Vienna Rectifier Based Design for DFIG Energy System Using Pi/Fuzzy Controller

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Abstract- **Vienna rectifier as generator-side converter of wind energy conversion system (WECS) using a induction generator(IG) has several advantages compared to conventional back-to-back inverter , such as higher efficiency and improved total harmonic distortion. On the other hand, direct torque control (DTC) of the generator in WECS is of interest, particularly for low-power applications due to several merits, including fast torque response, insensitivity to model and associated parameters, elimination of rotor position sensor, and reduced computations. In this paper, the effects of Vienna rectifier voltage variations are determined using PWM technique, and DTC of induction generator by the Vienna rectifier is implemented, considering the constraints imposed by the Vienna rectifier. Experimental tests for a1-kW prototype are presented, which confirm the simulations and theoretical results.**

Index Terms- **Vienna rectifier, DTC, high voltage gain, low switching loss.**

I. INTRODUCTION

Wind energy is regarded as an important renewable energy resource compared to other types, mainly because of its cost effectiveness and high reliability [3-4]. On the other hand, the popularity of induction generator grows day to day in the wind power industry, particularly for direct-driven wind turbine applications, due to capability of multiple-pole design , high efficiency, high reliability, low weight, and low volume. Consequently, the demand for power electronic devices with higher rating at lower cost has risen, particularly when all energy should go through the grid interface system. Several topologies are proposed to be utilized as grid interface system, mainly focused on improving the generator side converter. Most common topologies employ three-phase diode rectifier and three-phase pulse width-modulation (PWM) rectifier as generator-side converter [15].

In configurations using a diode rectifier, the dc-bus voltage is the control parameter to adjust IG speed . Therefore, the requirement for controlling rectifier output voltage leads to employing a dc/dc converter or a z-source inverter [7].

Although the diode rectifier has cost and reliability advantages, however, the following drawbacks cause a tendency for three-phase PWM rectifier:

- high-generator-current total harmonic distortion (THD);
- torque oscillations which result in decreasing efficiency and lifetime ;
- uncontrolled generator power factor.

In order to overcome these problems, a three-phase six-switch rectifier (SSR) is utilized. Since conventional SSR has six semiconductor switches, several topologies are proposed and investigated to decrease system cost by lowering the number of switches and reviewed in . A three-switch buck-type rectifier as generator-side converter is used in which is robust but requires an extra stage to boost dc voltage [10]. A z-source inverter is utilized as grid-side inverter to boost voltage and improve system robustness against short circuit. It should be noted that the z-source inverter has a lower efficiency and requires two capacitors and inductors compared to conventional SSR. Another topology is a half-controlled converter presented . This low-cost topology is reliable and able to work in high frequency, but the generator current THD deteriorates compared to conventional SSR. Also, this topology produces even harmonics, which is undesirable. Employing a neutral point clamped (NPC) converter as generator-side converter is investigated in . Lower voltage stress and power quality make this converter a good choice.

For high-voltage applications, where switching frequency is limited. However, due to higher cost, it is not popular for low-voltage systems. It is worth to bring attention to papers describing matrix variables converter as grid interface.

In such configuration, the power converter requires no bulky and costly in energy storage components also, the controller is simple, because of one-stage ac–ac operation.

Objective: The main aim of this project presents a Vienna rectifier based design for offshore wind energy system using PWM technique. The results demonstrate low switching loss high gain and high power density

II.VIENNA RECTIFIER

The VIENNA rectifier and the three-level power structure results in a low blocking voltage stress on the power semiconductors and a small input inductor value and size. Therefore, Vienna is an ideal choice for the implementation of a medium power, unity power factor rectifier that also has a high power density. Three-phase AC to DC diode rectifier with three low-power and low frequency, four quadrant switches, with high power factor. The main features were low cost, small size, high efficiency and simplicity. The high power factor was achieved with three active bidirectional switches rated at a small fraction of the total power, and gated at the line frequency.

