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# Analysis of Hybrid Renewable Energy System using NPC Inverter

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***Abstract:*** *In a variable-speed wind energy conversion system (WECS), the mechanical frequency of the generator varies, and in order to keep the stator voltage and frequency constant, the rotor voltage and its frequency have to be varied. Thus the system requires a power conversion unit to supply the rotor with a variable frequency voltage that keeps the stator frequency constant irrespective of the wind speed. The rotor of a doubly fed induction generator (DFIG) driven by a wind turbine needs rotor excitation so the stator can supply a load or feed the grid. In the scheme proposed, the rotor of the DFIG draws power either from three-phase ac mains or from a set of photo voltaic (PV) panels depending on the availability of the solar power. Maximum power point tracking techniques can be used for power extraction. A neutral point clamped multi-level inverter is used to convert the rectified voltage from ac mains and dc voltage from PV panels to a variable frequency voltage to supply the rotor.*

***Keywords—****doubly fed induction generator; boost regulator; NPC multilevel inverter; photovoltaic panel; wind turbine*

## I. INTRODUCTION

Since the amount of energy available from conventional sources is limited, non-conventional energy sources are considered for power generation. Among these sources, wind and solar power are the most abundant and attractive. For wind energy conversion, fixed speed systems using squirrel cage induction generator were implemented earlier. At present, variable speed systems are being used for system operation with higher efficiency, absence of speed control, and reduced flicker. Generally doubly fed induction generators (DFIGs) are used for variable speed wind energy conversion systems (WECSs). Permanent magnet machines which do not need gear box can also be used, but not for high capacity installations. The power converter, in the case of DFIG, needs to provide only 20%-30% of the output power, so the system can use converters as well as filters with lower ratings.

The increasing use of power from renewable sources has made it necessary for the sources to behave, as much as possible, like conventional power plants in terms of supporting the network voltage and frequency with good power quality. Several schemes have been proposed to solve these problems. In most DFIG-based WECSs, the load or grid is directly connected to the stator of the DFIG, and the rotor injection is controlled using an ac-dc-ac converter. Instead of two back-to-back converters, a diode rectifier followed by an inverter can also be used. For systems with only rotor-side converter, pulse width modulation (PWM) converters are used where the grid side PWM rectifier is controlled to provide a constant dc link voltage and the rotor side PWM inverter controls the generator to provide required real and reactive power. In these schemes, the mechanical and electrical frequencies are decoupled making variable speed operation possible. Back to back multilevel inverters were also tried by some researchers for higher capacity installation. In this paper, a new power conditioning scheme is proposed for DFIG-based WECS that uses a 3-phase diode rectifier followed by a boost regulator as grid side converter and a multilevel neutral point clamped (NPC) inverter to supply variable frequency voltage to the rotor. The system also includes photo voltaic (PV) panels which can supply the boost regulator and reduce the power drawn from the utility. The proposed system includes voltage feedback to regulate the output voltage from the DFIG.

## II. PROPOSED POWER CONVERSION SYSTEM

Fig. 1 shows the complete block diagram of the proposed system designed using the software PSIM PSIM has a wind turbine model with variable wind speed and blade pitch angle input, and a wound rotor induction machine model that can be used as a DFIG. The boost regulator provides a constant dc-link voltage for the inerter from the variable voltage dc input from the rectifier. Using a diode rectifier instead of a PWM rectifier not only reduces the complexity of the system but eliminates the need for additional control. The reason for using a multilevel inverter is its ability to provide a better output power quality and lower switch ratings. The present scheme uses a three-level inverter with neutral point clamping whose output voltage is controlled by controlling the amplitude modulation index. The control voltage needed for this purpose is generated by the inverter controller based on vector control scheme that uses the d-q axis current control. Using maximum power point tracking (MPPT) technique, the torque reference (Tref) is calculated for a given generator speed. The q axis current reference (Iqref) is then generated by minimizing the difference between the reference and actual torques. On the other hand, the stator side voltage is controlled to generate d axis current reference (Idref). The d-q axis reference rotor currents provide the control voltage (Vctrl) which is used to generate the gate pulses for the 12 switches of the inverter. The inverter voltage is then fed to the rotor of the DFIG.

