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Application of Different ZCS Based Wind Energy Conversion Systems

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Abstract*—Various renewable energy sources currently contribute to the world's power. Due to many air currents dispersed across the troposphere and stratosphere, wind energy is one of the most prevalent renewable energy sources present in the atmosphere. Modern wind energy conversion systems (WECS) are more in demand as a result of the need for a viable alternative renewable energy source. Following a short introduction, the categorization of WECS is examined in this article using eye-catching pictures. We examine the different mechanical and electrical parts of WECS. The paper also explains the power distribution inside WECS and its control mechanisms. The current state of WECS, areas where it could be improved, and possible futures are looked at.

Index Terms*— Wind Energy Systems, ZCS, Wind Energy Conversion Systems, Power Converters, etc.

I. INTRODUCTION

Due to global population growth, rising per capita energy consumption, and extensive industrialization, there is an unceasing increase in the demand for energy. The supply of traditional fossil fuels is constrained [1]. Consequently, there will be additional energy crises in the future. As a result, the use of renewable energy sources, including solar, wind, biogas, tidal, ocean, and solar energy, is growing rapidly. One of them that offers the greatest promise is wind energy. For more than a century, people have utilized wind energy for a variety of things all around the world. Wind energy has been used throughout history in a variety of ways, including the employment of sails on boats and rafts and the powering of grain mills by the wind [6-7].

With different air currents extending over the troposphere and stratosphere, wind energy has historically been the most prevalent kind of energy accessible in the atmosphere. For thousands of years, people have used wind energy for a variety of things all across the world. Wind energy has been used throughout history in a variety of ways, including the use of sails on boats and rafts and the powering of mills to grind grains. Up to the 19th century, wind power was a mainstay of maritime transportation. Around the turn of the tenth century, vertical axis turbines resembling a carousel were discovered in Persia being used to pump water and crush food grains on a very limited scale [8-13]. The term "post mill" refers to the horizontal axis turbines that were used in England and that had to be manually positioned in accordance with the direction of the wind currents. Since the 17th century, large-scale wind energy harvesting has been used throughout Europe [14]. These have paved the way for the 21st century's more efficient and beneficial use of wind, allowing us to store energy in the form of electricity using wind turbines thanks to advancements in design and optimization [15]. Wind turbines, generators, control mechanisms, and an integrating technique make up the wind energy conversion system (WECS), which is an integrated system. By transforming wind energy into mechanical energy, turbines are in charge of capturing the kinetic energy of the wind. The shaft power measured at the rotor shaft and the power present in the wind stream flow determine the efficiency of the turbines [16]. The mechanical components support the moving components and are primarily used to convert electrical energy into mechanical power and transmit it to the system's electrical components. Numerous variables, including wind density, turbine rotor form, blade dimensions, wind velocity, and others, affect how much power may be extracted from a wind current. The high power WECS have a high torque at a low turbine speed. When the turbine shaft is spinning between six and twenty times per minute, these turbines may generate more than 1 MW of electricity. The generator shaft, on the other hand, has low torque and fast speed, so a gearbox is needed to connect it to the rotor shaft [17].

Economy advantages and Benefits of Wind Energy Conversion

- Wind power is cost-effective. Land-based utility-scale wind is one of the lowest-priced energy sources available today, costing 1–2 cents per kilowatt-hour after the production tax credit. Because the electricity from wind farms is sold at a fixed price over a long period of time (e.g., 20+ years) and its fuel is free, wind energy mitigates the price uncertainty that fuel costs add to traditional sources of energy.
- Wind creates jobs. The U.S. wind sector employs more than 100,000 workers, and wind turbine technicians are one of the fastest growing American jobs. According to the Wind Vision Report, wind has the potential to support more than 600,000 jobs in manufacturing, installation, maintenance, and supporting services by 2050.
- It's a clean fuel source. Wind energy doesn't pollute the air like power plants that rely on the combustion of fossil fuels, such as coal or natural gas, which emit particulate matter, nitrogen oxides, and sulphur dioxide—causing human health

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problems and economic damage. Wind turbines don't produce atmospheric emissions that cause acid rain, smog, or greenhouse gases.