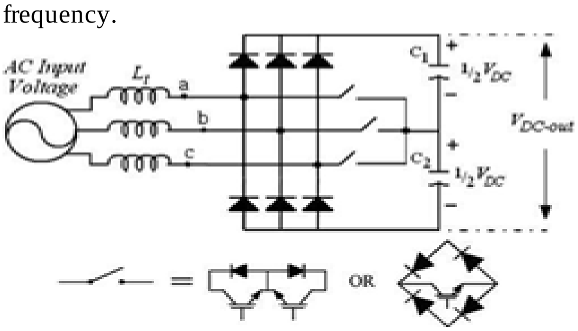

Fig. 1. Vienna Rectifier

The Vienna rectifier has the output capacitors C1 and C2. Each of the bi-directional switches sa, sb, sc can be built by using one switch and one diode bridge rectifier or two switches and two diode rectifiers. All these components are switched in such a manner that the EMI noise and the power losses are reduced and only smaller magnetic are needed, thus saving cost and improving converter reliability. Moreover, made sure only the standard high-frequency low-cost powdered iron-core type or ferrite-core type input inductors are used.

III.WIND ENERGY

Energy is the primary and most universal measure of all kinds of work by human beings and nature. Everything that happens in the world is the expression of flow of energy in one of it forms .

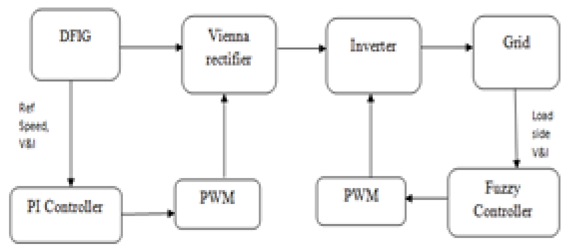

Fig. 2. Block Diagram of Proposed System

Energy is an important input in all sectors of a country's economy. The standard of living is directly related to per capita energy consumption. An excellent style manual for science writers is Due to rapid increase in the population and standard of living we are faced with energy crisis. Conventional sources of energy are increasingly depleted. Hence, Non-Conventional Energy Sources have emerged as potential source of energy in India and world at large. Among the various non-conventional energy sources, wind energy is emerging as the potential major source of energy for growth. Wind results from air in motion due to pressure gradient that is caused by the solar energy irradiating the earth.

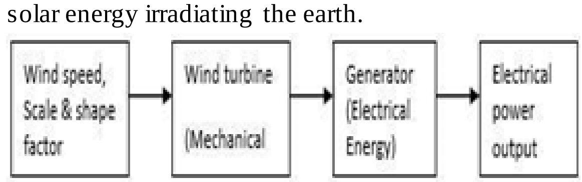

Fig. 3. Conversion of Wind Energy to Electrical Power

IV.WIND POWER

Wind possesses energy by virtue of its motion .Any device capable of slowing down the mass of moving air can extract part of the energy and convert into useful work.

Following factors control the output of wind energy converter:

- •The wind speed
- •Cross-section of the wind swept by rotor
- •Conversion efficiently of rotor
- •Generator
- •Transmission system

Theoretically it is possible to get 100% efficiency by halting and preventing the passage of air through the rotor. However, a rotor is able to decelerate the air column only to one third of its free velocity.
A 100% efficient wind generator is able to convert maximum up to 60% of the available energy in wind into mechanical energy. In addition to this, losses incurred in the generator or pump decrease the overall efficiency of power generation to 35%

A.PRINCIPLE OF ENERGY CONVERSION

Wind mills or turbines works on the principle of converting kinetic energy of the wind in to mechanical energy.
Power available from wind mill = ½ þA V³
þ – air density = 1.225 Kg. / m³ at sea level.(changes by 10-15% due to temperature and pressure variations)
A – area swept by windmill rotor = þD² sq-m.
(D – diameter)
V – wind speed m/sec.
Air density, which linearly affects the power output at a given speed, is a function of altitude, temperature and barometric pressure. Variation in temperature and pressure can affect air density up to 10 % in either direction. Warm climate reduces air density.
The combined effects of wind speed and rotor diameter can be observed by the following graph.

