

## Wind Energy Conversion System Using Cascaded H-Bridge Multi Level Inverter

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### ABSTRACT

In this paper cascaded H-bridge multilevel inverter operation is explained. Here maximum power is extracted from a wind energy conversion system using permanent magnet synchronous generator along with cascaded H bridge multi-level inverter. The copper losses in the rotor are eliminated and higher efficiency is obtained by using permanent magnet synchronous generator. A five level cascaded H-bridge multilevel inverter circuit along with PMSG based WECS is simulated using MATLAB.

**Keywords-** Permanent-magnet synchronous generator (PMSG), wind energy conversion system (WECS), Multilevel inverter.

### I. INTRODUCTION

The design of a wind turbine system is to be done complicated task due to the parameters involved and the often conflicting requirements, such as the low cost, ruggedness, good output power quality and dynamic characteristics[2]-[4].

To get variable speed operation, a power electronics converter interface is used to connect the generator to the grid, which is shown in fig.1. To overcome the limitations linked to maximum voltage a blocking capability of existing power semiconductor devices, several new techniques and topologies have been developed, such as diode-clamped inverter, Flying capacitor inverter, and cascaded H-bridge inverter. A number of modulation techniques are used in multilevel inverters[11]. They can generally be classified into three categories:

- Multi-step, staircase of fundamental frequency switching;
- Space Vector PWM (SVPWM);
- Multi-carrier PWM.

This paper focuses on space vector PWM techniques which have been extended for use in cascaded H-bridge multi-level inverter topologies. By using SVPWM method for cascaded H bridge multi-level inverter[9], output voltage signal can be optimized with respect to a switching utilization and different phase relationships: A three-phase five-level cascaded H-bridge inverter is shown in Fig.2

Previously, only one source was used, without the use of transformers. It interfaced a single

DC source with a cascade multilevel inverter, where the other DC sources are capacitors [4].

### II. Modeling of the system

#### 1.1 Aerodynamic part

The time-average mechanical input power  $P_m$  at the

$$P_m = (1/2) \rho A v_w^3 C_p(\lambda)$$

Where,

$\rho = 1.25 \text{ Kg/m}^3$  denotes Air density,

$A = \pi R^2$  is the area of the rotor,

$V_w$  is the wind velocity,

$C_p(\lambda)$  is the aerodynamic power coefficient,

$\lambda = R \omega_m V_w$

The rotor aerodynamic torque harmonics due to the tower shadow and wind shear effects must be taken into account in the simulation, since they affect the output power quality. These are modeled as variations of the wind speed acting at the aerodynamic center of each blade from the ground, as a function of its angular position  $\theta_i$ , is

$$h_i = H_{hub} + c R \sin(\theta_i), \quad i = 1 \dots 3$$

where,  $H_{hub}$  is the hub height.

### III. Wind Turbine Model

#### 2.1 Generator Model

The voltage equations of a permanent magnet synchronous generator in the dq reference frame are given by

$$V_{qs} = -R_s i_{qs} + \omega_m \psi_{ds} + \frac{d\psi_{qs}}{dt} \quad (2.1)$$

$$V_{ds} = -R_s i_{ds} - \omega_m \psi_{qs} + \frac{d\psi_{ds}}{dt} \quad (2.2)$$

Where  $v$  is the voltage,  $i$  the current,  $\psi$  the flux linkage,  $R$  the resistance,  $\omega_m$  the angular velocity of turbine rotor. The subscripts 'd' and 'q' stand for direct and quadrature components, respectively (see Fig. 2.1), the subscript 's' for stator. The quantities are given in per unit (p.u.). The correlation between physical values and per unit can be found.

GENERATOR WINDINGS CURRENT

$$I_a = [I_d \sin(\omega t) + I_q \cos(\omega t)]$$

$$I_b = [I_d \sin(\omega t - 2\pi/3) + I_q \cos(\omega t - 2\pi/3)]$$

$$I_c = [I_d \sin(\omega t + 2\pi/3) + I_q \cos(\omega t + 2\pi/3)]$$

Where  $L_{qm}$ ,  $L_{dm}$  are the mutual inductances in q and d axes, respectively, and  $L_{os}$  is the stator leakage inductance. The torque in the air gap  $T_{ag}$  is given by

$$T_{ag} = \psi_{ds} i_{qs} - \psi_{qs} i_{ds} = \psi_f i_{qs} + (L_{dm} - L_{qm}) i_{qs} i_{ds} \quad (2.3)$$

#### IV. PERMANENT MAGNET SYNCHRONOUS GENERATOR

A permanent magnet synchronous generator (PMSG) is a generator that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets [3]. A conventional megawatt-scale wind power plant consists of a low-speed wind turbine rotor, gearbox and high-speed (1000–1500 rpm) electric generator. The rotor of a typical wind turbine rotates at the speed of 15–100 rpm (150–500 rpm for small-scale wind turbines).