• It's sustainable. Wind is actually a form of solar energy. Winds are caused by the heating of the atmosphere by the sun, the rotation of the Earth, and the Earth's surface irregularities. For as long as the sun shines and the wind blows, the energy produced can be harnessed to send power across the grid.

• Wind turbines can be built on existing farms or ranches. This greatly benefits the economy in rural areas, where most of the best wind sites are found. Farmers and ranchers can continue to work the land because the wind turbines use only a fraction of the land. For using their land, the owners of wind power plants pay rent to the farmer or rancher. This gives the farmer or rancher more money.

Militarizing Factors against Effective Wind Energy Conversion

• Wind power must still compete with conventional generation sources on a cost basis. Even though the cost of wind power has decreased dramatically in the past several decades, wind projects must be able to compete economically with the lowest-cost source of electricity, and some locations may not be windy enough to be cost competitive.

• Good land-based wind sites are often located in remote locations, far from cities where the electricity is needed. Transmission lines must be built to bring the electricity from the wind farm to the city. However, building just a few already-proposed transmission lines could significantly reduce the cost of expanding wind energy.

• Wind resource development might not be the most profitable use of the land. Land that is good for putting up wind turbines has to compete with other uses for the land, some of which may be more valuable than making electricity.

• Turbines might cause noise and aesthetic pollution. Although wind power plants have relatively little impact on the environment compared to conventional power plants, concern exists over the noise produced by the turbine blades and visual impacts on the landscape.

• Wind farms can impact local wildlife. Birds have been killed by flying into spinning turbine blades. Most of these problems have been resolved or greatly reduced through technology development or by properly sitting wind plants. Bats have also been killed by turbine blades, and research is ongoing to develop and improve solutions to reduce the impact of wind turbines on these species. Like all energy sources, wind projects can alter the habitat on which they are built, which may alter the suitability of that habitat for certain species.

II. Wind Energy Conversion System

A wind energy conversion system (WECS) is a complex system of interconnected components that operate together to convert the kinetic energy in the wind into mechanical energy and subsequently into electrical energy with the aid of generators.

Wind power has been a fast-growing alternative power source in the world. It is renewable and widely distributed. It also reduces toxic gas emissions. In 2012, global wind energy capacity grew by 19 percent, with the wind industry installing a record level of 44,711 MW of new clean wind power, and over 150,000 wind turbines operating around the world in over 90 countries [1]. In 2013, the global capacity growth rate has been above 14 percent [2].

However, steam engines became progressively more efficient and more economic as the 19th century advanced. Because steam engines could also provide power on demand, the use of windmills went into decline. This decline was accelerated by the later development of internal combustion engines and by the trend in fossil fuels which became more readily available and less costly. Since 1973, the trend of decreasing fuel prices has been sharply reversed, and it is now accepted that the era of very cheap fuel has ended. This trend in addition to the global efforts in reducing greenhouse gas emissions mainly caused by fossil fuels has resulted in investing increasingly in renewable energy sources. Among the various types of renewable energy, wind energy is now emerged as one of the most promising of the renewable energy technologies. It is predicted that by 2020 up to 12% of the world's electricity will be supplied from wind energy [5].

Classification of Wind Energy Conversion Systems (WECSs)

Depending on a variety of variables, the WECSs are divided into many groups. The categorization of WECS based on the system's rotating axis, turbine, power control, rotational speed control criteria is the most prevalent.