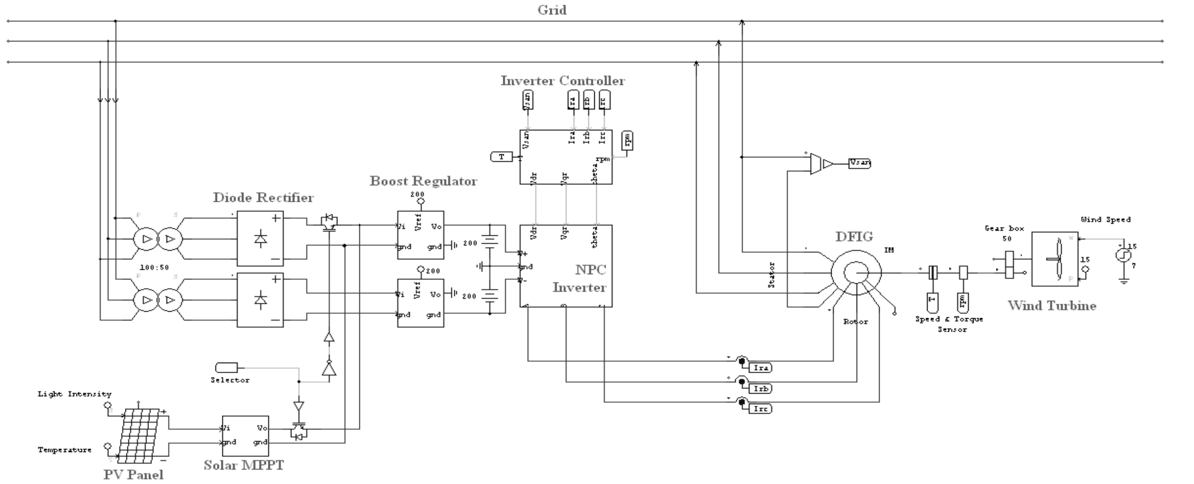



**Fig 1: Circuit diagram of proposed system**

**A. Rectifier and Boost Regulator**

A boost regulator whose output is constant irrespective of the fluctuations in the input voltage and load. It is done by varying the duty cycle (D) for the switch so that the output given by the equation, Vout = Vin / (1-D) is always constant. Using a triangular wave and a comparator, a gate pulse with a duty cycle proportional to the PI controller output is generated. For fast simulation, the average model of the boost regulator has been used. The average model basically uses two dependent sources to realize the following equations derived from boost regulator operation.

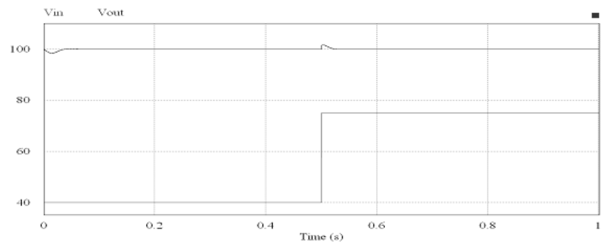



**Fig 2: Step input voltage and constant output voltage**

**B. NPC Inverter (Diode Clamped)**

In order to get a higher fundamental output voltage and power level, the dc-link voltage (Vdc) for the conventional bridge inverter has to be increased which means one has to use a series-connected pair in place of each device. The connection of matched devices in series, considering dynamic voltage sharing during switching, is difficult. So this scheme uses a 3-level neutral point clamped (NPC) inverter which consists of 4 switches with anti parallel diodes and 2 diodes per phase. The switches Qa1 and Qa4 are the main switches that work together like a conventional 2-level bridge inverter. The auxiliary switchesQa2 and Qa3 clamp the output potential to the neutral point with the help of the clamping diodes. Thus they insert a new potential level in the output voltage, resulting in reduced harmonics. The simulation results show that, without any filter, the THD for the NPC inverter is about 11.2% compared to 25% for the bridge inverter. The harmonic spectra shows that not only the THD is lower for NPC inverter but also the individual harmonics have been reduced with the lowest order harmonic (LOH) = mf – 4 where mf is the ratio between the triangular frequency and reference sine frequency.