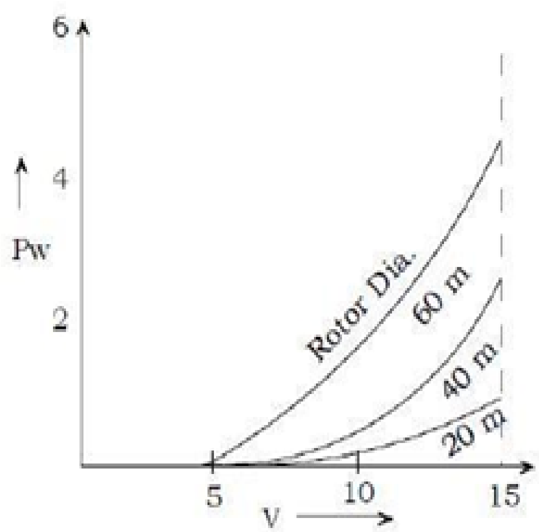

Fig. 4. Graph of Wind Speed and Rotor Diameter

This graph indicates that wind machines should have large rotors and should be located in areas of high wind speeds.

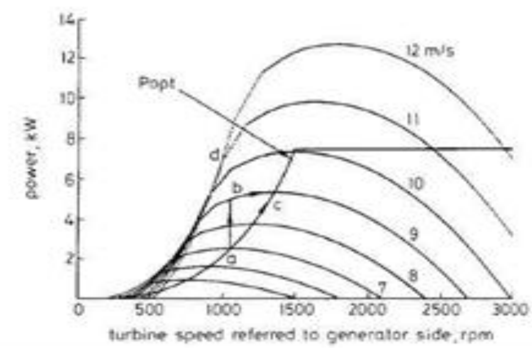

Fig. 5. Wind turbine characteristics

V.INDUCTION GENERATOR MODEL AND EQUATIONS

A double-Fed induction generator is a standard wound rotor induction generator with its stator windings directly connected to the power grid and rotor connected to the power grid through a frequency Converter. In modern DFIG designs, the frequency converters are usually built by two, three phase self-commutated back-to-back PWM converters with an intermediate capacitor link for DC bus voltage regularity. The converter that is connected to the rotor called 'rotor side converter' and the other named 'grid side converter'. By controlling the grid and rotor converters, the DFIG can be adjusted to achieve many capabilities versus conventional squirrel cage induction generators. dq representation of DFIG machine for the stator side, are given by

$\lambda ds = - Lsids + Lm\ idr$ (1)
$\lambda qs = - Lsiqs + Lm\ iqr$ (2)
$Vds = -Rsids - \omega s\lambda qs + d\lambda ds/dt$ (3)
$Vqs = -Rsiqs - \omega s\lambda ds + d\lambda qs/dt$ (4)

For rotor side
$\lambda dr = - Lridr - Lm\ ids$ (5)
$\lambda qr = - Lriqr + Lm\ iqs$ (6)
$Vdr = Rridr - s\omega s\lambda qr + d\lambda dr/dt$ (7)
$Vqr = Rriqr + s\omega s\lambda ds + d\lambda qr/dt$ (8)

The electrical output power from the induction generator is given by
$Ps = 3/2\ (vdsids + vqsiqs)$ (9)
$Pr = 3/2\ (vdridr + vqriqr)$ (10)
$Pg = Ps - Pr$ (11)

Where Ps is the power delivered by the stator side, Pr is the power delivered by the rotor side, Pg is the total power generated and delivered to the grid.

