Modelling and Simulation of Multilevel Inverter for Wind Energy Conversion System Interfacing to Grid

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Abstract:
Wind energy conversion systems (WECS) include a variety of non-linear power electronic devices which have a significant contribution towards harmonic emissions. Harmonic emissions are threat for electrical power quality. Hence, harmonic analysis and mitigation has become an integral part of WECS. Multilevel inverters have been widely used for harmonic mitigation with the added benefits of low switching stress and high voltage capability. Diode clamped multi-level inverter utilizes the diodes as the clamping device to clamp the dc bus voltage so as to achieve steps in the output voltage. The validity of the proposed topology has been verified by simulation, which may provide possibility for the wind power system to be integrated with medium voltage power grid without a step-up transformer.

Keywords: Permanent Magnet Synchronous Generator (PMSG), Diode clamped multi level inverter, Phase disposition PWM, pitch angle control and diode rectifier

1. INTRODUCTION

Wind is the renewable source of energy available in plenty. Wind energy is harnessed by WECS comprising a wind turbine, a generator, power electronic converter, the corresponding control system and the load or grid. Permanent magnet synchronous generators (PMSG) along with variable speed variable frequency operation are being widely used in low power application. It is most efficient as compared to the other machines, highly robust and easy maintenance due to the absence of slip ring and exciter system. The most standard way of implementing a grid connected PMSG WECS with variable speed variable frequency operation is using a two stage conversion: the first one a rectifier that is, an AC-DC stage and the second one an inverter that is, a DC-AC stage. The AC-DC stage consists of three phase bridge diode rectifier or thyristorised converter, followed by dc capacitance filter. Second stage consists of IGBT based inverter, which involves several control techniques. AC-DC converters are most suitable method to extract the AC power from the generator in variable speed operation. However, the use of these converters injects non-sinusoidal current with sinusoidal voltage into the system. In order to meet the demand for high voltage and high power, multilevel converters are used. Multilevel converters reducing the output voltage and current harmonic content, increase the output voltage, make output waveform closer to the sine wave. Additionally, the reduction of low frequency harmonics from the ac voltages at the different levels reduces the size of the ac inductance, and hence decreases overall expense of the system. Multilevel converters control output, frequency and voltage including the phase angle providing a fast response and autonomous control. This paper adopts double multi-level back to back converter structure, that is to say, generator side and load side converter. The maximum power tracking and generator stable operation is realized by using the phase disposition sinusoidal pulse width modulation.

2. SYSTEM DESCRIPTION AND MODELLING

A. Model Of Wind Energy Conversion System

The main components of a direct-drive permanent magnet synchronous generator (PMSG) wind turbine are the wind turbine and the PMSG. The wind turbine captures the power from the wind for the system, and the PMSG transforms the mechanical power into electric power. In this paper the basic principles of the electric power generation will be introduced, and the mathematical models of the wind turbine and the PMSG will be developed and analysed. Figure 1 shows the model of wind energy conversion system.

B. Modeling of Wind Turbines

In order to investigate the effectiveness of the energy conversion in wind energy conversion systems, first the available energy stored in the wind needs to be determined. Actually, the energy in the wind can be treated as the kinetic energy of a large amount of air particles with a total mass, \( m \), moving at a wind velocity \( V_w \). Assuming that all the air particles are moving at the same speed and direction before impacting the rotor blades of the wind turbine, the potential available kinetic energy stored in the wind can be expressed as following:

\[
E = \frac{1}{2} m V_w^2
\]
Where, \( E \), is the kinetic energy of the moving air particles, and \( m \) is the total mass of the air particles, while, \( V \), is the velocity of the air particles (wind speed).

\[
P_M = 0.5 \times \rho \times C_p(\lambda, \beta) \times A \times V_{\text{wind}}^3
\]

(2)

Where \( P_M \) is Mechanical output power of the turbine (W), \( \rho \) is Air density (kg/m\(^3\)), \( A \) is Turbine swept area (m\(^2\)), \( V_{\text{wind}} \) is the velocity of the air particles (wind speed). \( \beta \) is tip speed ratio. The power coefficient, \( C_p \) is defined as-

\[
C_p(\lambda, \beta) = C_1 - C_2 \times \beta - C_3 \times \beta \times \lambda - C_4 \times \lambda
\]

(3)

Where
\[
\lambda = \frac{R \times W_m}{V_{\text{wind}}}
\]

and coefficients \( C_1 = 0.5176, \ C_2 = 116, \ C_3 = 0.4, \ C_4 = 5, \ C_5 = 21, \) and \( C_6 = 0.0068 \).