The use of a gearbox causes many technological problems in a wind power plant. These problems may be avoided using an alternative – a direct-drive low-speed PM synchronous generator[4]. The power from the rotation of the wind turbine rotor is transferred to the generator through the drive train: hub with blades, the main shaft, and the generator. The drive train of the wind turbine can be modeled as the so-called two-mass model without gearbox.

##### 3.1 PMSG Model

$$\psi_{qs} = (L_{qm} + L_{\sigma s}) i_{qs} \quad (3.1)$$

$$\psi_{qs} = (L_{dm} + L_{\sigma s}) i_{ds} + \psi_f \quad (3.2)$$

Where  $\psi_f$  is the flux produced by the permanent magnets. By substituting flux linkages eq. 2.2 in eq. 2.1 the voltage-current relationship can be obtained

$$U_{qs} = -R_s i_{qs} + \omega_m (L_{dm} + L_{\sigma s}) i_{ds} + \omega_m \psi_f \quad (3.3)$$

$$U_{ds} = -R_s i_{ds} - \omega_m (L_{qm} + L_{\sigma s}) i_{qs} \quad (3.4)$$

The dynamic model of PMSG has been built in the d-q rotating reference frame. The electrical model of the PMSG in the d-q synchronous reference frame[2], with the voltage and torque equations are given

$$\frac{di_q}{dt} = \frac{1}{L_{qs} + L_{ls}} ((-R_s i_q + \omega_e (L_{ds} + L_{ls}) i_d + \psi_f) + v_q) \quad (3.5)$$

$$\frac{di_d}{dt} = \frac{1}{L_{ds} + L_{ls}} ((-R_s i_d + \omega_e (L_{qs} + L_{ls}) i_q + v_d)) \quad (3.6)$$

Where  $v_d$  and  $v_q$  are voltages in the d-q axis,  $i_d$  and  $i_q$  are the current in the d-q axis,  $R_s$  is the stator resistance,  $L_d$  and  $L_q$  are the d-q axis inductance,  $\omega_e$  is electrical rotational speed,  $\psi_f$  is permanent magnetic flux given by the magnets and finally  $p$  is the number of pole pairs[1]. The Fig. 2.3 shows the equivalent electric circuit of PMSG in d-q rotating reference frame

The generator rotor is equipped with surface mounted permanent magnets and no damping windings.

#### V. SPACE VECTOR MODULATION

Space vector modulation techniques have been increasingly used in last decade, because they allow reducing commutation losses [10]. The underlying theory behind space vector modulation is to apply space vectors as illustrated in Fig. 4.1 for varying time periods in a pattern based on the SVM algorithm. Only one switch may be closed per phase leg in order to prevent a short circuit.

The Phase-Shifted (PS) scheme shifts four carrier signals by 90° in order to provide a five-level PWM pattern in each phase.

#### VI. WORKING PRINCIPLE OF CASCADED H BRIDGE INVERTER

Fig. 2 shows the multilevel -cascaded H-Bridge configuration. The output of this cell will have three levels namely +V, 0 and -V. The switch position and the output voltage and the state of the H-Bridge are given in table I. using one single H-Bridge, a three level inverter can be realized [11]. Under fault conditions, faulty cells can be bypassed and still the inverter will function with reduced output voltage levels. Since the cells are identical, faulty unit can be replaced quickly and downtime of the inverter can be reduced; hence high reliability can be achieved.

#### VII. Features of Cascaded H-Bridge Inverter

Higher voltage levels can be synthesized using devices of low voltage rating. If  $V$  is the dc voltage of each of the H-Bridge cell, then each device will experience a off-state voltage of  $V$  volts and a N-level cascaded H-Bridge can synthesize peak-to-peak voltage of  $(N * V)$  volts . Phase voltage of an N-level cascaded H-Bridge will have N levels; hence wave shape will be improved and will result in improved THD Improved wave shape can be obtained even with fundamental frequency switching and step modulation[12].

In multi-level inverters, the frequency modulation index,  $m_f$ , and the amplitude modulation  $m_a$ , are defined as

$$m_f = \frac{f_c}{f_r} \quad m_a = \frac{A_r}{(N-1)A_c} \quad (7.1)$$

The first step in the converter analysis involves definition of the load voltages in terms of the inverter line-to-ground voltages, which may be expressed as [14]

$$\begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} v_{ag} \\ v_{bg} \\ v_{cg} \end{bmatrix} \quad (7.2)$$

Under proper multi-level converter operation, the line-to-ground voltages may be directly controlled to be some fraction of the dc link voltage. In particular, the line-to-ground voltage for phase  $x$  is given by eq.(7.3)

$$v_{xg} = \frac{S_x}{(n-1)} \quad s_x = 0,1,\dots,(n-1) \quad (7.3)$$

where  $n$  is the number of voltage levels that the converter is capable of producing and  $s_x$  is the switching state determined by the modulator for phase  $x$ .