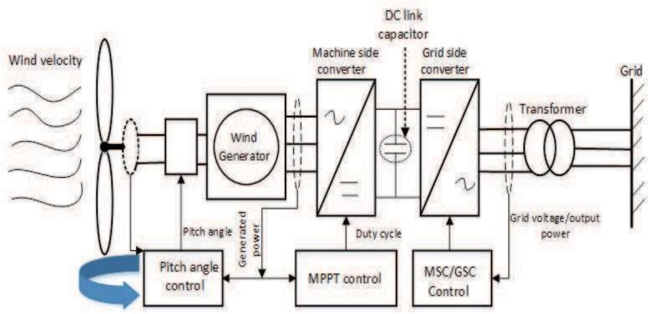

Figure 1: Wind energy conversion system with different control subsystem

Rotational Axis

The horizontal axis wind turbine (HAWT), which spins in an axis parallel to the ground, and the vertical axis wind turbine (VAWT), which rotates in an axis perpendicular to the ground, are two primary axes of rotation that are available for a turbine with regard to the ground. Both kinds of turbine systems have the same purpose: to turn kinetic energy into electrical energy by using the wind pressure that The turbine in this kind of turbine is installed on the shaft, which also serves as the turbine structure's tower, and the rotor's blades are arranged vertically on the shaft. However, there are several VAWT designs, such as the Darrious and Savonious rotor turbines [30]. These turbine types are significantly simpler and less expensive to install and maintain than other kinds. The length of the tower may be kept short since the turbine blades do not need to clear the space between the ground and the rotor's hub, which also lessens shaft vibration brought on by the spinning mass.

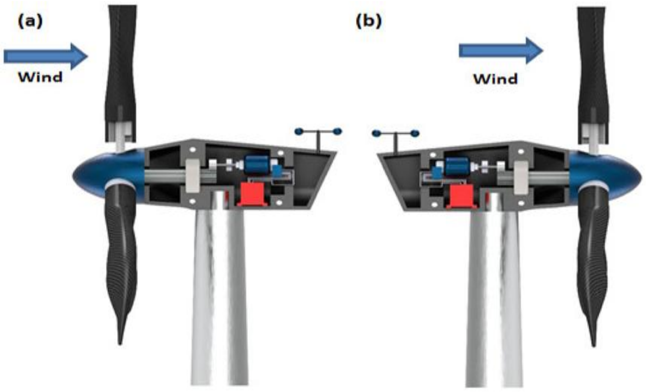

Figure 2: (a) Upwind HAWT (when wind is coming from the front side of the turbine blades)
(b) Downwind HAWT (when wind is coming from the back side of the turbine blades)

Turbines

The electrical output of turbines is another way to classify them. The size of the wind farm is determined by the output power. Based on this, the three types of currently used turbine system technologies are as follows:

a. Low Power turbines: These turbine systems have an average maximum output of 30 kW. These devices are used in distant areas to meet home electrical needs and to recharge batteries. In an emergency, they are also utilised to lessen reliance on conventional power sources; the turbine produces. Depending on the terrain, the shafts of the generator and the turbine are set at different heights and parallel to the ground to face the appropriate wind speed. The turbine's enhanced height also makes it easier for it to revolve with enough clearance from the ground. The mechanical parts of the turbine are housed in an aerodynamically designed structure known as a nacelle.

b. Medium Power Turbines: This category includes turbines with an output ranging from 30 kW to 300 kW. However, in small towns, they are mostly used to power dwellings. They are utilised in conjunction with other renewable energy sources or other power storage technologies.

c. High Power Turbines: These are systems that carry out extensive power generation. These are included in the big wind farms connected to the power networks in charge of distributing electricity across cities.

Power Control

Since wind flow is the only source of electricity that turbines can produce, controllability is crucial in their design. Each turbine is rated to produce a given amount of power, as was already indicated. When the turbine is exposed to greater winds than they were intended to endure, this power is exceeded. While this increases power, there is a chance that mechanical breakdowns might occur because of greater vibrations and the associated imbalanced loads. The three controlling techniques of pitch controllers, active stalls, and passive stalls may be used to limit power generation under higher wind speeds. Grid side controller and phase lock loop controller are two other control strategies. Additionally, a crowbar circuit is included as protection for the whole electrical system [31].

Different optimization strategies are used to get the highest amount of energy possible from the wind resources. These are carried out by simulating the outcomes and modelling the various WECS components.

