

WIND ENERGY SYSTEMS

CHAPTER TWO

WIND ENERGY SYSTEMS

2.1 Introduction

A (WECS) transforms wind kinetic energy to mechanical energy by using rotor blades. This energy is then transformed into electric energy by a generator Wind power systems can provide electricity whether or not you are tied to the grid [4]. Wind generators can be used in stand-alone systems or combined with solar panels and/or hydro power. While we've been using wind generators off-grid for many years, the grid intertied wind power system is the new kind on the block. Electricity produced by wind generation can be used directly, as in water pumping applications, or it can be stored in batteries for household use when needed. Wind generators can be used alone, or they may be used as part of a hybrid system, in which their output is combined with that of photovoltaics, and/or a fossil fuel generator. Hybrid systems are especially useful for winter backup of home systems where cloudy weather and windy conditions occur simultaneously [5].

The most important decision when considering wind power is determining whether or not your chosen site has enough wind to generate the power for your needs, whether it is available consistently, or available in the season that you need it.

2.1.1 Advantages of wind energy systems

• Wind energy systems are energized by the naturally flowing wind, therefore it can be considered as a clean source of energy. Wind energy does not pollute the air like power plants that rely on combustion of fossil fuels, such as coal or natural gas. Wind turbines do not produce atmospheric emissions that cause acid rain or greenhouse gases.

- Wind energy is available as a domestic source of energy in many countries worldwide and not confined to only few countries, as in the case of oil.
- Wind energy is one of the lowest-priced renewable energy technologies available today.
- Wind turbines can also be built on farms or ranches, thus benefiting the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to use their land because the wind turbines use only a small fraction of the land. Wind power plant owners make rent payments to the farmer or rancher for the use of the land [6].

2.1.2 Disadvantages of wind energy systems

- Wind power has to compete with conventional power generation sources on a cost basis. Depending on the wind profile at the site, the wind farm may or may not be as cost competitive as a fossil fuel based power plant. The technology requires a higher initial investment than fossil-fueled solutions for power supply.
- The major challenge to using wind as a source of power is that the wind is intermittent and it does not always blow when electricity is needed. Wind energy cannot be stored; and not all winds can be harnessed to meet the timing of electricity demands.
- Good wind sites are often located in remote locations, far from cities where the electricity is needed. In developing countries, there is always the extra cost of laying grid for connecting remote wind farms to the supply network.
- Although wind power plants have relatively little impact on the environment compared to other conventional power plants, there is some concern over the noise produced by the rotor blades, and aesthetic

(visual) impacts. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants [6].

2.2 Overview of wind energy conversion system

2.2.1 On-land and offshore applications

Large capacity wind farms have traditionally been placed on land for several reasons: easy construction, low maintenance cost, and proximity to transmission lines. On the other hand, offshore wind farms are also commercially viable. One of the main reasons for the offshore wind farm development is the lack of suitable wind resources on land. This is particularly the case in densely populated areas such as in some European countries. Another important reason is that the offshore wind speed is often significantly higher and steadier than that on land. Considering that the energy obtained by wind turbines is proportional to the cube of the wind speed, the turbines can capture more energy when operating offshore. Moreover, the environmental impact, such as audible noise and visual impact, is minimal in offshore applications. These factors are the primary drivers for the development of offshore wind turbine technology [4].

The increase of turbine power capacity and reduction of maintenance costs are crucial for offshore wind farms. The average power rating of installed offshore wind turbines was around 2.9 MW as of 2009 [8], and the power rating of the generators for offshore applications is expected to increase in the next decade. To reduce the maintenance cost, direct-driven wind turbines using low-speed permanent magnet synchronous generators (PMSGs) is a viable technology. The maintenance costs for these turbines are reduced due to elimination of the gearbox and brushes. For offshore wind farms, the foundation and transmission cable add significantly to the total project costs [4].

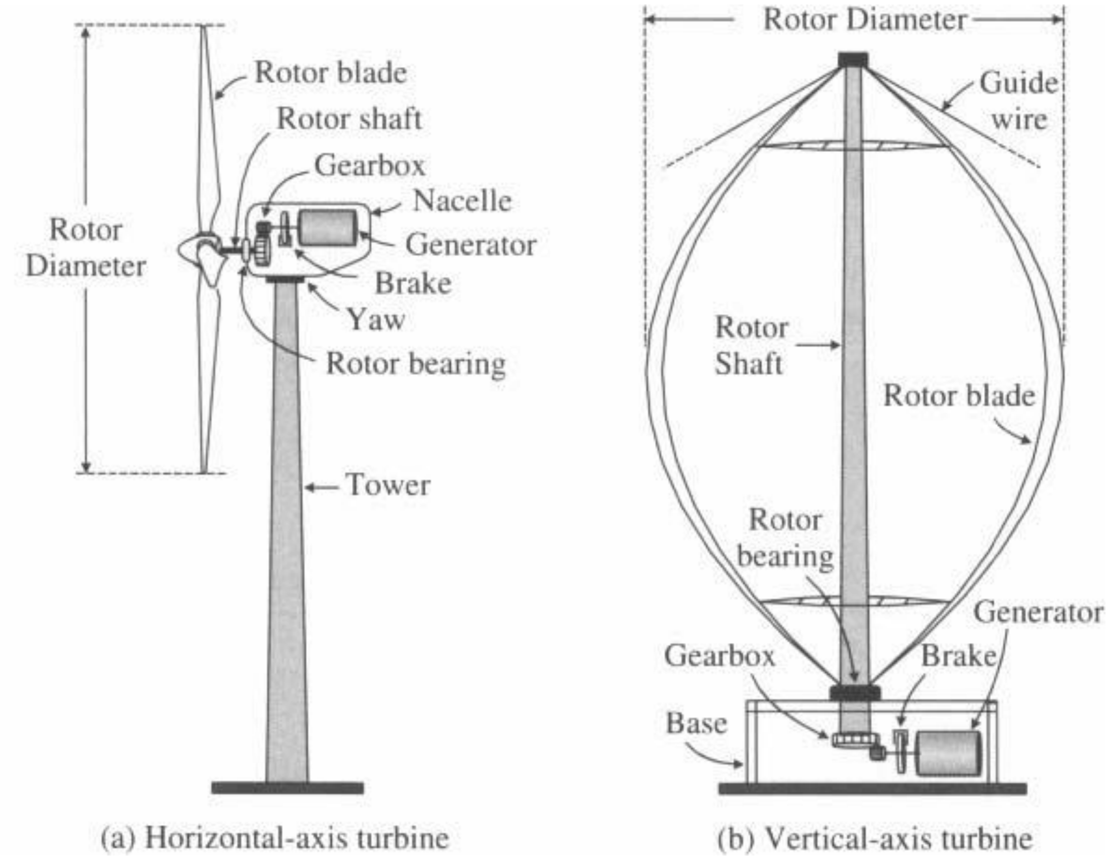
2.2.2 Horizontal- and vertical-axis wind turbines

Wind turbines can be categorized based on the orientation of their spin axis into horizontal- axis wind turbines (HAWT) and vertical-axis wind turbines (VAWT) [9], as shown in Figure 2.1.

In horizontal-axis wind turbines, the orientation of the spin axis is parallel to the ground as shown in Figure 2.1 a. The tower elevates the nacelle to provide sufficient space for the rotor blade rotation and to reach better wind conditions. The nacelle supports the rotor hub that holds the rotor blades and also houses the gearbox, generator, and, in some designs, power converters. The industry standard HAWT uses a three blade rotor positioned in front of the nacelle, which is known as upwind configuration.

However, downwind configurations with the blades at the back can also be found in practical applications. Turbines with one, two, or more than three blades can also be seen in wind farms.

In vertical-axis wind turbines, the orientation of the spin axis is perpendicular to the ground. The turbine rotor uses curved vertically mounted airfoils. The generator and gearbox are normally placed in the base of the turbine on the ground, as shown in Figure 2.1 b. The rotor blades of the VAWT have a variety of designs with different shapes and number of blades. The design given in the figure is one of the popular designs. The VAWT normally needs guide wires to keep the rotor shaft in a fixed position and minimize possible mechanical vibrations.



(a) Horizontal-axis turbine
(b) Vertical-axis turbine

Figure 2.1: Horizontal- and vertical-axis wind turbines.

2.2.3 Fixed- and variable-speed turbines

Wind turbines can also be classified into fixed-speed and variable-speed turbines. As the name suggests, fixed-speed wind turbines rotate at almost a constant speed, which is determined by the gear ratio, the grid frequency, and the number of poles of the generator. The maximum conversion efficiency can be achieved only at a given wind speed, and the system efficiency degrades at other wind speeds. The turbine is protected by aerodynamic control of the blades from possible damage caused by high wind gusts. The fixed-speed turbine generates highly fluctuating output power to the grid, causing disturbances to the power system. This type of turbine also requires a sturdy mechanical design to absorb high mechanical stresses [8].

On the other hand, variable-speed wind turbines can achieve maximum energy conversion efficiency over a wide range of wind speeds. The turbine can continuously adjust its rotational speed according to the wind speed. In doing so, the tip speed ratio, which is the ratio of the blade tip speed to the wind speed, can be kept at an optimal value to achieve the maximum power conversion efficiency at different wind speeds [9].

2.3 Wind turbine components

A wind turbine is composed of several parts to achieve kinetic-to-electric energy conversion. The side view of a typical wind turbine is shown in Figure 2.2. There are several variants to this layout of components, particularly for direct-drive (gearless) wind turbines. Nonetheless, the figure serves as a general reference to locate and describe the different parts in modern wind turbines.

The wind kinetic energy is converted to mechanical energy by the blades mounted on the rotor hub. The rotor hub is installed on the main shaft, also known as the lows peed shaft. The mechanical energy is transmitted through the drive train (shafts, bearings, and gearbox) to the generator, which converts mechanical energy into electric energy.

This conversion is usually assisted by a power converter system which delivers the power from the generator to the grid. Most of the wind turbine components are enclosed in a nacelle on top of the tower.

There are other parts that are not directly involved in the power conversion but are important to ensure the proper, efficient, and reliable operation of the system. Examples include the pitch system, yaw system, mechanical brake, wind speed and direction sensors, power distribution cables, heat dissipation/exchange system, lightning protection system, and structural components such as the tower, foundation, and nacelle enclosure. Large wind turbines are also equipped with an uninterruptable power supply or backup energy system that ensures uninterrupted operation of essential parts such as the control system, pitch drive, and brakes. In direct-drive (gearless) turbines, the absence of the gearbox and high-speed shaft leads to a more compact drive train and, hence, a shorter nacelle. However, the wider diameter of low-speed generators requires a taller nacelle structure. This phenomenon is more evident in wound rotor synchronous generators than (PMSGs) [4].