In addition reactive power and the electrical torque is given by

$$Qs = 3/2(vqsids - vdsiqs) \quad (12)$$

$$Te = - 3/2(\lambda dsiqs - \lambda qsids) \quad (13)$$

VI. DESIGN AND CONTROL OF AC-DC-AC PWM

POWER CONVERTER

A. DESIGN OF PWM

In the electric generation system that contains variable-speed wind tribunes, there exist three components. These are wind tribune, generator, and power converter. Power converters consist of two subsections: generator-rectifier and inverter-grid or load. In AC/DC and DC/AC power converters, different power electronic elements can be used. In this study, in the PWM power converter circuit, a two-level voltage source rectifier (VSR) and in the two-level voltage source inverter (VSI) circuit, an IGBT circuit element was used.

The grid-side inverter will draw harmonic currents inside the grid or load and because of the load impedance, harmonic voltages will occur. The voltage harmonics are in the most irregular position when the converters (rectifiers and inverters) are used. Because of the current and voltage harmonics, the quality of the obtained power will be the worst value. By using various control methods and filtering circuits, reactive power can be kept under control.

It must protect or regulate the output voltage and frequency values of the wind power generation systems according to the predetermined operation values. After the output voltage and frequency of the system are regulated according to the pre-determined values, it can be connected to the grid or load. This kind of regulation to the desired voltage and frequency values is made by means of power electronic circuit elements. During the realization of the power electronic interface circuit, any output variables of the wind power generation system (voltage, frequency, active, and reactive) must be controlled according to the determined reference value.

In this study, the inverter of the wind power generation system is connected to the load side. DC-AC PWM inverter consists of 6 IGBT (insulated gate bipolar transistors) semi conductive elements. It can be used as a voltage source converter. To operate the VSC, minimum DC link voltage is required. To increase the voltage phases of VSC and DC/DC converters of which voltage phases increase step by step can be defined. VSC can be operated both as an inverter and rectifier.

B.CONTROL STRATEGY OF GENERATOR-SIDE AC-DC PWM CONVERTER

In the variable-speed wind energy conversion system, there are two devices used for AC-DC conversion. One is a passive diode rectifier, which can easily convert AC to DC but cannot control its output voltage, and there may be much harmonic current in the AC source. The other conversion device is the active rectifier, which has a switching circuit topology of AC-DC power conversion. The active rectifier can convert variable frequency and variable voltage to a fixed DC voltage. In the case of IG variable-speed wind energy system, the power is generated at variable voltage both in frequency and amplitude. The power electronic interface is required to convert the variable voltage and frequency into a constant grid or load voltage and frequency.

In this study, two back-to-back PWM power converters are used for VSWECS. For generator-side converter, the full-bridge three-phase IGBT-PWM active rectifier is shown. The IGBT-PWM active rectifier is used as voltage regulator and it is controlled by using a current control algorithm .The reference speed is calculated according to the wind turbine output power and regulated to the desired output power.

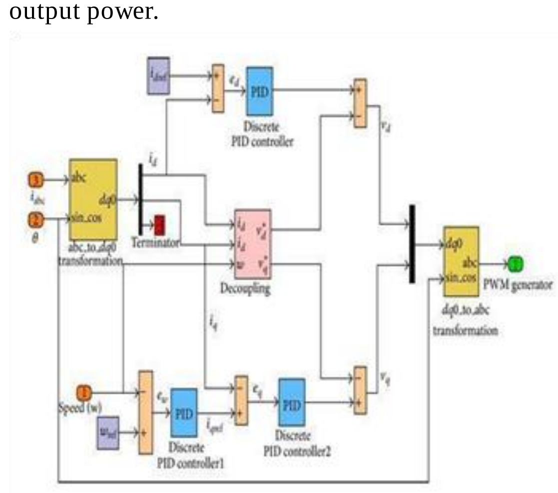

Fig. 6. Block Diagram of Generator side PWM Converter

Based on the speed error, the commanded q-axis reference current iqref is determined through the speed controller. In this system, the following proportional-integral (PI) controller is employed as the speed controller