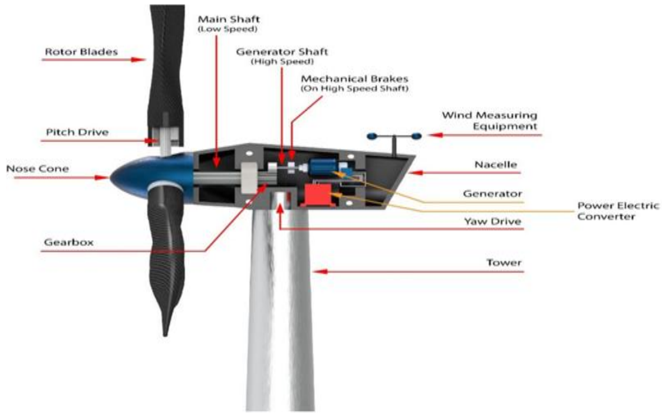

Figure 3: Components of WECS

III. COMPONENTS OF WECS

A symphony between the mechanical and electrical components makes up the WECS, an integrated system. There are several elements that connect the different wind energy conversion system ideas we've already covered. These systems do fact share a lot of parts that allow the kinetic energy of the wind to be converted into electrical energy and then effectively stored in the cells. The wind turbine assembly itself, which is the greatest tangibly present portion of grid-connected WECS, is one of its largest components. The complex mechanical devices that make up wind turbines are made up of a number of tiny parts that feed the electrical parts.

Mechanical Components

A wind turbine's mechanical components play a significant role in the energy conversion process. Due to their dynamic nature, wind flows include some energy. By permitting a mass to rotate and send it to the proper position to interact with the electrical components, the mechanical regime allows for the introduction of "work" into the system. The following are a few of the key mechanical elements of WECS:

a. Rotor: The collection of the hardly distinguishable components that interact with the wind makes up the rotor assembly. The blades, hub, and nose cone make up the assembly. The aerodynamic components that start the drive are the blades. They resemble an aero plane propeller in HAWTs and work on a similar concept. A conventional

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horizontal axis wind turbine's blade produces lift, which causes it to rotate axially as the wind blows.

b. The Main Shaft: The primary shaft, which connects the gearbox to the rotor hub, is a solid extrude produced from either forged high carbon steel or cast iron/steel. Currently, the megawatt-sized wind turbines revolve slowly and have a large torque. The primary shaft is sometimes known as the low-speed shaft as a result. A 5 MW power turbine, for instance, has an input shaft speed of roughly 12 rpm and a torque of about 4000 kNm [18]. From a structural perspective, this torque value may be regarded as excessive, since a torque transmission of 4000 kNm would need around a 9 m cross section of EN316 type steel.

c. Mechanical Brakes: Inside the housing, brakes are safety measures that may be used in an emergency to stop the turbine during storms or strong winds. For effective braking, they are mounted directly onto the low torque, high-speed generator shaft rather than the high torque, low-speed main shaft. By keeping the braking torque low, this prevents them from overheating and breaking down in emergency Brakes that are activated by hydraulic or electromechanical systems are installed on modern high-power turbines (both disc and drum type brake mechanisms). Braking at the generator shaft's maximum speed may lead to heavy wear on the latter and greater fire risks owing to elevated temperatures. As a result, they are only employed once the pitch and/or yaw drives, which lower the rotor's starting speed, have been properly activated.

d. Nacelle: This is the structure that contains the majority of the mechanical parts. The nacelle, which is located on the tower behind the rotor in horizontal axis wind turbines, is the building. The needed reduction and gearbox design have a big impact on the nacelle's size and form. This fibre glass structure's design minimizes turbulence to allow for less vibration throughout the building.

Electrical Components

Both the mechanical and the electrical components are positioned in the nacelle, while certain electrical components are located on the ground distant from the tower. There is a primary role for the electrical subsystem to transform the wind's mechanical energy into electrical energy. Fig. 4 shows a schematic of a typical grid-connected WECS.