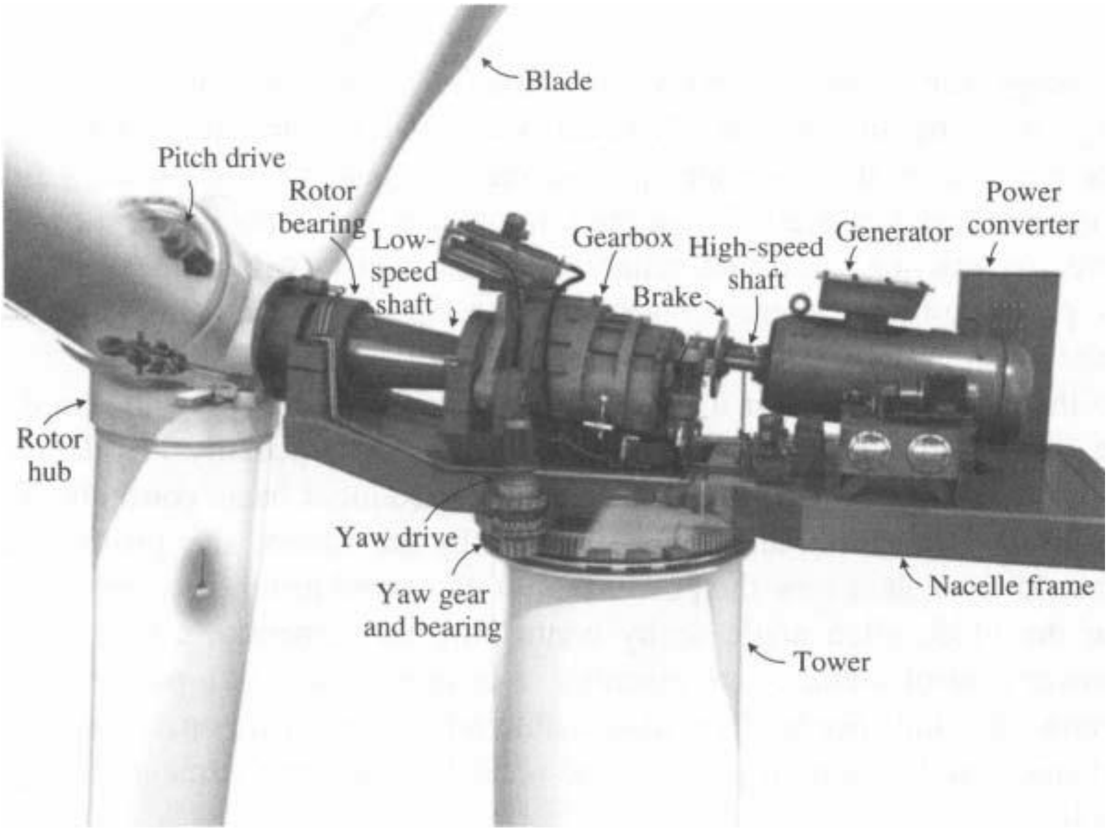


Figure 2.2: Main components of a wind turbine[4]

2.3.1 Turbine blade

The blade is the most distinctive and visible component of a wind turbine. It is also responsible for carrying out one of the most essential tasks of the energy conversion process: transforming the wind kinetic energy into rotational mechanical energy. Blades have greatly evolved in aerodynamic design and materials from the early windmill blades made of wood and cloth. Modern blades are commonly made of aluminum, fiberglass, or carbon-fiber composites that provide the necessary strength-to-weight ratio, fatigue life, and stiffness while minimizing the weight [3].

Although single- and two-bladed wind turbines have found practical applications, the three-blade rotor is considered the industry standard for large wind turbines. Turbines with fewer blades operate at higher rotational speeds. This is an advantage from the drive train point of view since they require a gearbox with a lower gear ratio, which translates into lower cost. In addition, fewer blades imply lower costs. However, acoustic noise increases proportionally to the blade tip speed. Therefore, acoustic noise is considerably higher for single- and two-bladed turbines, which is considered an important problem, particularly in populated areas.

Singe-blade turbines have an asymmetrical mechanical load distribution. The turbine rotors are aerodynamically unbalanced, which can cause mechanical vibrations. Moreover, higher rotational speed imposes more mechanical stress on the blade, turbine structure, and other components, such as bearings and gearbox, leading to more design challenges and lower life span.

Rotors with more than three blades are not common since they are more expensive (more blades). Operating at lower rotational speeds requires a higher gear ratio. The lagging wind turbulence of one blade can affect the other blades since they are closer to each other. Hence, the three-blade rotor presents the best trade-off between mechanical stress, acoustic noise, cost, and rotational speed for large wind turbines [4].

2.3.2 Pitch mechanism

The pitch mechanism in large wind turbines enables the rotation of the blades on their longitudinal axis. It can change the angle of attack of the blades with respect to the wind, by which the aerodynamic characteristics of the blade can be adjusted. This provides a degree of control over the captured power to improve conversion efficiency or to protect the turbine. When the wind speed is at or below its rated value, the angle of attack of the blades is kept at an optimal value, at which the turbine can capture the maximum power available from the wind. When the wind speed exceeds the rated value, the pitch mechanism is activated to regulate and limit the output power, thus keeping the power output within the designed capability. For this purpose, a pitch range of around 20 to 25 degrees is usually sufficient. When the wind speed increases further and reaches the limit of the turbine, the blades are completely pitched out of the wind (fully pitched or feathering), and no power will be captured by the blades. The wind turbine is then shut down and protected.

The pitch mechanism can be either hydraulic or electric. Electric pitch actuators are more common nowadays since they are simpler and require less maintenance. Traditionally, all blades on the rotor hub are pitched simultaneously by one pitch mechanism. Modern wind turbines are often designed to pitch each blade individually, allowing an independent control of the blades and offering more flexibility. The pitch system is usually placed in the rotor hub together with a backup energy storage system for safety purposes (an accumulator for the hydraulic type or a battery for the electric type) [4].

2.3.3 Gearbox

The rotor of a large three-blade wind turbine usually operates in a speed range from 6-20 rpm. This is much slower than a standard 4- or 6-pole wind generator with a rated speed of 1500 or 1000 rpm for a 50 Hz stator frequency and 1800 or 1200 rpm for a 60 Hz stator frequency. Therefore, a gearbox is necessary to adapt the low speed of the turbine rotor to the high speed of the generator.

The gearbox conversion ratio (r_{gb}), also known as the gear ratio, is designed to match the high-speed generator with the low-speed turbine blades.

The gearboxes are generally made of superior quality aluminum alloys, stainless steel, and cast iron. The gearbox usually generates a high level of audible noise. The noise mainly arises from the meshing of individual teeth. The efficiency of the gearbox normally varies between 95% and 98%. The gearbox is a major contributor to the cost of the wind turbine in terms of initial investment and maintenance.

Random changes in wind speed and strong wind gusts result in sudden load variations on the gearbox. These sudden changes produce wear and tear on the gearbox, reducing its life span. As a result, the gearbox needs regular maintenance. The elimination of the gearbox contributes to reliability improvements and cost reduction. In order to eliminate the gearbox, a generator with the same rated rotational speed of the turbine rotor is required. This can be achieved by a low-speed generator. Gearless configurations have been adopted by several manufacturers due to the reduced cost, maintenance, audible noise, and power losses [4].

2.3.4 Rotor mechanical brake

A mechanical brake is normally placed on the high-speed shaft between the gearbox and the generator, but there are some turbines in which the brake is mounted on the low-speed shaft between the turbine and gearbox. The main advantage of placing the brake on the high-speed shaft is that it handles much lower braking torque. The brake is normally used to aid the aerodynamic power control (stall or pitch) to stop the turbine during high speed winds or to lock the turbine into a parking mode during maintenance. Hydraulic and electromechanical disc brakes are often used[9].

To minimize the wear and tear on the brake and reduce the stress on drive train during the braking process, most large wind turbines use the aerodynamic power control to reduce the turbine speed to a certain level or zero, and then the mechanical brake to stop or lock the wind turbine [4].

2.3.5 Wind Power Generators

The conversion of rotational mechanical energy to electric energy is performed by the generator. Different generator types have been used in wind energy systems over the years. A classification of most common electric generators in large (WECS) is presented in Figure 2.3. Depending on their construction and operating principle, the wind generators are divided in two main groups: (IGs) and (SGs). Both induction and synchronous generators have wound rotors, which are fed by slip rings through brushes or by a brushless electromagnetic exciter. The wound-rotor induction generator, also known as the (DFIG), is one of the most commonly used generators in the wind energy industry [10]. The wound-rotor synchronous generator (WRSG) is also found in practical WECSs with high numbers of poles operating at low rotor speeds.

The (SCIGs) are also widely employed in wind energy systems where the rotor circuits (rotor bars) are shorted internally and therefore not brought out for connection with external circuits. In permanent-magnet synchronous generators (PMSGs), the rotor magnetic flux is generated by permanent magnets. Two types of PMSG are used in the wind energy industry: surface mounted and inset magnets [4].

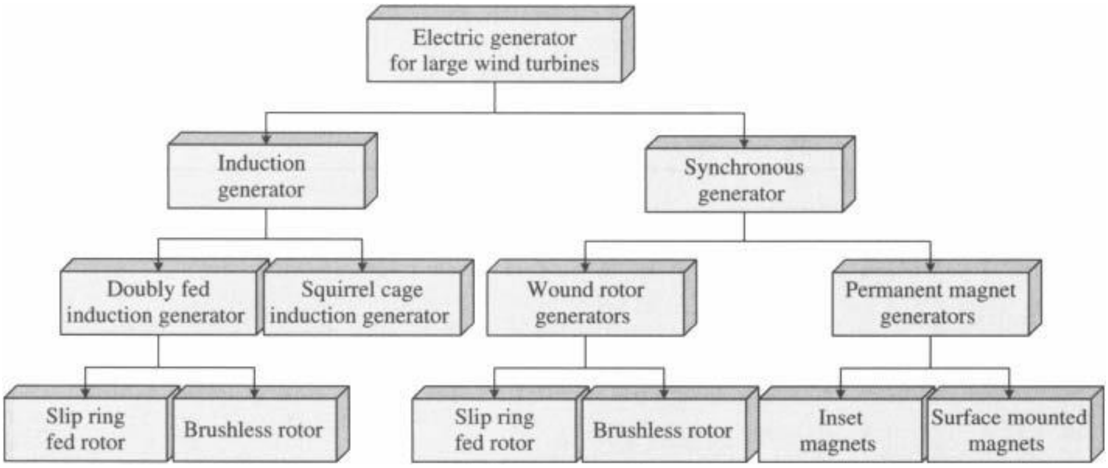


Figure 2.3: Classification of commonly used electric generators in large wind turbines.

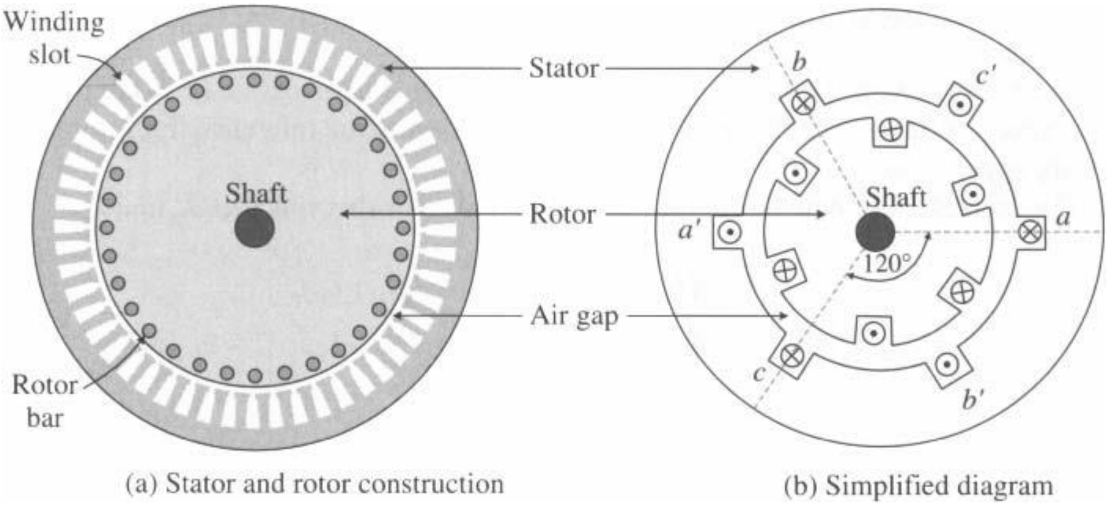
2.3.5.1 Induction generator

There are two main types of induction generators in the wind energy industry: (DFIGs) and (SCIGs). These generators have the same stator structure and differ only in the rotor structure. Figure 2.4 a shows the construction of a squirrel-cage induction generator. The stator is made of thin silicon steel laminations. The laminations are insulated to minimize iron losses caused by induced eddy currents. The laminations are basically flat rings with openings disposed along the inner perimeter of the ring. When the laminations are stacked together with the openings aligned, a canal is formed, in which a three-phase copper winding is placed.

The rotor of the SCIG is composed of the laminated core and rotor bars. The rotor bars are embedded in slots inside the rotor laminations and are shorted on both ends by end rings. When the stator winding is connected to a three-phase supply, a rotating magnetic field is generated in the air gap. The rotating field induces a three-phase voltage in the rotor bars. Since the rotor bars are shorted, the induced rotor voltage produces a rotor current, which interacts with the rotating field to produce the electromagnetic torque.

The rotor of the DFIG has a three-phase winding similar to the stator winding. The rotor winding is embedded in the rotor laminations but in the exterior perimeter. This winding is usually fed through slip-rings mounted on the rotor shaft. In DFIG wind energy systems, the rotor winding is normally connected to a power converter system that makes the rotor speed adjustable.