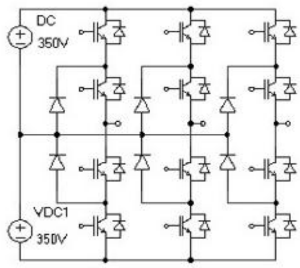



**Fig 3: Three phase of a NPC**

**C. Inverter Controller**

The Inverter controller shown in Fig. 4 is designed using vector control scheme. The inner control loop, that controls the d-q axis current, is designed for a faster response. The main part of the controller is the maximum power point tracking (MPPT) block. Fig 5 shows a set of graphs for a particular wind turbine showing the relationship between its output power and turbine speed for various wind speeds. The mechanical power from a wind turbine is given by

$$P_m = ½ * C_p * \rho * \Pi * R^2 * \omega_w^3 \quad (1)$$

where Cp is the power coefficient, ρ is the air density (kg/ $m^3$), $\omega_w$ is the wind velocity (m/s) and R is the radius of the area swept by blades (m). The equation for torque is given by

$$T_{opt} = K_{Topt} * \omega_m^2 \quad (2)$$

where $K_{Topt}$ is the optimum torque coefficient in W/(rad/s)$^3$ and $\omega_m$ is the generator shaft speed (rad/s).

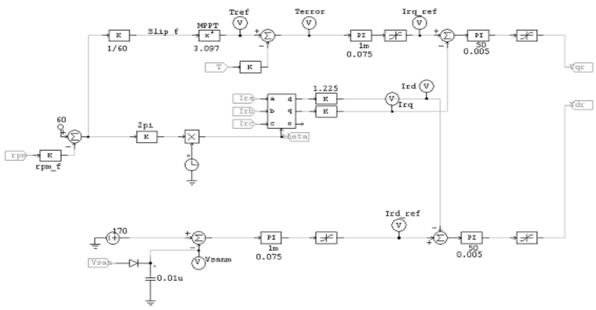


**Fig 4: Proposed controller for inverter**

Using the rated values, Kopt for the machine is obtained as 3.097W/(rad/s)2.Using this coefficient and slip frequency the optimum torque is calculated. Controlling the shaft torque according to the reference gives the q axis rotor current reference which controls the q axis current and provides q axis control voltage for the inverter. The d axis control voltage is obtained by controlling the d axis current based on a stator voltage feedback loop. This loop maintains a constant stator voltage (phase) amplitude at 170 volts.

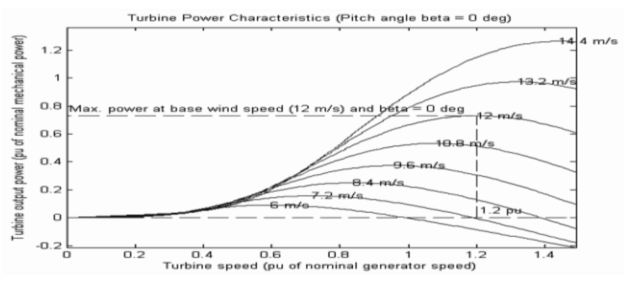



**Fig 5: Power vs. generator speed characteristics for a wind turbine at different wind speeds**

**D. PV panel and MPPT**

PV panels are used in the system in place of the ac mains whenever possible to save energy drawn from the ac mains. It is connected in parallel with the output of the diode rectifier and is capable of supplying a dc voltage to the boost converter. Other than boosting the dc level to 200V, the boost converter can also be used as the maximum power point tracker for the PV panel. It is a simple technique using the relationship between the short circuit current and panel output current at maximum power. Normally the gate pulse of the switch is controlled by the output of a PI controller output based on the current error. In this scheme an extended pulse repeating at a low frequency is supplied to the gate of the switch to make it a short for a longer period allowing the measurement of the short-circuit current of PV panel. The gate pulse is generated from a 5kHz triangular carrier signal and the extended pulse, for Isc measurement, has a frequency of 500Hz. To store the measured value of Isc, a sample and hold circuit block which is controlled by a signal, also of 500Hz, that gives a short pulse to the block at the end of Isc measurement. The simulation results also show that the output power from the panel closely follows the maximum power curve that has a step translated from the input step in the light intensity (500 ~ 900W/m2).