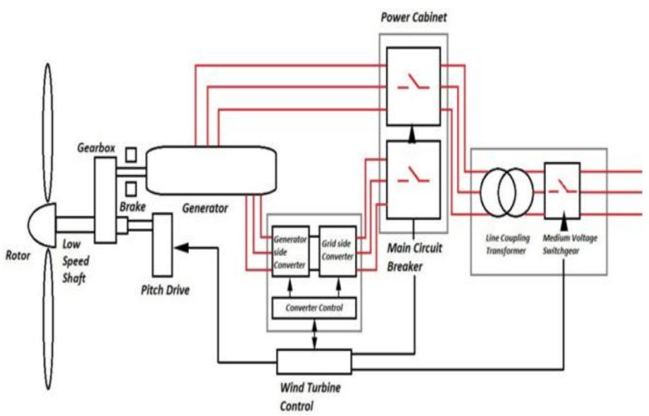

Figure 4: Block Diagram of a typical grid-connected WECS.

The step-by-step conversion begins with the generator, power electronic converters, transformer, wind farm collection point, and power channels etc.

a. Generator: Electromechanical components that convert rotational motion into electrical power are known as wind generators. They transform rotational kinetic energy into electric potential. Using Faraday's electromagnetic induction law, an AC generator moves a conductor loop in a static magnetic field. A squirrel cage induction generator (SCIG) and a wound rotor induction generator (WRIG) were introduced about 35 years ago [27] to the market (WRIG). DFIGs, PMSGs, and wound rotor synchronous generators (WRSGs) are some of the other types of generators in use (WRSG). This kind of WECS has a stator that is connected to the grid, and an external power converter [28].

b. Power Converter: Wind speed has a significant impact on the generator's output electric properties. As a result, various voltages and frequencies would be generated by each turbine at different times, making it impossible to connect them to the grid directly. Thus, a power converter serves as an interface between the turbine and the electric grid. Following a rectifier and an inverter circuit, the power converter transfers the output voltage from AC to DC and back to AC with a constant voltage and frequency.

c. Step-up Transformer: Wind speed has a significant impact on the generator's output electric properties. As a result, various voltages and frequencies would be generated by each turbine at different times, making it impossible to connect them to the grid directly. Thus, a power converter serves as an interface between the turbine and the electric grid. Following a rectifier and an inverter circuit, the power converter transfers the output voltage from AC to DC and back to AC with a constant voltage and frequency.

d. Wind Farm Collection Points or Point of Common Coupling: The point of common coupling (PCC) is a connecting ground of all the turbines of a wind farm. The preferred mode of connection in the wind farms is a parallel connection, which facilitates either maintaining a desired potential difference or having a defined node for connecting more turbines if necessary [24].

IV. Control Techniques Used in WECS

A turbine may benefit from the control systems for safe operation. But in order to power such systems, methods are used that allow the turbine to produce the most power possible under different air circumstances while also extending the structure's lifespan by managing the loading conditions. Pitch angle, yaw angle, and other configurational elements are altered by the strategies, which also define the operating parameters. Some of the control mechanisms that will be addressed in this study are included into the grid-connected WECS. Six tiers of controls, listed chronologically, make up the controls related to contemporary wind energy conversion systems. The first level, or Control Level 1, deals with parameters that change slowly, while Control Level 6 deals with parameters that change quickly. The Level 1 is in charge of giving other control levels power directives. The control hierarchy's loops keep an eye on the WECS's sudden functions. Transmission system and distribution system operators (TSO/DSO) exercise control at Level 1. Control in Level 2: Centralized control for wind farms in Level 3: Centralized control for wind turbines There are mechanical controls and electrical controls at this level. Pitch control and yaw control are mechanical controls. Reactive power generation (RPG) and fault ride-through are two electrical control methods (FRT) Controls that are electromechanical: Damping control