A simplified diagram of the induction generator is shown in Figure 2.4 b, where the multiple coils in the stator and multiple bars in the rotor are grouped and represented by a single coil for each phase [4].



(a) Stator and rotor construction (b) Simplified diagram

Figure 2.4: Cross-sectional view of an SCIG

2.3.5.1.1 Doubly fed induction generator

The doubly fed induction generator (DFIG) wind energy system is widely accepted in today's wind energy industry. The DFIG is essentially a wound rotor induction generator in which the rotor circuit can be controlled by external devices to achieve variable speed operation. A typical block diagram of the DFIG wind energy system is shown in Figure 2.5 . The stator of the generator is connected to the grid through a transformer, whereas the rotor connection to the grid is done through power converters, harmonic filters, and the transformer.

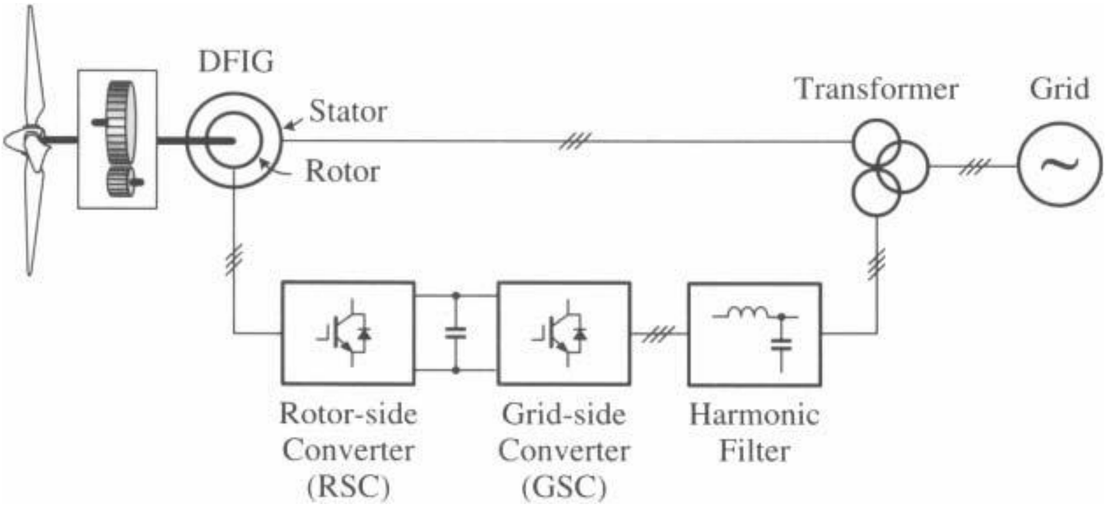


Figure 2.5: Simplified block diagram for DFIG wind energy conversion system.

The power rating for the DFIG is normally in the range of a few hundred kilowatts to several megawatts. The stator of the generator delivers power from the wind turbine to the grid and, therefore, the power flow is unidirectional. However, the power flow in the rotor circuit is bidirectional, depending on the operating conditions [11]. The power can be delivered from the rotor to the grid and vice versa through rotor-side converter (RSCs) and grid-side converters (GSCs). Since the maximum rotor power is approximately.

30% of the rated stator power, the power rating of the converters is substantially reduced in comparison to the WECS with full-capacity converters.

With variable speed operation, a DFIG wind energy system can harvest more energy from the wind than a fixed-speed WECS of the same capacity when the wind speed is below its rated value. The cost of the power converters and harmonic filters is substantially lower than that in the WECS with full-capacity converters. The power losses in the converters are also lower, leading to improved overall efficiency. In addition, the system can provide leading or lagging reactive power to the grid without additional devices. These features have made the DFIG wind energy system one of the preferred choices in the wind energy market.

2.3.5.2 Synchronous Generator

Synchronous generators (SGs) are widely used in wind energy conversion systems of a few kilowatts to a few megawatts. The synchronous generators can be classified into two categories: (WRSGs) and (PMSGs). In the WRSG the rotor flux is generated by the rotor field winding, whereas the PMSG uses permanent magnets to produce the rotor flux. Depending on the shape of the rotor and the distribution of the air gap along the perimeter of the rotor, synchronous generators can be categorized into salient-pole and no salient-pole types.

Similar to the induction generator, the synchronous generator is mainly composed of a stator and a rotor. The construction of the stator of both wound-rotor and permanent-magnet synchronous generators is essentially the same as that of an induction generator and, therefore, is not repeated here. This subsection provides an overview of the rotor configuration for the WRSG and PMSG [4].

2.3.5.2.1 Wound-rotor synchronous generators

The wound rotor synchronous generator has a wound-rotor configuration to generate the rotor magnetic flux. Figure 2.6 illustrates a typical salient-pole WRSG, where only twelve poles are shown for better appreciation of the rotor structure. The field winding is wound around pole shoes, which are placed symmetrically on the perimeter of the rotor in a radial configuration around the shaft to accommodate large number of poles. The generator has an uneven air gap flux distribution due to the salient structure of the rotor.

The rotor-field winding of the synchronous generator requires DC excitation. The rotor current can be supplied directly by brushes in contact with slip rings attached to the shaft and electrically connected to the rotor winding. Alternatively, a brushless exciter physically attached to the shaft can be used. The exciter generates AC currents that are rectified to DC using a diode bridge for the rotor winding. The first option is simple but requires regular maintenance of the brushes and slip rings, whereas the second option is more expensive and complex but needs little maintenance [4].

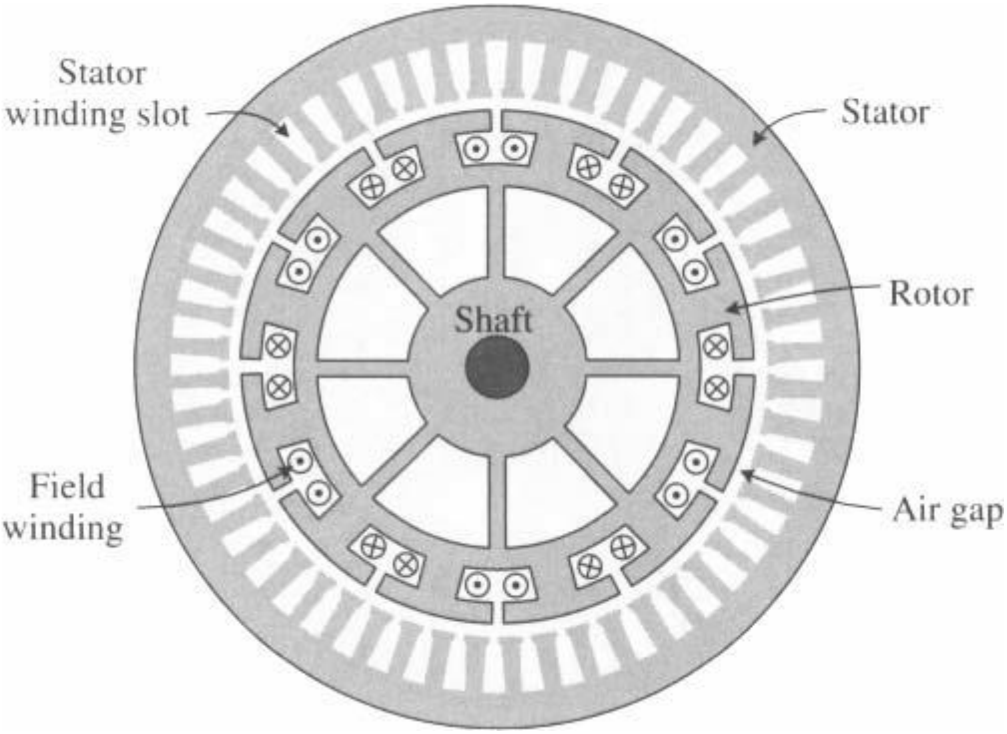


Figure 2.6: Salient-pole, wound-rotor synchronous generator (twelve-pole configuration).

2.3.5.2.2 Permanent-magnet synchronous generators

In the PMSG, the rotor magnetic flux is generated by permanent magnets, and these generators are, therefore, brushless. Because of the absence of the rotor windings, a high power density can be achieved, reducing the size and weight of the generator. In addition, there are no rotor winding losses, reducing the thermal stress on the rotor. The drawbacks of these generators lie in the fact that permanent magnets are more expensive and prone to demagnetization.

Depending on how the permanent magnets are mounted on the rotor, the

PMSG can be classified into surface-mounted and inset PM generators [4].

2.3.6 Yaw drive

The main function of the yaw drive is to maximize the captured wind energy by keeping the turbine facing into the wind. It usually consists of more than one electric motor drive, yaw gear, gear rim, and bearing, as can be observed in Figure 2.7, where a four drive yaw system is illustrated. A set of yaw brakes are disposed around the yaw rim to lock the position of the turbine when facing the wind or during maintenance. The yaw drive uses a planetary gear to lower the rotating speed of the yaw gear. All the motors are commanded by the same signals and lock after turning the wind turbine into the desired position. The yaw system typically needs to generate torque from 10,000 to 70,000 Nm to turn the nacelle. In older wind turbines, the yaw control is also used for power regulation. For example, to limit the power captured by the turbine during high wind gusts, the turbine can be horizontally turned out of the wind. However, this technology is no longer in use since the power regulation by means of yaw control is very limited for three reasons. First, the large moment of inertia of the nacelle and turbine rotor along the yaw axis reduces the speed of response of the yaw system. Second, the cosine relationship between the component of the wind speed perpendicular to the rotor disc and the yaw angle makes the power capture insensitive to the yaw angle. For example, 15 degrees of yaw change only brings power reduction of a few percent. Third, yaw control imposes mechanical stress on different parts of the turbine, causing vibrations that could reduce the life span of the turbine[4].

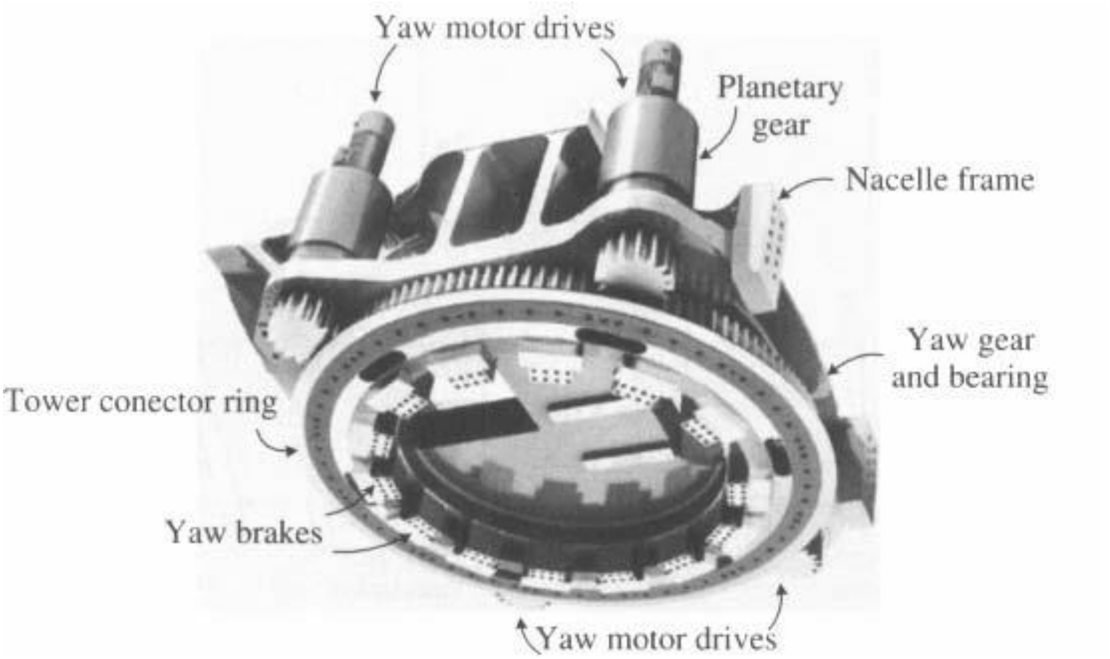


Figure 2.7: Yaw drive system of a large wind turbine

2.3.7 Tower and foundation

The main function of the tower is to support the nacelle and the turbine rotor, and provide the rotor with the necessary elevation to reach better wind conditions. Most towers for wind turbines are made of steel. Concrete towers or towers with a concrete base and steel upper sections are sometimes used as well. The height of the tower increases with the turbine power rating and rotor diameter. In addition, the tower must be at least 25 to 30 m high to avoid turbulence caused by trees and buildings. Small wind turbines have towers as high as a few blade rotor diameters. However, the towers of medium and large turbines are approximately equal to the turbine rotor diameter. The highest tower to date is a 160 m steel lattice tower for a 2.5 MW wind turbine.