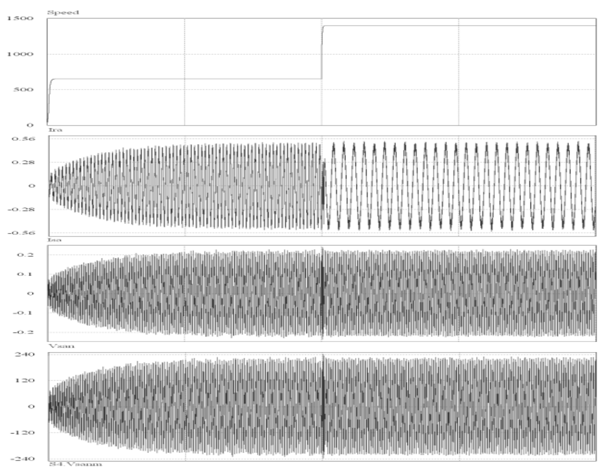
**E. Doubly Fed Induction Generator**

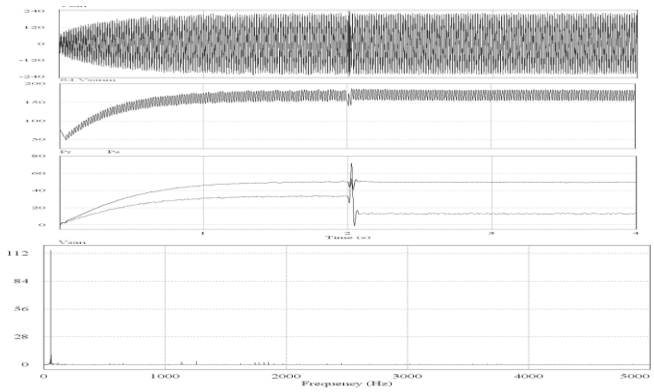
Doubly-fed electric machines are basically electric machines that are fed ac currents into both the stator and the rotor windings. Most doubly-fed electric machines in industry today are three-phase wound-rotor induction machines. Although their principles of operation have been known for decades, doubly-fed electric machines have only recently entered into common use. This is due almost exclusively to the advent of wind power technologies for electricity generation. Doubly-fed induction generators (DFIGs) are by far the most widely used type of doubly-fed electric machine, and are one of the most common types of generator used to produce electricity in wind turbines. Doubly-fed induction generators have a number of advantages over other types of generators when used in wind turbines.

The primary advantage of doubly-fed induction generators when used in wind turbines is that they allow the amplitude and frequency of their output voltages to be maintained at a constant value, no matter the speed of the wind blowing on the wind turbine rotor. Because of this, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor (e.g., to maintain the power factor at unity), while keeping the power electronics devices in the wind turbine at a moderate size. In variable-speed wind turbines, the rotation speed of the wind turbine rotor is allowed to vary as the wind speed varies. This precludes the use of asynchronous generators in such wind turbines as the rotation speed of the generator is quasi-constant when its output is tied directly to the grid.

## III. SIMULATION RESULTS

The rotor injection power is higher for lower wind speeds and lower for higher wind speed since at higher speed more power can be extracted from the turbine. The output voltage has a THD of about 9% and the individual harmonics are also no more than 3% of the fundamental voltage. The figure also shows the harmonic profile of the output voltage.





## IV. CONCLUSIONS

A simple and economical power converter system has been designed to provide power from wind farm either to the grid or to an isolated load. To reduce the power drawn by the rotor from the grid, an auxiliary source for rotor injection has been included in the system i.e. the PV panel. The source for the converter can be selected manually or based on the availability of solar power. MPPT technique used for the wind turbine ensures high efficiency at all wind speeds reducing the power rating of the converter. The surplus power output from PV panel, if available, can be stored in the battery for future use. The use of NPC inverter reduces the harmonics in the stator voltage. Both the boost regulator and inverter controller have good dynamic response with a very low overshoot and a low settling time.

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