### VIII. Simulation Tools

Today with the growth in computational power there is a wide selection of software titles available for electrical simulations such as ACSL, ESL, EASY5, and PSCSP are for general systems. In this paper MATLAB simulation is used.

### III Tables and figures

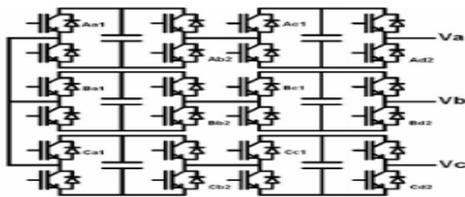


Fig.1 Three phase structure of a Five-level Cascaded multilevel inverter.

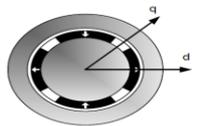
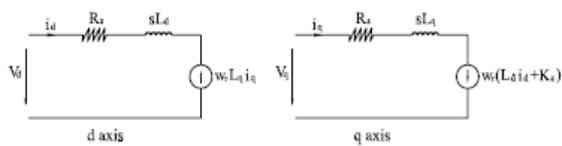


Figure 2.1: Salient-pole permanent magnet synchronous machine in dq reference frame.



Fig(2.3) Equivalent circuit of PMSG in d-q reference frame

### IX. 9. SIMULATION CIRCUIT

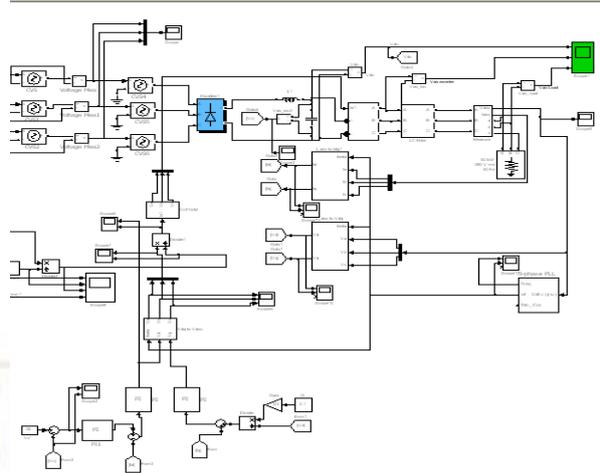
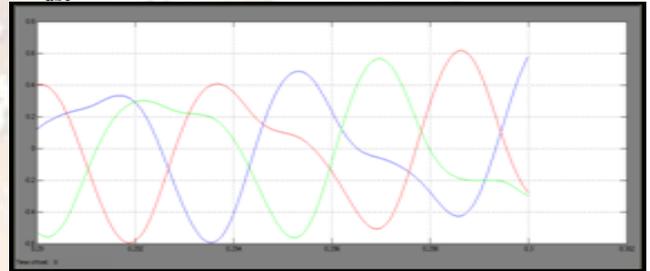


Fig 9.1 Simulation circuit of PMSG with closed loop

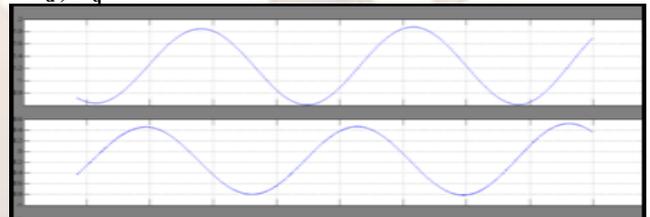
### 9.1 SIMULATION RESULTS

#### 1. $V_{abc}$ of Inverter



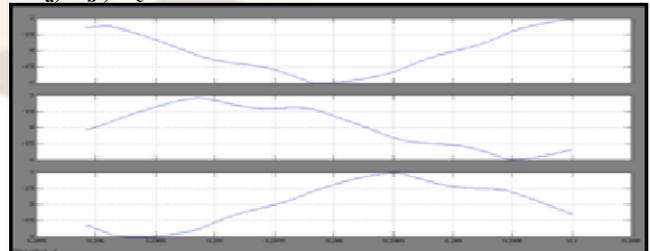
The above graph shows the waveform of  $V_{abc}$  of the inverter

#### 2. $V_d, V_q$ waveforms



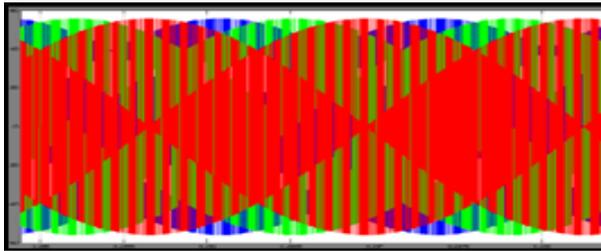
The above graph shows the voltage waveform which is transformed into d,q axes