The tower also houses the power cables connecting the generator or power converters to the transformer located at the base of the tower. In some cases, the transformer is also included in the nacelle and the cables connect the transformer to the wind farm substation. In large multimegawatt turbines, the power converters may be located at the base of tower to reduce the weight and size of the nacelle. The stairs to the nacelle for maintenance are often attached along the inner wall of the tower in large wind turbines.

Special attention should be given to the structural dynamics in order to avoid vibration caused by the mechanical resonance modes of the wind turbine. The top head mass (THM) of the nacelle and the turbine rotor has a significant bearing on the dynamics of the tower and foundation. In practice, low THM is generally a measure of design for reduction of manufacturing and installation costs [4].

The wind-turbine foundation is also a major component in a wind energy system. The types of foundations commonly used for on-land wind turbines include slab, multipile, and monopile types. Foundations for offshore wind turbines are particularly challenging since they are located at variable water depths and in different soil types. They have to withstand harsh conditions as well. This explains the wide variety of foundations developed over the years for offshore turbines, some more proven than others [9].

2.3.8 Wind sensors (anemometers)

The pitch/stall and yaw control systems require wind speed and direction measurements, respectively. The pitch/stall control needs the wind speed to determine the angle of attack of the blade for optimal operation. The yaw control requires the wind direction to face the turbine into the wind for maximum wind power capture. In addition, in variable speed turbines, the wind speed is needed to determine the generator speed for maximum power extraction.

Most large wind turbines are equipped with sensors, also referred to as anemometers, for wind data collection and processing. The wind speed sensor is usually made of a three-cup vertical-axis microturbine driving an optoelectronic rotational speed transducer. The wind direction is measured by a wind vane connected to an optoelectronic angle transducer. These are the main components of a wind measurement system, and are usually located on the top back part of the nacelle. More than one sensor system may be used in a wind turbine for more reliable and accurate measurements.

Ultrasonic anemometers are also used in practical wind turbines. They measure the wind speed by emitting and receiving acoustic signals through the air and monitoring the transmission time. Several emitters and receptors are disposed in such a way that a three-dimensional measurement can be made. The transmission time is affected by both wind speed and direction. With a given physical distribution of the sensors, the wind speed and direction can be computed from the propagation times. The ultrasonic anemometers are more accurate and reliable tha0n the mechanical ones with moving parts. However, they are more expensive [4].

CHAPTER THREE

POWER ELEYRONIC CONVERTERS

CHAPTER THREE

POWER ELEYRONIC CONVERTERS

3.1 Introduction

Power electronic converters are a family of electrical circuits which convert electrical energy from one level of voltage/current/frequency to another using semiconductor-based electronic switches. The essential characteristic of these types of circuits is that the switches are operated only in one of two states - either fully ON or fully OFF - unlike other types of electrical circuits where the control elements are operated in a (near) linear active region. As the power electronics industry has developed, various families of power electronic converters have evolved, often linked by power level, switching devices, and topological origins. The process of switching the electronic devices in a power electronic converter from one state to another is called modulation, and the development of optimum strategies to implement this process has been the subject of intensive international research efforts for at least 30 years. Each family of power converters has preferred modulation strategies associated with it that aim to optimize the circuit operation for the target criteria most appropriate for that family. Parameters such as switching frequency, distortion, losses, harmonic generation, and speed of response are typical of the issues which must be considered when developing modulation strategies for a particular family of converters [12].

Power Converters are widely used in (WECS). In fixed-speed WECS, the converters are used to reduce inrush current and torque oscillations during the system start-up, whereas in variable-speed WECS they are employed to control the speed/torque of the generator and also the active/reactive power to the grid [13]. According to the system power ratings and type of wind turbines, a variety of power converter configurations are available for the optimal control of wind energy systems.

3.2 Two-level voltage source converters

The primary function of a voltage source converter (VSC) is to convert a fixed DC voltage to a three-phase AC voltage with variable magnitude and frequency. A simplified circuit diagram for a two-level voltage source converter for high-power medium- voltage applications is shown in Fig 3.1. The converter is composed of six group of active switches, S1 ~ S6, with a free-wheeling diode in parallel with each switch. Depending on the DC operating voltage of the converter, each switch group consists of two or more IGBT or IGCT switching devices connected in series [12].

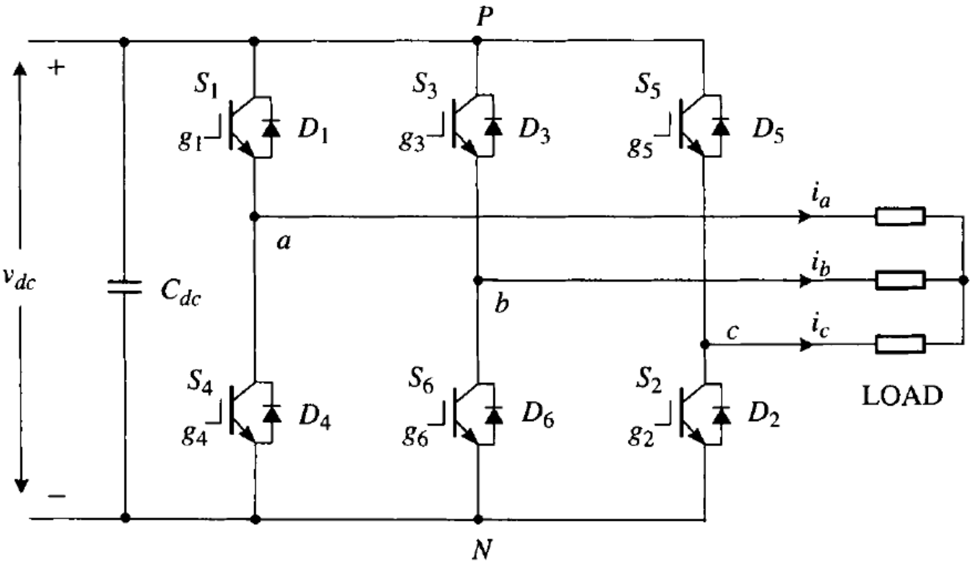


Figure 3.1: Simplified two-level converter

The converter has been widely used in industry for many different applications. When the converter transforms a fixed DC voltage to a three-phase AC voltage with variable magnitude and frequency for an AC load, it is often called an inverter. When the converter transforms an AC grid voltage with fixed magnitude and frequency to an adjustable DC voltage for a DC load, it is normally known as an active rectifier or PWM rectifier. Whether it serves as an inverter or a rectifier, the power flow in the converter circuit is bidirectional: the power can flow from its DC side to the AC side, and vice versa [4].

3.2.1 Sinusoidal PWM

The principle of the sinusoidal PWM scheme for the two-level converter is illustrated in Figure 3.2 , where v_{ma}, v_{mb}, and v_{mc} are the three-phase sinusoidal modulating waveforms and v_{cr} is the triangular carrier signal. The fundamental-frequency component in the inverter output voltage can be controlled by the amplitude-modulation index:

$$m_a = \frac{v\hat{}_m}{v\hat{}_{cr}} \qquad (3.1)$$

where $v\hat{}_m$ and $v\hat{}_{cr}$ are the peak values of the modulating and carrier waves, respectively. The amplitude-modulation index ma is usually adjusted by varying $v\hat{}_m$while keeping $v\hat{}_{cr}$ fixed. The frequency-modulation index is defined by

$$\mathrm{m_f} = \frac{\mathrm{f_{cr}}}{\mathrm{f_m}} \qquad (3.2)$$

where $\mathrm{f_m}$ and $\mathrm{f_{cr}}$ are the frequencies of the modulating and carrier waves, respectively

The operation of switches $\mathrm{S_1}$ to $\mathrm{S_5}$ is determined by comparing the modulating waves with the carrier wave. When $\mathrm{v_{ma}} > \mathrm{v_{cn}}$ the upper switch $\mathrm{S_1}$ in inverter leg a ism turned on. The lower switch $\mathrm{S_4}$operates in a complementary manner and thus is switched off. The resultant inverter terminal voltage $\mathrm{v_{aN}}$, which is the voltage at the phase-a terminal with respect to the negative DC bus N, is equal to the DC voltage $\mathrm{V_{dc}}$.

When $v_{ma} < v_{cn}$, S_4 is on and S_1 is off, leading to $v_{aN} = 0$ as shown in Figure 3.2. Since the waveform of v_{aN} has only two levels, V_{dc} and 0, the inverter is often referred to as a two-level inverter. It is noted that to avoid possible short-circuiting during switching transients of the upper and lower devices in an inverter leg, a blanking time (or dead time) should be implemented, during which both switches are turned off.

The inverter line-to-line voltage V_{ab}can be determined by

$V_{ab} = v_{aN} - v_{bN}$.

The wave form of its fundamental-frequency component v_{ab1} is also given in the figure. The magnitude and frequency of v_{ab1} can be independently controlled by m_a and f_m, respectively.

The switching frequency of the active switches in the two-level inverter can be found from $f_{sw} = f_{cr} = f_m \times m_f$. For instance, v_{aN} in Figure 3.2 contains nine pulses per cycle of the fundamental frequency. Each pulse is produced by turning S_1 on and off once. With the fundamental frequency of 60 Hz, the resultant switching frequency for S_1 is

$f_{sw} = 60 \times 9 = 540$ Hz, which is also the carrier frequency f_{cr} It is worth noting that the device switching frequency may not always be equal to the carrier frequency in multilevel inverters.

When the carrier wave is synchronized with the modulating wave (m_f an integer), the modulation scheme is known as synchronous PWM, in contrast to asynchronous PWM, whose carrier frequency f_{cr} is usually fixed and independent of f_m. The asynchronous PWM features a fixed switching frequency and easy implementation with analog circuits. However, it may generate no characteristic harmonics, whose frequency is not a multiple of the fundamental frequency. The synchronous PWM scheme is more suitable for implementation with a digital processor [4].

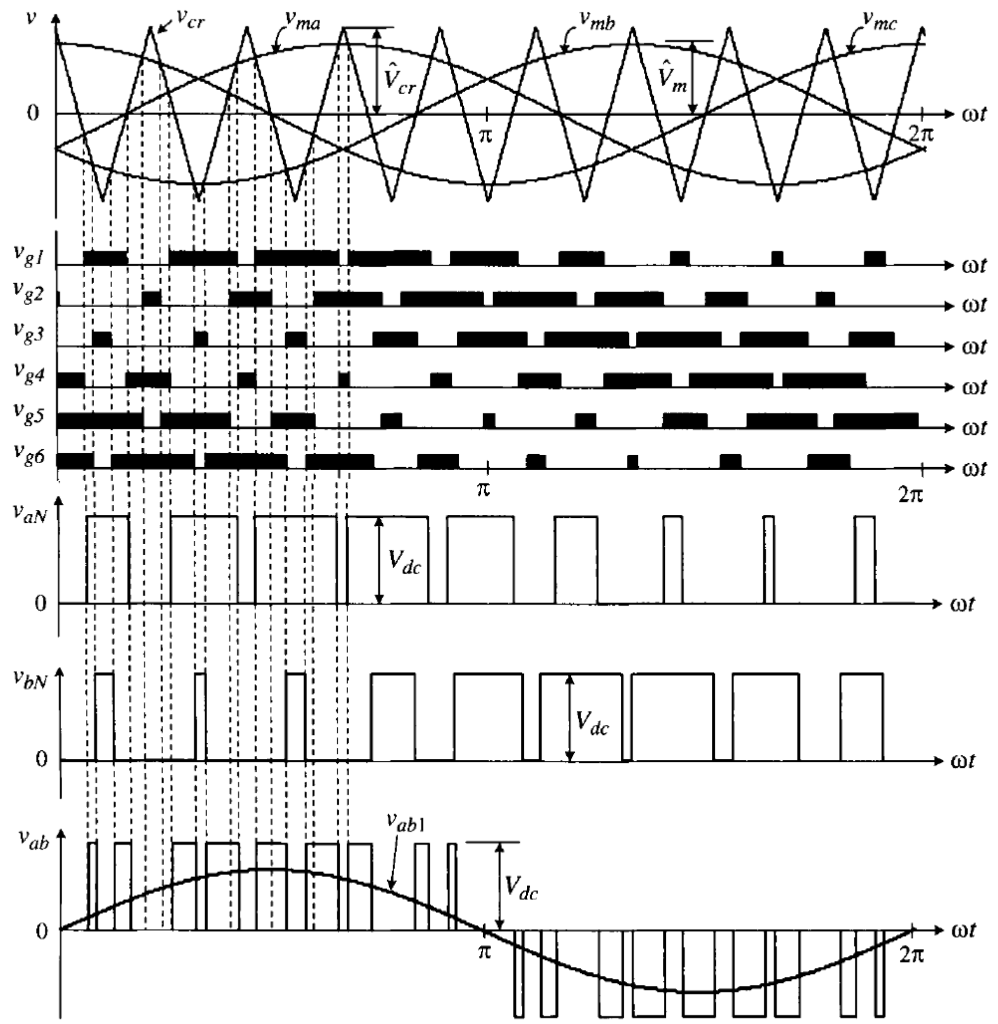


Figure 3.2: Sinusoidal pulse-width modulation (SPWM).