Fig 2: CpVs Tip speed Ratio Curve

Figure 2 shows the power coefficient with respect to tip speed ratio. It is observed that the \( C_p_{\text{max}}(\lambda, \beta) = 0.48 \) is maximum power coefficient value for \( \lambda = 8 \) and for \( \beta = 0 \). This value of \( \lambda_{\text{opt}} \) results in optimal point where maximum power is captured from wind by the turbine.

Fig 3: Wind Turbine Power Characteristic

Figure 3 shows the wind turbine power characteristics obtained for various values of the wind tangential speed. It is observed that maximum power (active) is achieved through optimal wind speeds and not at high wind velocity. The wind turbine does not operate when the wind speed is less than the minimum speed because the captured wind energy is not enough to compensate the losses and operation cost.

C. Drive train modeling.

This element converts the mechanical torque and the machine speed.

\[
T_{\text{aero}} = g_r \times T_m
\]

(4)

\[
\Omega_m = g_r \times \Omega
\]

(5)

\[
J \frac{d\Omega}{dt} = T_m - T_r \times f \times \Omega_m
\]

(6)

where, \( T_{\text{aero}} \) is the aerodynamic torque, \( \Omega_m \) is the machine speed, \( J \) is the mechanical inertia, \( T_r \) is the electromagnetic torque, and \( f \) is the friction coefficient.

D. PMSG modeling

The modeling of PMSG type electrical equipment is made through the following equations, represented by d-q reference frame.

\[
V_d = R_s i_d + L_d \frac{di_d}{dt} - w_L q i_q
\]

(7)

\[
V_q = R_s i_q + L_q \frac{di_q}{dt} - w_L d i_d + w_e \phi_m
\]

(8)

Where \( V_d \) and \( V_q \) are d and q components of stator voltages (V), \( i_d \) and \( i_q \) are d and q components of stator currents (A), \( R_s \) is stator resistance (ohms), \( L_d \) and \( L_q \) are machine inductances (H) is the electrical speed (rad/s) is the magnetic flux (wb).

The electrical torque is obtained through the following equation-

\[
T_e = \frac{2}{3} p \{ \phi_m i_q + (L_d - L_q)i_d i_q \}
\]

(9)

\[
T_m - T_e = B \omega_r + J \frac{d\omega_r}{dt}
\]

(10)

Where \( B \) is the rotor friction (kgm2/s), \( J \) is the rotor inertia (kgm2), \( \omega_r \) is rotor speed (rad/s). \( T_m \) is the mechanical torque produced by wind (Nm). The machine dynamics can be simplified by assuming \( (L_d = L_q = 0) \).

3. MULTILEVEL INVERTER

Multilevel inverter is based on the fact that sine wave can be approximated to a stepped waveform having large number of steps. The steps being supplied from different DC levels supported by series connected batteries or capacitors. The unique structure of multi-level inverter allows them to reach high voltages and therefore lower voltage rating device can be used. As the number of levels increases, the synthesized output waveform has more steps, producing a very fine stair case wave and approaching very closely to the desired sine wave. It can be easily understood that as motor steps are included in the waveform the harmonic distortion of the output wave decrease, approaching zero as the number of levels approaches infinity. Hence Multi-level inverters offer a better choice at the high power end because the high volt-ampere ratings are possible with these inverters without the problems of high dv/dt and the other associated ones.