$iq\text{ref} = Kpe\omega + KI\int e\omega dt$ (1)

While the fault between reference speed and measure speed is eω, the gain parameters of the speed controller are, respectively, KP and KI, which are proportional and integral gain parameters. d-q-axes voltages demanded depending on fault currents are determined by means of the current controller. In this system, the following PI controllers with decoupling terms are utilized for the current controller

$V^*d = Kpi\text{ed} + KIi\int \text{eddt} + \omega r\text{Lidm}$ (2)

$V^*q = Kpi\text{eq} + KIi\int \text{eq}\ dt - \omega r(\text{Lidm} - \text{Ke})$ (3)

where KPi and KIi are the proportional and integral gain coefficients of the current controller, respectively; ed = idref − id is the d-axis current error and e q = i qref − i q is the q-axis current error. The decoupling terms (−ω r L q i q) and ω r(L d i d + λ m) are used , respectively, for the independent control of the d- and q-axis currents. The commanded dq-axes voltages (v d*, v q*) are transformed into the physical abc quantities (v a*, v b*, v c*) and given to the PWM generator to generate the gate pulse for the IG-side converter. The output voltage of the IG is adjusted with the active rectifier.

C.GRID-SIDE INVERTER CURRENTS

The basic relations for active and reactive powers delivered to the grid are given by

$P\text{grid} = 3/2(V\text{dgrid}.\text{idgrid} + V\text{qgrid}.\text{iqgrid})$ (4)

$Q\text{grid} = 3/2(Vq\text{grid}.id\text{grid} - Vd\text{grid}.iq\text{grid})$ (5)

where Pgrid and Qgrid are the active and reactive powers delivered to the grid respectively .v is the grid voltage, and i is the grid current. The subscripts “dgrid” and “qgrid” stand for the d and q-axis components of grid variables. For a balanced grid voltage, qgrid is equal to zero in synchronous reference frame.

Therefore, the active and reactive power equations simplify as

$P\text{grid} = 3/2(V\text{dgrid} \cdot \text{idgrid})$ (6)

$Q\text{grid} = -3/2(V\text{dgrid} \cdot \text{iqgrid})$. (7)

Considering (6) and (7), the active and reactive powers are controlled by idgrid and iqgrid, respectively. The dc-bus voltage error generates a reference value for iq (iqgrid) using a proportional–integral controller. This automatically delivers extracted power to the grid.

Qgrid = 0means a 180◦ phase difference between grid voltage and injected current to the grid.

Although a conventional SSR is used in this paper as grid side converter, two balanced dc voltages of Vienna rectifier provide the opportunity of utilizing a three-level NPC inverter B-4 inverter . The NPC inverter decreases the harmonics injected to the grid and increases efficiency, and the B-4 inverter decreases the total cost as it contains only four switches in the structure. Considering cost, efficiency, or power quality, the choice of two-level, NPC, or B-4 inverter can be determined.

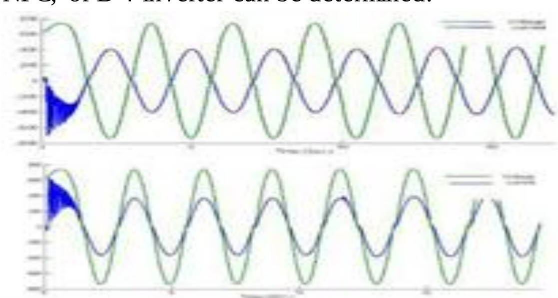

Fig. 7. Rotor Voltage And Current.(a) Under Sub-Synchronous. (b) Under Super-Synchronous.