3.2.2 Harmonic contents

Figure 3.3 shows a set of simulated waveforms for the two-level inverter, where V_{ab} is the inverter line-to-line voltage, $V_a$is the load phase voltage and i_a is the load current. The inverter operates under the condition of m_a = 0.8, m_f = 15, f= 60 Hz, and f_{sw}= 900 Hz with a rated three-phase inductive load. The load power factor is 0.9 per phase. We can observe the following:

- All the harmonics in V_{ab} with the order lower than (m_f – 2) are eliminated.
- The harmonics are centered around m_f and its multiples such as $2m_f$ and $3m_f$.

The above statements are valid for $m_f \geq 9$ provided that mf is a multiple of 3 [13].

The waveform of the load current i_a is close to sinusoidal with a THD of 7.73%. The low amount of harmonic distortion is due to the elimination of low-order harmonics by the modulation scheme and the filtering effect of the load inductance [12].

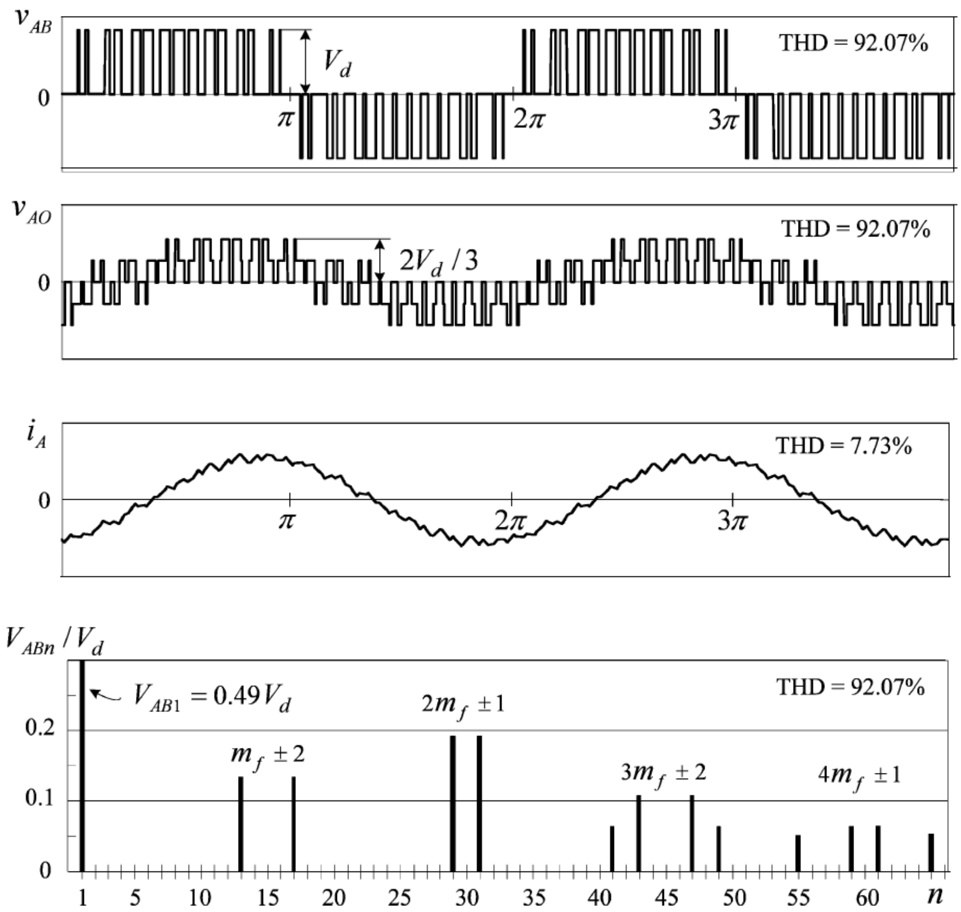


Figure 3.3: Simulated waveforms for the two-level inverter operating at m_a = 0.8, m_f=15, f_m= 60 Hz, and f= 900 Hz.

3.3 Three-level neutral point clamps converters

The diode-clamped multilevel inverter employs clamping diodes and cascaded DC capacitors to produce AC voltage waveforms with multiple levels [16]. The inverter can be generally configured as a three-, four-, or five-level topology, and the three-level inverter, often known as neutral point clamped (NPC) inverter, has found wide practical application, especially in medium-voltage (MV) variable-speed drives [16]. The NPC inverter is also a good candidate for MV (3 kV-4 kV) wind energy systems. The main features of the NPC inverter include reduced dv/dt and THD in its AC output voltages in comparison to the two-level inverter discussed earlier. More importantly, the inverter can be used in the MV wind energy systems without switching devices in series. For instance, the NPC inverter using 6 kV IGBT or IGCT devices is suitable for the 4 kV WECS, for which there is no need to connect the switches in series.

3.3.1 Converter configuration

Figure 3.4 shows the simplified circuit diagram for the three-level NPC inverter. The inverter leg a is composed of four active switches S_1 to S_4 with four antiparallel diodes D_1 to D_4. In practice, either an IGBT or IGCT can be employed as a switching device.

On the DC side of the inverter, the DC bus capacitor is split into two, providing a neutral point Z. The diodes connected to the neutral point, D_{z1} and D_{z2}, are the clamping diodes. When switches S_2 and S_3 are turned on, the inverter output terminal a is connected to the neutral point through one of the clamping diodes. The voltage across each of the DC capacitors is E, which is normally equal to half of the total DC voltage V_{dc}.

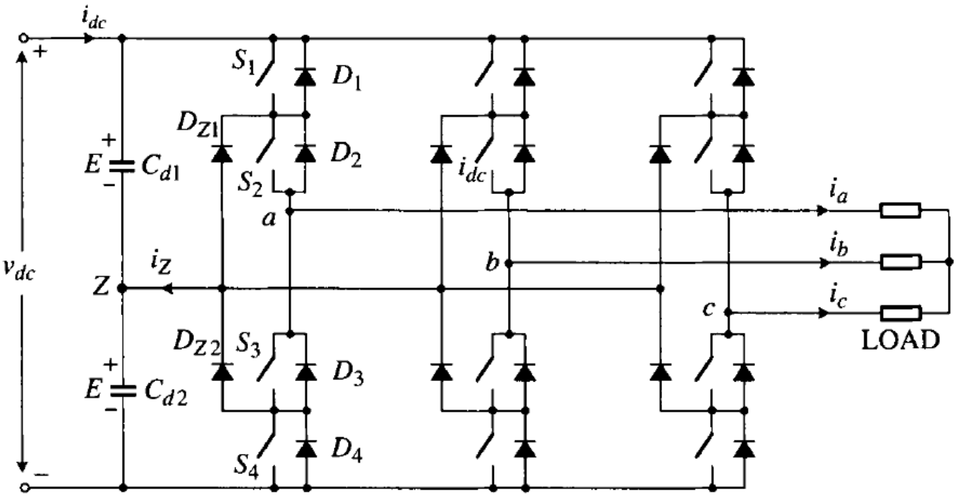


Figure 3.4: Three-level NPC inverter.

The operating status of the switches in the NPC inverter can be represented by switching states as shown in Table 4-5. Switching state P denotes that the upper two switches in leg a are on and the inverter terminal voltage v_{aZ}, which is the voltage at terminal a with respect to the neutral point Z, is +E, whereas N indicates that the lower two switches conduct, leading to $v_{aZ} = -E$.

Switching state O signifies that the inner two switches S_2 and $S_3$are on and $v_{aZ}$is clamped to zero through the clamping diodes. Depending on the direction of load current i_a, one of the two clamping diodes is turned on. For instance, a positive load current ($i_a > 0$) forces $D_{z1}$to turn on, and the terminal a is connected to the neutral point Z through the conduction of D_{z1} and S_2.

It can be observed from Table 3.1 that switches S_1 and S_3 operate in a complementary manner. With one switched on, the other must be off. Similarly, S_2 and S_4 are complementary pair as well.

Table 3.1 Definition of switching states

Switching state	Device switching states (Phase *a)*				Inverter terminal voltage v_{aZ}
	S_1	S_2	S_3	S_4	
P	On	On	Off	Off	E
O	Off	On	On	Off	0
N	Off	Off	On	On	-E

Figure 3.5 shows an example of switching states and gate signal arrangements, where v_{g1} to v_{g4} are the gate signals for S_1, to S_4, respectively. The gate signals can be generated by carrier-based modulation, space vector modulation, or selective harmonic elimination schemes. The waveform for v_{aZ} has three voltage levels, +E, 0, and -E, based on which the inverter is referred to as a three-level inverter

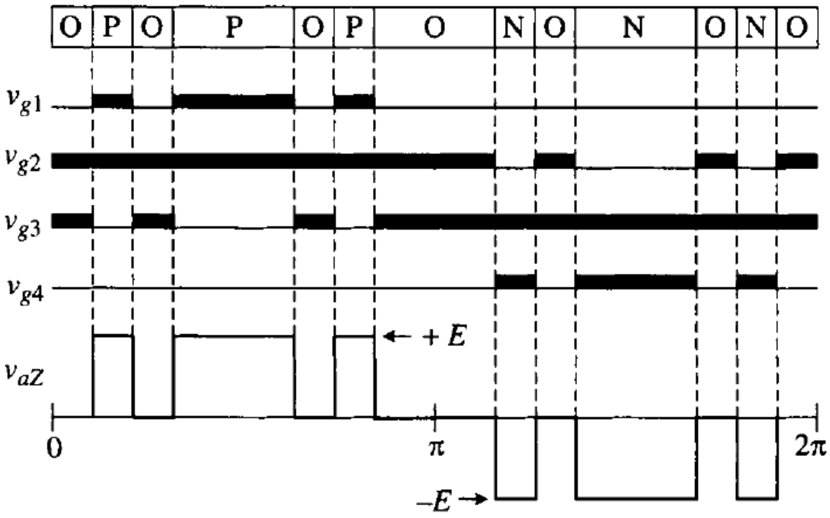


Figure 3.5: Switching states, gate signals, and inverter terminal voltage v_{aZ}.

3.4 Cascaded H-bridge multilevel converter

Cascaded H-bridge (CHB) multilevel converter is one of the popular converter topologies used in high-power (MV) drives [18]. It is composed of a multiple units of single-phase H-bridge power cells. The H-bridge cells are normally connected in cascade on their ac side to achieve medium-voltage operation and low harmonic distortion. In practice, the number of power cells in a CHB converter is mainly determined by its operating voltage and manufacturing cost. For instance, in the MV drives with a rated line-to-line voltage of 3300 V, a nine-level converter can be used, where the CHB inverter has a total of 12 power cells using 600 V class components [17]. The use of identical power cells leads to a modular structure, which is an effective means for cost reduction.