4. MULTILEVEL INVERTER TOPOLOGIES

The basic three types of multilevel topologies used are

(1) Diode clamped multilevel inverters

(2) Flying capacitors multilevel inverter or Capacitor clamped multilevel inverter
(3) Cascaded inverter with separate dc source

A. Diode Clamped Multilevel Inverter
The first invention in multilevel converters was the so-called neutral point clamped inverter. It was initially proposed as a three level inverter. It has been shown that the principle of diode clamping can extended to any level. A diode clamped leg circuit is shown in Figure. The main advantages and disadvantages of this topology are:

Advantages:
• High efficiency for the fundamental switching frequency.
• The capacitors can be pre-charged together at the desired voltage level.
• The capacitance requirement of the inverter is minimized due to all phases sharing a common DC link.

Disadvantages:
• Packaging for inverters with a high number of levels could be a problem due to the quadratically relation between the number of diodes and the numbers of levels.
• Intermediate DC levels tend to be uneven without the appropriate control making the real power transmission a problem.
• Uneven rating in the diodes needed for the converter.

Some of the applications using Multilevel Diode Clamped converters are:
• An interface between High voltage DC transmission line and AC transmission line.
• High power medium voltage variable speed drives.
• Static VAR compensation

5. 10-LEVEL DCMI
A three-phase nine-level diode-clamped inverter is shown in fig.4. Each phase is constituted by 16 switches (eight switches for upper leg and eight switches for lower leg). Switches Sa1 through Sa8 of upper leg form complementary pair with the switches Sa1’ to Sa9’ lower leg of the same phase. The complementary switch pairs for phase ‘A’ are (Sa1, Sa1’), (Sa2, Sa2’),(Sa3, Sa3’),(Sa4, Sa4’),(Sa5, Sa5’),(Sa6, Sa6’),(Sa7, Sa7’),(Sa8, Sa8’), and similarly for B and C phases. Clamping diodes are used to carry the full load current.

6. PULSE WIDTH MODULATION
Pulse Width Modulation refers to a method of carrying information on a train of pulses, the information being encoded in the width of the pulses. The pulses have constant amplitude but their duration varies in direct proportion to the amplitude of analog signal. PWM is the most popular method for producing a controlled output for inverters. They are quite popular in industrial applications. The modulation techniques used for high switching frequency PWM are;

(1) Space vector modulation(SVM)
(2) Sinusoidal PWM

SINUSOIDAL PWM
In this modulation technique there are multiple numbers of output pulses per half cycle and pulses are of different width. The width of each pulse is varying in proportion to the amplitude of a sine wave evaluated at the centre of the same pulse. Carrier Based Pulse width modulation (CBPWM) or SPWM technique has been extensively used, because it improves the harmonic spectrum of the inverter by moving the voltage harmonic components to higher frequencies The
gating signals are generated by comparing a sinusoidal reference with a high frequency triangular signal.

7. SIMULATION AND RESULTS

Wind energy conversion system simulink

The modeling of wind turbine and PMSG is carried out in MATLAB to determine its parameters. Harmonics generate due to Power electronic converters and non linear load should be reduced. Diode clamped multilevel inverter with for the wind energy system. Performance parameters are valuated for the proposed converter and the results are verified.

![MATLAB Simulink model for Wind Energy Conversion System](image)

RESULTS

The result obtained from wind energy system is given below:

![Speed in rad/sec](image)

![Rotar speed of PMSG](image)
This is result obtained from rectifier output;

**Fig. 10** Output dc voltage of rectifier
The grid side active power, reactive power, voltage and current is given below.

**Fig. 11** Grid side active and reactive power

**Fig. 12** Grid frequency
8. CONCLUSION
A diode clamped multilevel inverter is well suited for the current control of a DCMLI used as the grid interface of a higher power rated wind energy conversion system, since it has only a single dc source. The proposed fixed switching frequency control leads to an equal and uniform distribution of the switching stress among the various switches. It is shown that following the proposed gain calculation method ensures the operation of the DCMLI at the fixed frequency of the carrier. With the multicareer level shifted current control, the net switching frequency increases and the ripple magnitude is reduced leading to a higher feed forward gain and hence better control characteristics. It is shown through simulation results that the available wind power can be controlled to feed the load real power with the balance real power being supplied from the grid. In addition to real power injection, the objective of load compensation is also achieved leading to a balanced, distortion free, unity power factor source current. The voltages across the capacitors of the DCMLI remain balanced under all conditions with the proposed control method.

REFERENCES
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