#### 3. $V_a, V_b, V_c$ after Transformation



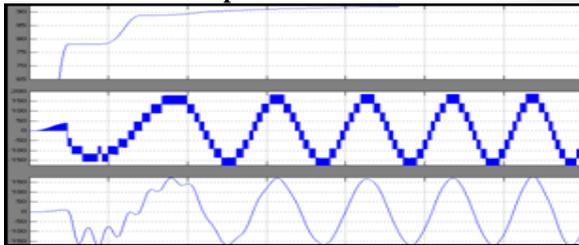
The above graph shows the voltage waveforms which is again transformed from two axes to three axes

#### 4. PMSG OUTPUT



The above graph shows the output voltages  $V_a$ ,  $V_b$ ,  $V_c$  of the PMSG

## 9.2 Simulation Output



Simulation for voltage across direct current ( $V_{dc}$ ), voltage across two terminal in inverter ( $V_{ab}$  inverter) and voltage across the load.

## X. Conclusion

Modeling and simulation results of a PMSG based variable speed wind energy system is analyzed in this paper. The proposed system deals with extracting maximum available power in the wind by forcing the WTG to rotate. Space Vector Modulation, has been presented here. Five-level cascaded H-bridge multi-level inverter has been simulated and controlled with SVPWM. SVPWM method proposed in this paper can be optimized or balanced the switch utilization in cascaded H-bridge multi-level Multilevel Inverter.

The advantages of this system with other solutions proposed in literature may be resumed as follows:

- 1, Calculation is made easier ;
- 2, Great flexibility in implementation of zero sequence injection PWM techniques in which duty cycle expression is available;
- 3, Simple implementation on low cost microprocessors.

## References

- [1] T. Tafticht, K. Agbossou, A. Cheriti, and M. L. Doumbia, "Output power maximization of a permanent magnet synchronous generator based standalone wind turbine," in *Proc. IEEE ISIE 2006*, Montreal, QC, Canada,
- [2] N. Yamamura, M. Ishida, and T. Hori, "A simple wind power generating system with permanent magnet type synchronous generator," in *Proc. IEEE Int. Conf. Power Electron. Drive Syst.*, 1999, vol. 2, pp. 849–854.
- [3] A. M. Knight and G. E. Peters, "Simple wind energy controller for an expanded operating range," *IEEE Trans. Energy Convers.*, vol. 20, no. 2, pp. 459–466, Jun. 2005, pp. 2412–2416.
- [4] Zhong Du, Leon M. Tolbert, John N. Chiasson, and Burak Ozpineci, "A Cascade Multilevel Inverter Using a Single DC Source", in IEEE conference, 2006.
- [5] M. Chinchilla, S. Arnaltes, and J. C. Burgos, "Control of permanent magnet generators applied to variable-speed wind-energy systems connected to the grid," *IEEE Trans. Energy Convers.*, vol. 21, no. 1, pp. 130–135, Mar. 2006.
- [6] K.A. Corzine, M.W. Wielebski, F.Z. Peng and Jin Wang, "Control of cascaded multilevel inverters", IEEE Transactions on Power Electronics, vol.19, no.3, May 2004, pp.732 -738
- [7] B.P. McGrath and D.G. Holmes, "Multicarrier PWM strategies for multilevel inverters", IEEE Transactions on Industrial Electronics, vol.49, no.4, Aug. 2002, pp.858 - 867
- [8]. Sanmin Wei and Bin Wu "A General Space Vector PWM control Algorithm for Multi-level inverters" IEEE 2003, pp 562-568.
- [9] N. Celanovic "A Fast Space Vector modulation Algorithm for Multilevel converter". Dissertation for partial fulfillment of the Ph.D. degree in Electrical and computer engineering".
- [10] Cataliotti A, Genduso F, Ricco Galluzzo G. A New Over Modulation Strategy for High-Switching Frequency Space Vector PWM Voltage Source Inverters" Proceeding of the IEEE ISIE 2002, L'Aquila July 2002.
- [11] KA. Cordne and Y.L Familiant, "A New Cascaded Multi-Level H-Bridge," IEEE Transactions on Power Elect. volume 17.
- [12]. Lei Hu, Hongyan Wang, yan Deng and Xiagning "A simple SVPWM of. Multilevel inverter".EEE.PowerElectrospecialconference, Achen, 2004.
- [14]. M.L. Tolbert and F.Z. Peng, "Multi- Level converter for Large Electric Drives IEEE. Trans. Indus Applica., Vol.35, No.1,1999.pp36-44.