The CHB multilevel converter requires a number of isolated dc supplies, each of which feeds an H-bridge power cell [16].

3.4.1 Five-level cascaded H-bridge converter

As the name suggests, the cascaded H-bridge multilevel converter uses multiple units of H-bridge power cells connected in a series chain to produce high ac voltages. A typical configuration of a five-level CHB converter is shown in Fig. 3. , where each phase leg consists of two H-bridge cells powered by two isolated dc supplies of equal voltage E.

The CHB converter in Fig. 3.6 can produce a phase voltage with five voltage levels. When switches S_{11},S_{12},S_{21}, and S_{22} conduct, the output voltage of the H-bridge cells H1 and H2 is $v_{H1} = v_{H2} = E$, and the resultant inverter phase voltage is $v_{AN} = v_{H1} + v_{H2} = 2E$, which is the voltage at the converter terminal A with respect to the converter neutral N. Similarly, with S_{31}, S_{41}, S_{32}, and S_{42} switched on, $v_{AN} = –2E$.

The other three voltage levels are E, 0, and –E, which correspond to various switching states summarized in Table 3.2 . It is worth noting that the converter phase voltage v_{AN} may not necessarily equal the load phase voltage v_{AO}, which is the voltage at node A with respect to the load neutral O.

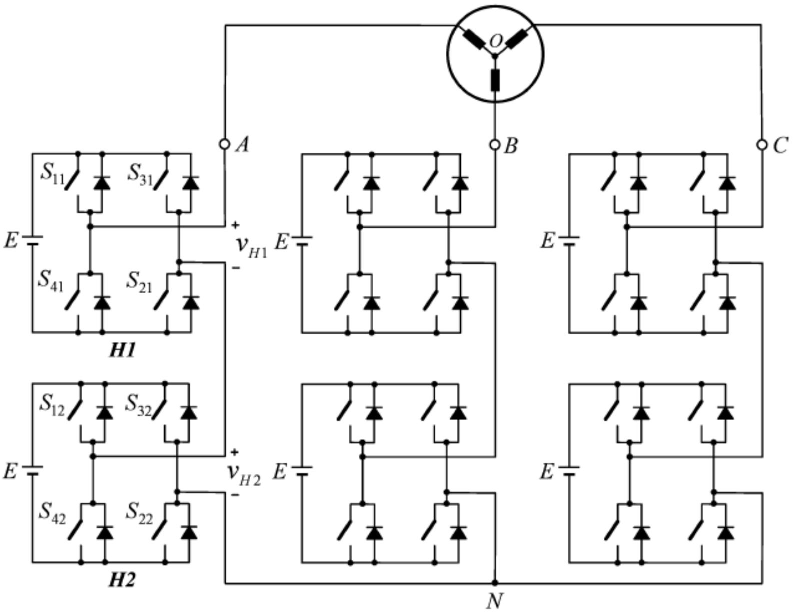


Figure 3.6: Five-level cascaded H-bridge converter.

It can be observed from Table 3.2 that some voltage levels can be obtained by more than one switching state. The voltage level E, for instance, can be produced by four sets of different (redundant) switching states. The switching state redundancy is a common phenomenon in multilevel converters. It provides a great flexibility for switching pattern design, especially for space vector modulation schemes.

The number of voltage levels in a CHB converter can be found from

$$m = (2H+1) \tag{3.3}$$

where H is the number of H-bridge cells per phase leg. The voltage level m is always an odd number for the CHB inverter while in other multilevel topologies such as diode-clamped converters, it can be either an even or odd number [16].

Table 3.2 Voltage Level and Switching State of the Five-Level CHB converter

Output Voltage v_{AN}	Switching state				v_{H1}	v_{H2}
	S_{11}	S_{31}	S_{12}	S_{32}		
2E	1	0	1	0	E	E
E	1	0	1	1	E	0
	1	0	0	0	E	0
	1	1	1	0	0	E
	0	0	1	0	0	E
0	0	0	0	0	0	0
	0	0	1	1	0	0
	1	1	0	0	0	0
	1	1	1	1	0	0
	1	0	0	1	E	-E
	0	1	1	0	-E	E
-E	0	1	1	1	-E	0
	0	1	0	0	-E	0
	1	1	0	1	0	-E
	0	0	0	1	0	-E
-2E	0	1	0	1	-E	-E

3.5 Back-to-back converter

The controlled rectifier and controlled inverter based converter is called back-to-back converter consisting of two conventional (PWM) Voltage Source converters (VSCs). It differs from the diode rectifier based converter for the rectification stage, where the diode rectifier with chopper circuit is replaced by controlled rectifier. The controlled rectifier gives the bidirectional power flow capability, which is not possible in the diode rectifier based power conditioning system. Moreover, the controlled rectifier strongly reduces the input current harmonics and harmonic losses. The grid side converter enables to control the active and reactive power flow to the grid and keeps the DC-link voltage constant, improving the output power quality by reducing (THD). The generator side converter works as a driver, controlling the magnetization demand and the desired rotor speed of the generator. The decoupling capacitor between grid side converter and generator side converter provides independent control capability of the two converters [19]. Figure 3.7 shows the back-to-back converter based wind turbine generator system.

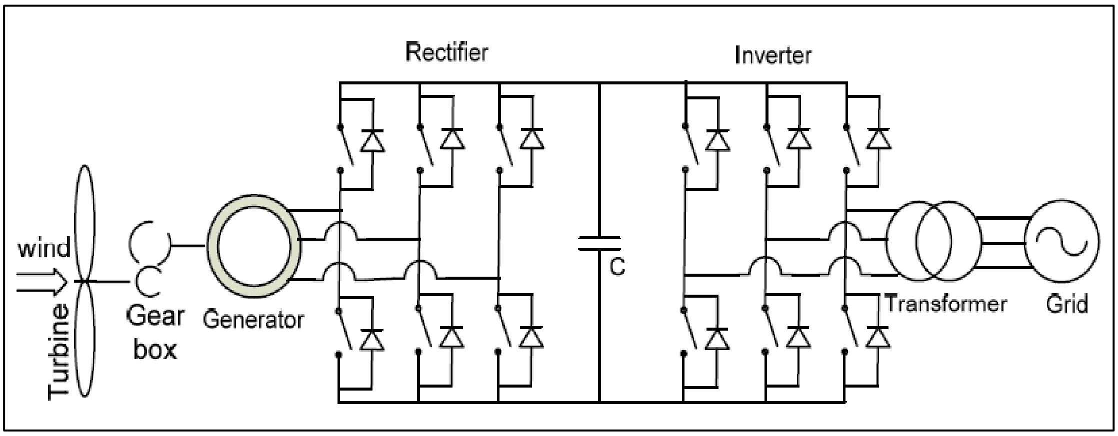


Figure 3.7: Back to back converter based wind turbine generator system

Recently, the back to back converter has also attracted significant interest for partial rating converter applications, where the wind turbine system employs doubly-fed induction generator [19]. To obtain sub- and super-synchronous speed operations the rotor side converter must be able to handle slip power in both directions. When the turbine speed is below the synchronous speed, the power input to the system through the stator winding is balanced by subtracting a small portion of power from the system through the rotor circuit. On the other hand, when the shaft speed is above the synchronous speed the power is balanced by adding a small portion of power to the system through the rotor circuit [19].

The main advantages of back to back converter are:

- The back to back converter is a bidirectional power converter.
- The DC-link voltage can be boosted to a level higher than the amplitude of the grid line to line voltage in order to achieve full control of the grid current.
- The capacitor between the inverter and rectifier makes it possible to decouple the control of the two inverters, allowing the compensation of asymmetry on both the generator side and the grid side.
- The component costs are low (commercially available in a module form) [19].

The main disadvantages are:

- The presence of the heavy and bulky DC-link capacitor increases the costs and reduces the overall lifetime of the system.
- The switching losses. Every commutation in both the grid inverter and the generator inverter between the upper and lower DC-link branch is associated with a hard switching and a natural commutation.

- The high switching speed to the grid may also require extra EMI-filters.
- The combined control of the controlled rectifier and inverter is quite complicated [19].

CHAPTER FOUR

SIMULATION RESULTS AND ANALYSIS

CHAPTER FOUR

SIMULATION RESULTS AND ANALYSIS

4.1 Introduction

In this chapter, the design of the back to back two level voltage source converter and back to back three level neutral diode clamp converter of the doubly fed induction generator has been made, and will be compared .

4.2 Two-level voltage source converter

Pulse Width Modulation-Voltage Source Converter with two-level output voltage (2L-PWM-VSC) is the most frequently used three-phase power converter topology thus far in wind turbines systems. The knowledge available in this field is extensive and it is a well-established technology. As the interface between the generator and grid in the wind turbine system, two 2L-PWM-VSCs are usually configured as a back-to-back structure (2L-BTB) with a transformer on the grid side, as shown in Fig 4.1. A technical advantage of the 2L-BTB solution is the relatively simple structure and few components, which contributes to a well-proven robust and reliable performance [20].

However, as the power and voltage range of the wind turbine are increasing, the 2L-BTB converter may suffer from larger switching losses and lower efficiency at Mega-Watts (MW) and Medium-Voltage (MV) power levels. The available switching devices also need to be paralleled or connected in series in order to obtain the required power and voltage of wind turbines; this may lead to reduced simplicity and reliability of the power converter [21].

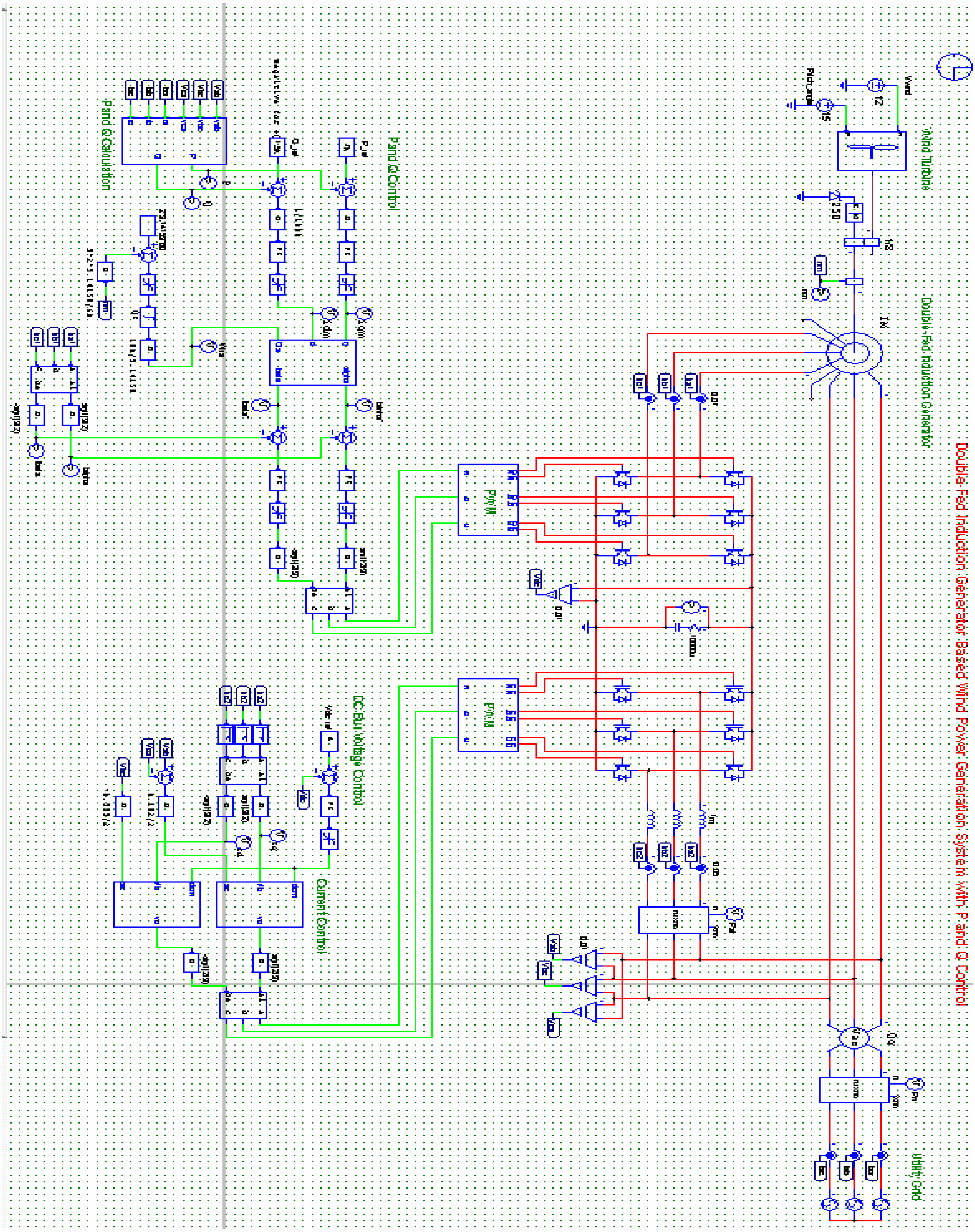


Fig 4.1. Two-level back-to-back voltage source converter for wind turbines.(2L-BTB)

Another problem in the 2L-BTB solution is the two-level output voltage. The only two voltage stages introduce relatively higher dv/dt stresses to the generator and transformer. Bulky output filters may be needed to limit the voltage gradient and reduce the THD [22].