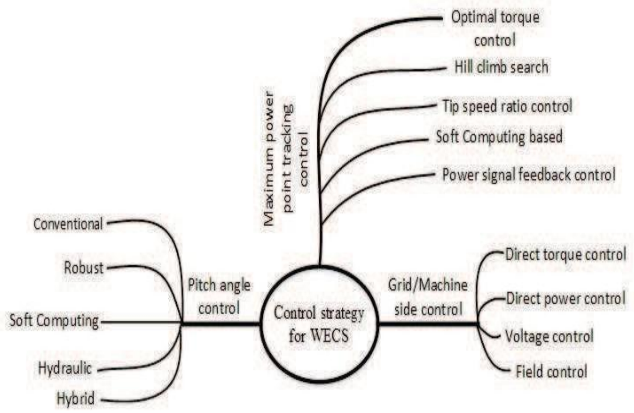

Figure 5: Different control strategy in WECS

a. **Ancillary services**
Control in Level 4: Grid connection (GC) and maximum power point tracking (MPPT) control
a. Integration and synchronization of grid
b. MPPT control
Controls in Level 5: Generator and control of grid
a. Speed, torque and power control of generator
b. Voltage oriented control of grid
Controls in Level 6: Power control converter
a. Current control of generator
b. DC chopper control
c. Current control of grid
The whole control process relies on a feedback mechanism. When there are grid faults, the fault ride-through control of control level 3 generates a fault enable signal, indicating a positive identification of a fault. Mechanical and electrical controls present in control levels 1 through 6 respond to this signal by coordinating for better control performance. The voltage and current of the grid, the angular speed and the voltage and current of the generator, the DC link voltage conditioner, the positioning of the rotor with respect to the mean position, and the wind speed from the anemometer mounted on the nacelle make up the feedback signals in a traditional wind energy conversion system.
Level 1: Transmission system operators or distribution system operators' supervisory control.
The output of a turbine, or even a whole wind farm, is not constant; rather, it changes with uncontrollable wind undulations. Reliability problems and an excessive infiltration of a large scale WECS into the existing power system result from the coupling of this unstable energy waveform with the available pool of energy. The TSO/DSO dispatch centres are connected to the WECSs, which continuously inform them of the statuses of both active and reactive power production. Based on the received status signals, the TSO/DSO transmits active and reactive signals to the appropriate wind farm configuration. Through consistent efforts made by the TSO/DSOs, large-scale wind farms have transformed their operation over time from being passive sources of electricity to active ones.
Level 2: Wind farm centralized control.
This serves as a conduit for communication between the wind farm and level 6 command. In a wind farm, communication wires link each turbine to the central hub. The TSOs and DSOs are informed of the WECS's status via it. The supervision of the operation of the wind farms is carried out by the data gathering and supervisory control systems. The centralized control of a wind farm determines the active and reactive power needs for each individual wind turbine in the farm, which are communicated chronologically according to the number of turbines in the farm. The static compensators of the wind farms, including the static synchronous compensator (STATCOM) and static var compensator (SVC), are started to meet the reactive power generation (RPG), when the centralized control realizes it is unable to do so normally because of the control's high reliance on feedback channels. The centralized control additionally examines the aerodynamic interactions in addition to all the activities needed to fulfil the level 6 criteria.
Level 3: Wind Turbine Centralized Control.
As we established in the categorization, the level 4 of the control system is a collection of electrical, mechanical, and electro-mechanical systems. Pitch and yaw control mechanisms, which are mechanical controls, are in charge of altering the physical operating parameters, while RPG and FRT are in charge of signal alterations and creating electrical controls. Damping is the third control, and it may be either mechanical or electronic. While electrical dampening protects electrical equivalents by reducing electrical sub-synchronous resonance in grids, mechanical damping is required to shield mechanical components from torsional vibrations in the power train and resonances in the tower brought by the wind.

V. PROPOSED Z SOURCE INVERTER BASED DC/DC CONVERTERS

A.Three Phase Quasi–Z Source Network Based DC/DC Converters

A three phase quasi-Z source combination is shown in figure below with DC/DC based converter. VDR helps to increase the density of the power. The capacitors used in the combination are considered as the basis for variation of the output. The inductors are used to provide the optimum power output by providing the constant current. Shoot-through duty cycles are initially adjusted to stabilize the outgoing PV voltage; later, a constant voltage is transmitted to the separation transformer.