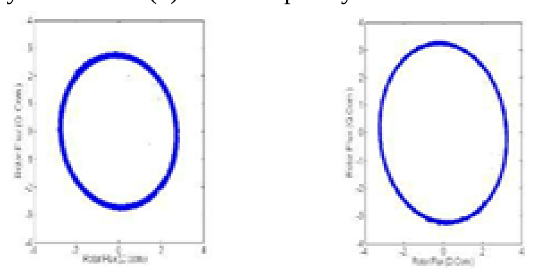

Fig.8. Rotor Flux.(a) Sub-Synchronous.(b)Super-Synchronous.

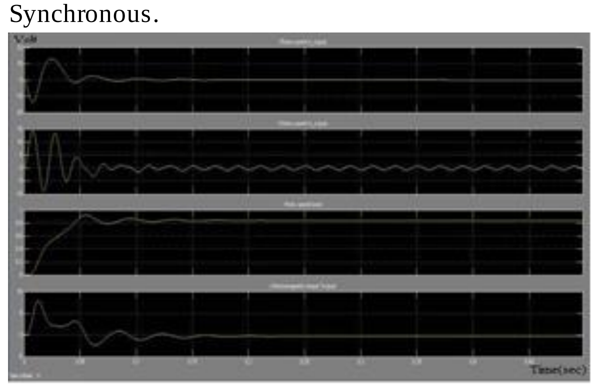

Fig. 9. (a) WIND SIDE Rotor Current, Stator Current, Rotor Speed, Electromagnetic Torque.

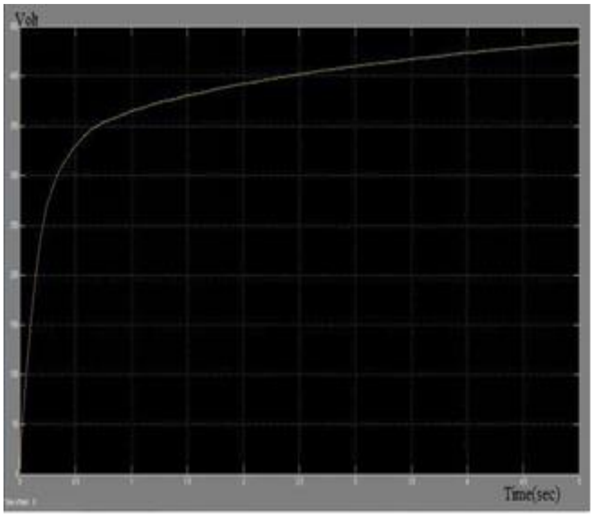

Fig.9. (b). Subsystem: Vienna Rectifier Output.

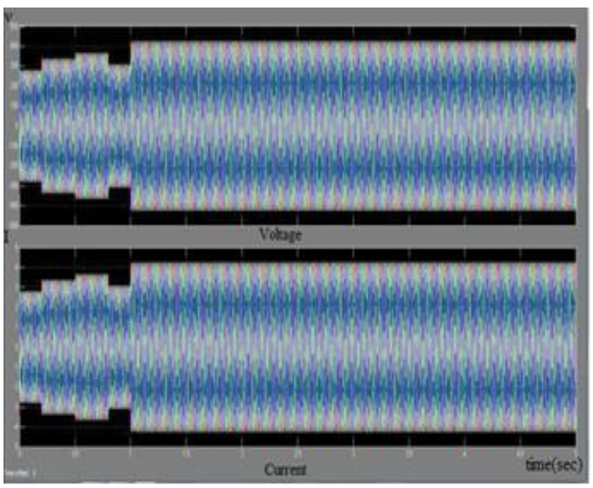

Fig. 10. Output Waveform

VII. CONCLUSION

The Vienna rectifier has been used as a DFIG generator-side converter to rectify ac output voltage of IG wind generator. Due to various advantages of PWM technique, such as insensitivity to generator parameters, reduced computation time, and position sensor elimination, PWM was implemented for Vienna rectifier control. PWM-controlled WECS was simulated. An experimental setup was implemented to validate system performance, which confirmed the simulation results and theory.

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