The three phase current and speed for the two level voltage source converter in figure 4.2 and 4.3 respectively

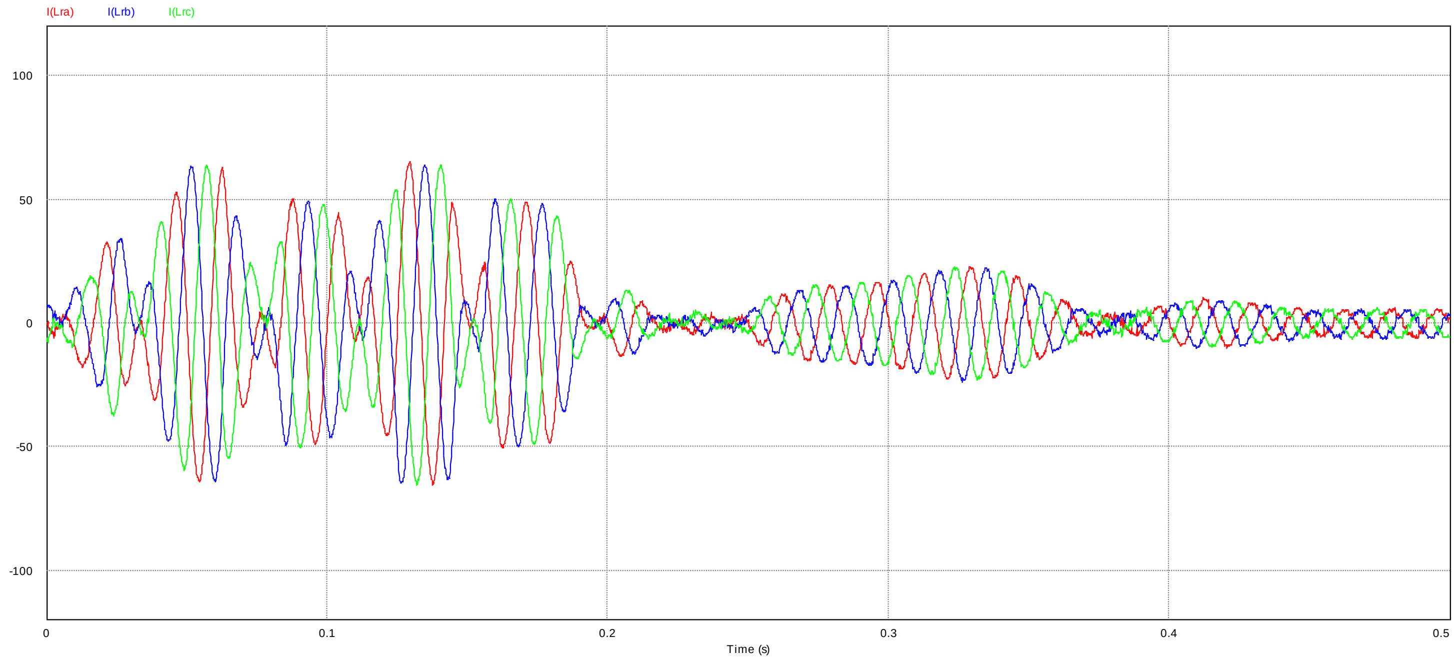


Fig 4.2.Three phase current for (2l-BTB-VSC) for wind turbine

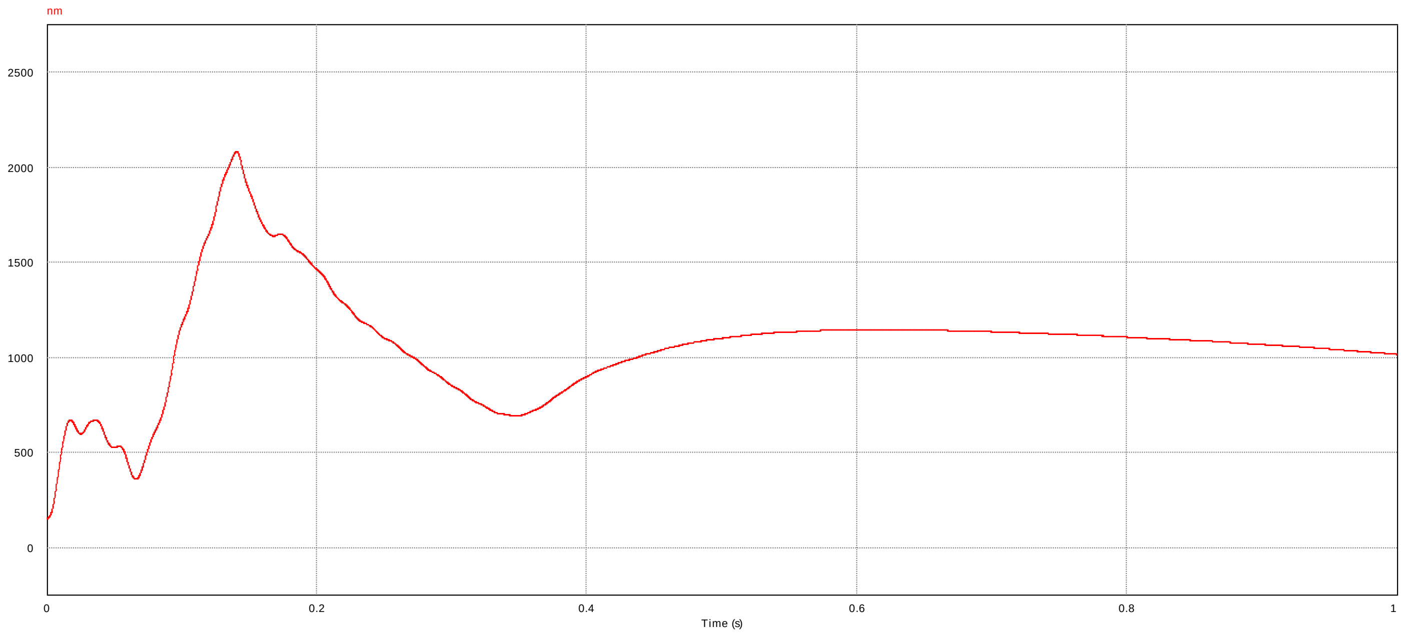


Fig 4.3. Speed for (2l-BTB-VSC) for wind turbine

4.3 Three-level neutral point diode clamped back-to-back topology (3L-NPC BTB)

Three-level Neutral Point diode Clamped topology is one of the most commercialized multi-level converters on the market. Similar to the 2L-BTB, it is usually configured as a back-to-back structure in wind turbines, as shown in Fig 4.4. , which is called 3L-NPC BTB for convenience [20].

It achieves one more output voltage level and less dv/dt stress compared to the 2L-BTB, thus the filter size is smaller. The 3L-NPC BTB is also able to output the double voltage amplitude compared to the two-level topology by the switching devices of the same voltage rating. The mid-point voltage fluctuation of DC-bus used to be a drawback of the 3L-NPC BTB. However, this problem has been extensively researched and is considered solved by the controlling of redundant switching status [23]. However, it is found that the loss distribution is unequal between the outer and inner switching devices in a switching arm, and this problem might lead to de-rated converter power capacity when it is practically designed [24].

The three phase current and speed for the three level voltage
neutral point diode clamped converter in fig 4.2 and 4.3 respectively

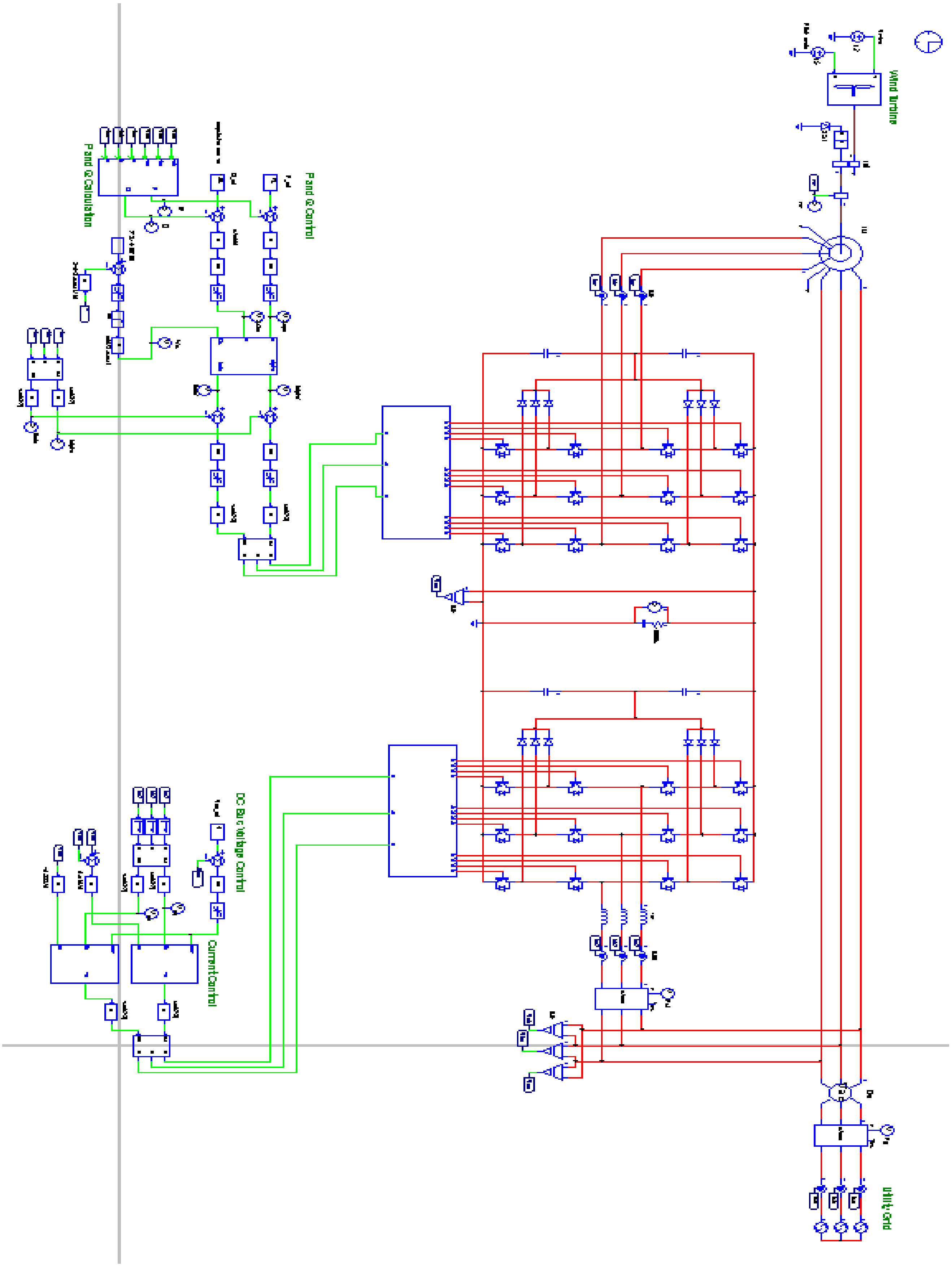


Fig 4.4 Three-level neutral point clamped back-to-back converter for wind turbines. (3L-NPC BTB)