The proposed configuration differs from the previous one with extra line divider converter, diode rectifier branch and the zig zag transformer.

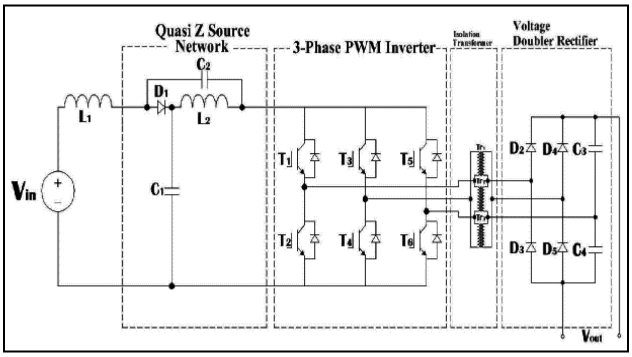

Figure 7: Three Phase Quasi-Z Source Network-Based DC/DC Converter with Isolation Transformer and VDR

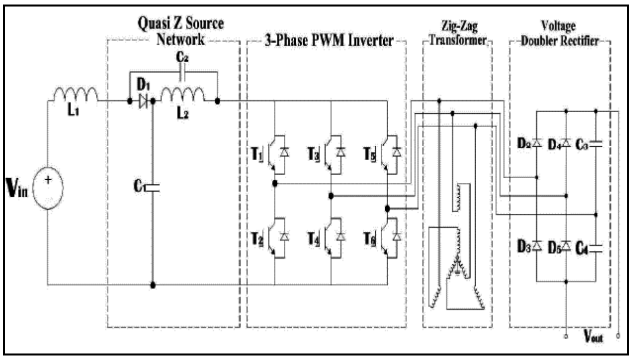

Figure 8: Proposed Three Phase Quasi–Z Source Network-Based DC/DC Converter with Zigzag Transformer and VDR

VI. SIMULATION RESULTS

The simulations are performed in order to study the voltage stress on the capacitors C3 and C4 with constant values of the capacitors C1 and C2. It is to be observed that the voltage stress on each capacitor should be nearly equal in order to get the maximum output from the configurations. At a given input voltage of 100V, the following parameters L1 = L2 = 2mH, C1 = C2 = 20μF and capacitors C3 and C4 various values such as 1.5 μF, 15 μF and 150 μF are randomly selected for the converter. The simulations are performed with different switching configurations with the frequency of 20 Khz. The dc output voltage obtained from these DC / DC converters and the power allocated to capacitors C3 and C4 for a double voltage reset circuit are presented in Tables 1 to 4.

Table 1: Output Dc Voltage Obtained for Three Phase Quasi Z Source Network Based DC/DC Converter with Isolation Transformer and VDR for Various Values of Capacitors C3 and C4 at Different Switching Schemes

Capacitor Values (C_3 and C_4 in μF)	Output DC Voltage (in volts)		
	Simple Boost PWM	Carrier based PWM	SVPWM
1.5	127.91	134.6	133.8
15	141.8	136.8	133.6
150	104.01	103.31	115.35

Table 2: Voltage Stress Shared by Capacitors C3 and C4 of Three Phase Quasi Z Source Network Based DC/DC Converter with Isolation Transformer and VDR

Capacitor Values (C_3 and C_4 in μF)	Voltage Shared by Capacitors C_3 and C_4 (in volts)		
	Simple Boost PWM	Carrier based PWM	SVPWM
1.5	(68.1 V, 59.81 V)	(57.85 V, 78.74 V)	(71.13 V, 62.53V)
15	(77.23 V, 64.56 V)	(60.45 V, 76.37 V)	(74.05 V, 59.54 V)
150	(57.59 V, 56.42 V)	(53.84 V, 49.47 V)	(57.43V,57.92V)