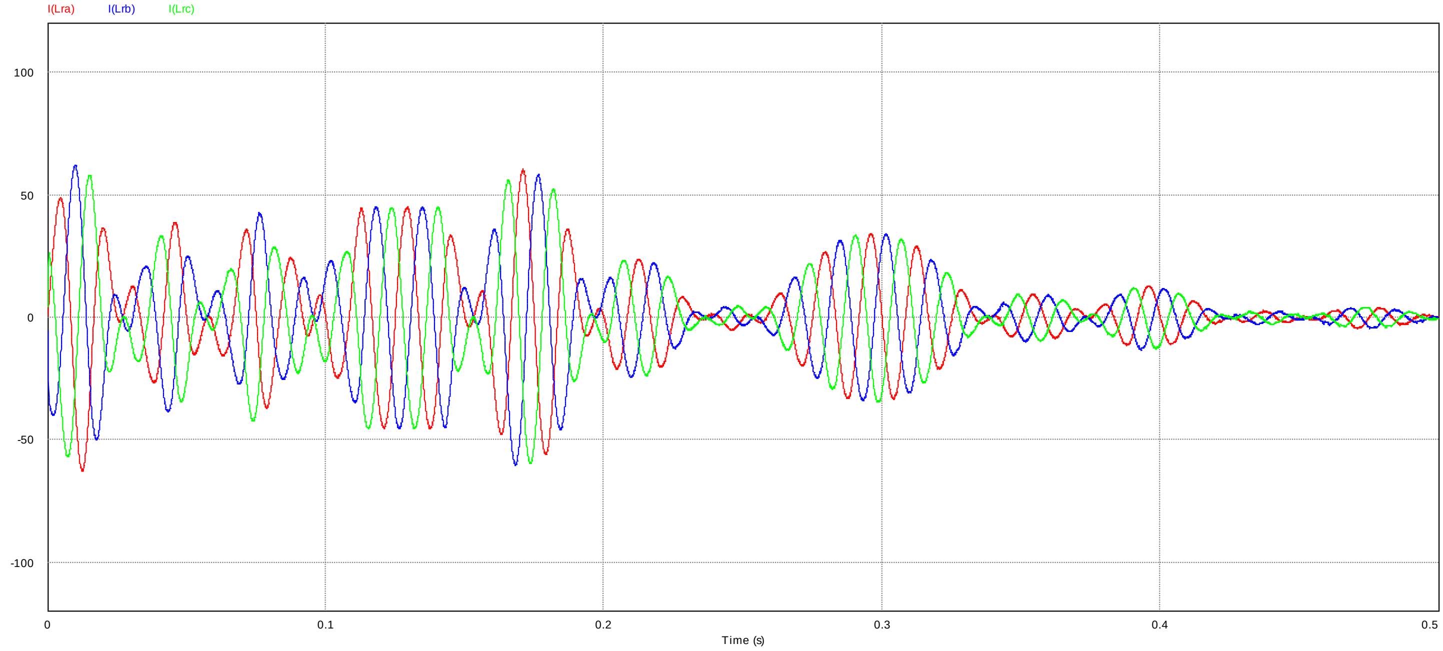


Fig 4.5.Three phase current for (3l-NBC-BTB) for wind turbine

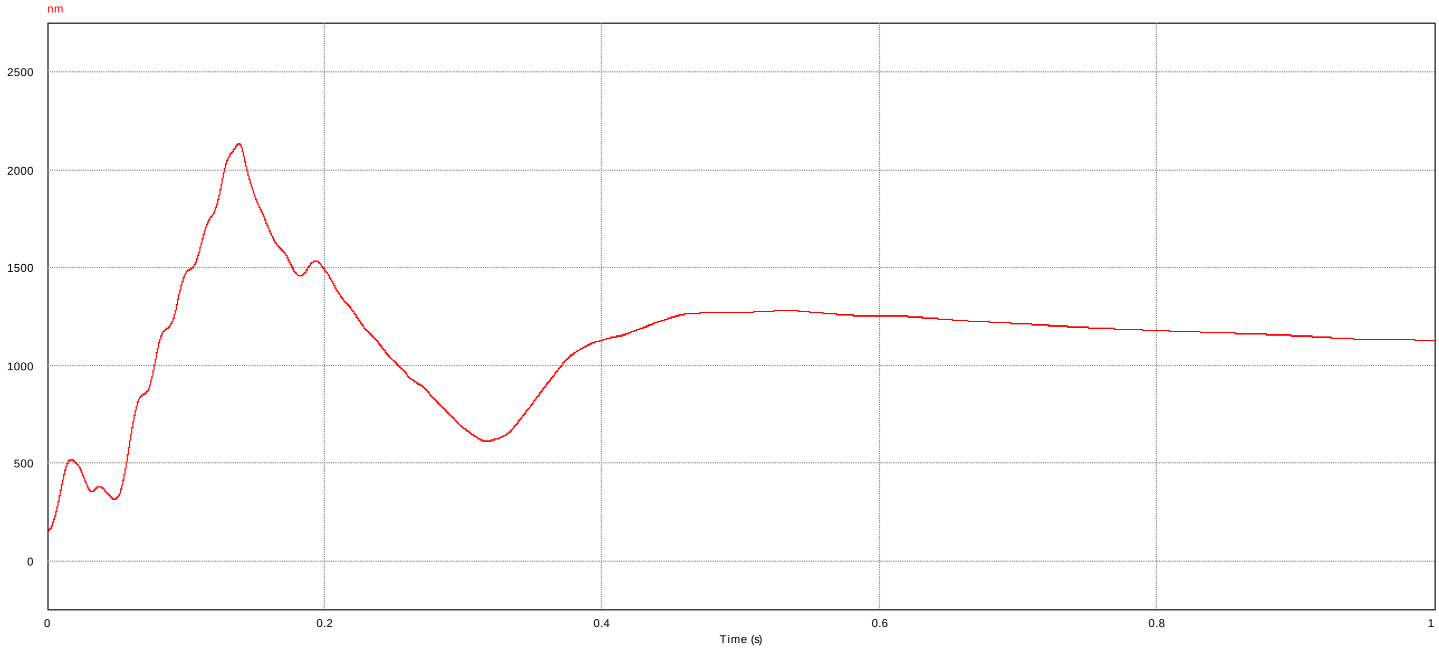


Fig 4.6.Speed for (3l-NBC-BTB) for wind turbine

4.4 Two-level vs. three-level converter

With a 3-level converter the output voltage waveform is produced by using pulse-width modulation with three voltage levels rather than two. This causes the output voltage and current to be less distorted and have a lower THD (total harmonic distortion) compared to the 2-level inverter. Figure 4.7: it is very apparent that the harmonics decrease for the 3-level inverter.

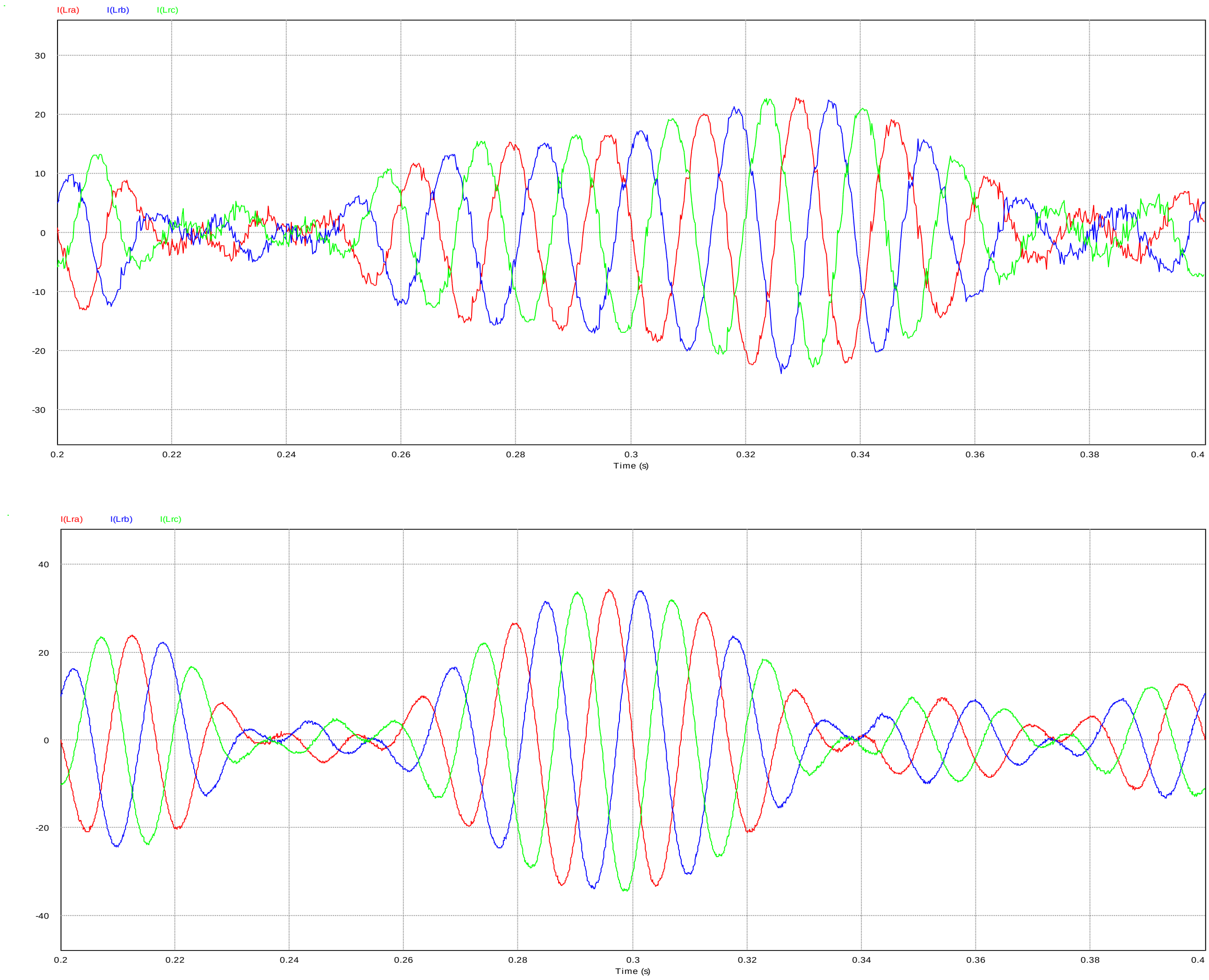


Fig 4.7: Comparison of the 2-level and 3-level converter output currents.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

CHAPTER FIVE
CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This research has summarized the most-recent in the field of the wind turbines regarding generators and converters, and provides the background and basic knowledge of the back-to-back converter for supplying DFIG based wind turbines. The principle of the converter based on the two level VSC topology and 3L-NPC VSC topology are studied in details.

Attention is paid to emerging multilevel converter topologies is a good and effective alternative solution to the classic two-level converter, and the output voltage of a two level VSC converter can assume only two discrete fixed potential values, while the output voltages of a multilevel converter can assume more values. The effect is a reduction of the switching harmonics, giving a more sinusoidal output voltage.

Cost is very often an important deciding factor in choosing whether or not to use power converters and which ones to choose. The multilevel converter has a higher component count than the two level VSC converters, and it can therefore be assumed that it also has a higher cost.

5.2 Recommendations

Based on the above analysis, it is recommended here that:

- There are many types of the wind energy conversion system (WECS) configuration, including WRSG, PMSG, and SCIG. Which can be used in the wind energy conversion with two and multi-level converter, and it is recommended to use and study them to see the effect of increasing levels of current ,voltage and THD with these types

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APPENDIX

APPENDIX

DFIG Data

Stator resistance and inductance Rs=0.1 m Ls=1m

Rotor resistance and inductance Rr=0.1 m Lr=1 m

Magnetizing inductance Lm=10 m

Moment of inertia =50 m

Ns/Nr Turns Ratio=2

Pair of poles= 3

Resistor capacitor branch R=.001 C=10000u

Grid side Peak Amplitude = 180

Grid side frequency =60