Table 3: Output Dc Voltage Obtained for Proposed Three Phases Quasi-Z Source Network-Based DC/DC Converter with Zigzag Transformer and VDR for Various Values of Capacitors C3 and C4 at Different Switching Schemes

Capacitor Values (C_3 and C_4 in μF)	Output DC Voltage (in volts)		
	Simple Boost PWM	Carrier based PWM	SVPWM
1.5	1041.9	920.3	1153
15	783.4	859.9	956.1
150	481.8	482.9	530.2

Table 4: Voltage Stress Shared by Capacitors C3 and C4 of Proposed Three Phases Quasi-Z Source Network-Based DC/DC Converter with Zigzag Transformer and VDR

Capacitor Values (C_3 and C_4 in μF)	Voltage shared by capacitors C_3 and C_4 (in volts)		
	Simple Boost PWM	Carrier based PWM	SVPWM
1.5	(566.1 V, 475.8 V)	(424.7 V, 405.8 V)	(633.3 V, 519.4 V)
15	(446.1V, 437.3 V)	(374 V, 385.9 V)	(490.7, 465.4 V)
150	(241 V, 240.8 V)	(242.7 V, 240.2 V)	(264.8 V, 265.4 V)

The results presented in above tables shows that, the capacitor values C3 and C4 when varied, shows significant change in the output and the voltage stress on the capacitors. The value of 15 µF gives optimum output in different switching methods for the inverter combination with isolation transformer, while the voltage stress on each capacitor is nearly equal with the capacitor value of 150µF. For the proposed converter with zigzag transformer, the maximum output is achieved at lowest value of the capacitors and the equal voltage stress is achieved with the capacitor value of 150µF.

VII. CONCLUSION

The simulation results for the Z source converter with different configurations and different switching methods are discussed in this paper. The isolation transformer and VDR based DC/DC converter output is varied with variation in the capacitor values C3 and C4 . The results show that, the output is maximum with the capacitor value of 15 µF whereas the voltage stress on the capacitors is nearly equal with 150 µF capacitor.

Table 3-4 presents the converter with Zigzag Transformer and VDR. The variation of capacitor values shows that, the maximum output is available with capacitor value of 1.5 µF. While the voltage stress is nearly equal with the 150 µF capacitor. For the proposed combination the 15 µF capacitor is selected in the proposed combination.

Modern wind energy conversion systems have come a long way and have been built using a variety of technologies. However, it offers a wide range of opportunities in the near future. The emphasis being shifted away from fossil fuel sources based on carbon has created a plethora of options that are just waiting to be explored. The mechanical and electrical parts of typical WECSs were thoroughly covered in this review study, along with the many design modifications that have aided in classifying the systems. The ecological uses of WECS and wind farms received a lot of attention in this review. Additionally, because wind flow is a less reliable energy source, the hydropower plant may be another sustainable alternative energy source. The least amount of water is used during the production of wind energy. It emits the fewest greenhouse gases overall. Following hydropower, photovoltaic, and geothermal as the most favorable social effects and sustainable renewable energy sources, respectively

Due of the former's suitability with large-scale power generation, HAWT designs for WECS have been embraced by the majority of commercial applications. Different methods and tactics for control were addressed. In the current setting, the majority of wind turbines use doubly fed induction generators, the control techniques of which have been listed to reflect the key characteristics of each design. The developing technologies for using wind energy have been emphasized in the context of the current situation, and future emerging technologies have also been discussed. Over the last several decades, wind energy has become significantly more reliable. In the foreseeable future, the growth of wind energy and other renewable energy sources will both continue.

According to our research, the most important components of wind turbines are the materials for the blade and generator. The recycling of composite is a cross-sector concern since synthetic polymer matrix composite materials are used in numerous wind power plant components. This major difficulty affects the supply chain companies as well as the wind power facilities themselves. In order to find efficient solutions and value chains for the total amount of composite waste, all the sectors involved with synthetic polymer matrix composite materials must work together to investigate the issue.

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