N. R. Bhasme, Dr. W. Z. Gandhare / International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com
Vol. 2, Issue4, July-August 2012, pp.2181-2185

Power Converters for Grid Integration of Wind Power Systems

N. R. Bhasme — Asstt. Professor
Dr. W. Z. Gandhare — Principal
Government College of Engineering, Aurangabad
Maharashtra- India

Abstract:

This paper presents the different power converters for grid integration of wind power systems. In wind power systems while integrating with grid, power quality issues are becoming more predominant. This can solve by using power electronics converters like two level back to back converter and matrix converters. Converters are compared on the basis of efficiencies, voltage conversion ratios and THDs.

Key words: Wind energy systems, power quality, two level back to back converter, three level and matrix converter.

1. Introduction

World Market for Wind Turbines sets a new record of 42 GW of new capacity in 2011, worldwide total capacity at 239 GW enough to cover 3 % of the world's electricity demand. Renewable delivered close to 20% of global electricity supply in 2010 and by early 2011 they comprised one quarter of global power capacity from all the sources. In several countries renewable represent a rapidly growing share of total energy supply. India added an estimated 2.7GW of grid connected renewables during 2010 mainly from wind but also from biomass, small hydropower and solar capacity for a total of nearly 19GW by January2011. Direct driven turbine designs captured 18% of the globalmarket..The increasing share of wind in power generation will change considerably the dynamic behaviour of the power system and may lead to a new strategy for power system frequency regulation in order to avoid degradation of frequency quality .Hence, network operators have to ensure that power quality is not compromised at consumer end. New technical challenges emerge due to increased wind power penetration, dynamic stability and power quality. Power electronic converters have been developed for integrating wind power with the electrical grid. The use of power electronic converters allows for variable speed operation of the wind turbine and enhancement in power extraction. In variable speed operation, sophisticated control methods require extracting maximum power from the turbine and providing constant voltage and frequency to the grid is required. In India out of installed capacity only 15% wind turbines are connected to the grid through power electronics converters. There is a ample scope in India for the use of power converters in wind power systems. During recent years different converter topologies have been investigated as to whether they can be applied in wind turbines such as Back-to-back, Multilevel, Tandem, Matrix, Resonant Converters. This paper is concerned of a wind energy system with different topologies for the power converters, mainly a two-level converter, three level and matrix converter providing constant voltage and frequency to the grid. Grid quality characteristics and limit values in accordance with DIN EN 50 160 and the VDEW give directives for in-plant generation. Converters are compared on the basis of efficiencies, voltage conversion ratios and THDs. Fig. 1 shows different converter applied in wind power systems.

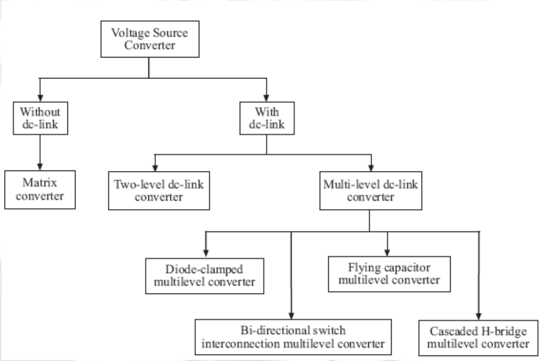


Fig 1. Different converters applied in wind power systems

2. Turbine and Electric Machine

The mechanical power of the turbine is given by:

$$P_m = \frac{1}{2}\rho A u^3 c_p \qquad (1)$$

where *Pm* is the power extracted from the airflow, ρ is the air density, *A* is the area covered by the rotor, *u* is the wind speed upstream of the rotor, and *cp* is the performance coefficient or power coefficient. The power coefficient is a function of the pitch angle of rotor blades θ and of the tip speed ratio λ , which is the ratio between blade tip speed and wind speed upstream of the rotor. The computation of the power coefficient requires the use of blade element theory and the knowledge of blade geometry. We consider the blade geometry using the numerical approximation developed in

[7], assuming that the power coefficient is given by:

$$C_p = 0.73\lambda_i e^{\frac{-18.4}{\lambda_{ii}}} \quad (2)$$

where λ_i and λii are respectively given by:

$$\lambda_i = \frac{151}{\lambda_{ii}} - 0.58\theta - 0.002\theta^{2.14} - 13.2 \quad (3)$$

$$\lambda_{ii} = \frac{1}{\frac{1}{(\lambda - 0.02\theta)} - \frac{0.003}{(\theta^3 + 1)}} \quad (4)$$

The maximum power coefficient is given for a null pitch angle and is equal to:

$$C_{p\max} = 0.4412 \quad (5)$$

where the optimum tip speed ratio is equal to

$$\lambda_{opt} = 7.057 \quad (6)$$

The power coefficient is illustrated in Figure 1 as a function of the tip speed ratio.

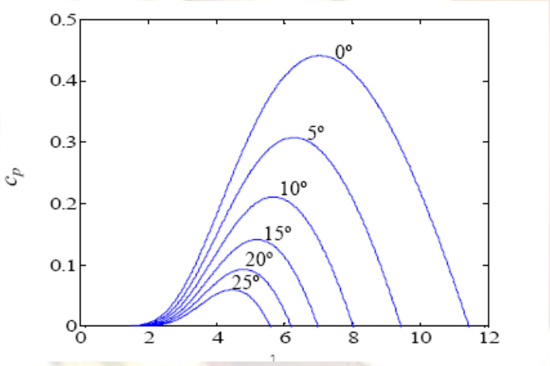


Fig. 2. Power coefficient curves versus tip speed ratio

The mechanical power extracted from the wind is modelled by (1) to (4). The equations for modelling rotor motions are given by:

$$\frac{dw_m}{dt} = \frac{1}{J_m}(T_m - T_{dm} - T_{am} - T_{elas}) \quad (7)$$

$$\frac{dw_e}{dt} = \frac{1}{J_e}(T_{elas} - T_{de} - T_{ae} - T_e) \quad (8)$$

where ωm is the rotor speed of turbine, *Jm* is turbine moment of inertia, *Tm* is the mechanical torque , *Tdm* is the resistant torque in the turbine bearing, *Tam* is the resistant torque in the hub and blades due to the viscosity of the airflow, *Telas* the torque of the torsional stiffness, w_e is the rotor speed of the electric machine, *Je* is the electric machine moment of inertia, *Tde* is the resistant torque in electric machine bearing,*Tae* is the resistant torque due to
the viscosity of the airflow in the electric machine, and *Te* is the electric torque. The equations for modelling a permanent magnetic synchronous machine, PMSM, can be found in diverse literature; using the motor machine convention, the following set of equations is considered:

$$\frac{di_d}{dt} = \frac{1}{L_d}(u_d + pw_e L_q i_q - R_d i_d) \quad (9)$$

$$\frac{di_q}{dt} = \frac{1}{L_d}\left[u_q - pw_e(L_d i_d + Mi_f) - R_q i_q\right] \quad (10)$$

where *i f* is the equivalent rotor current, *M* is the mutual inductance, *p* is the number of pairs of poles; and where in *d*- *q* axes *id* and *iq* are the stator currents, *Ld* and *Lq* are the stator inductances, *Rd* and *Rq* are the stator resistances, *ud* and *uq* are the stator voltages. A unity power factor is imposed to the electric machine, implyinga null *Qe* . The electric power *Pe* is given by:

$$P_e = \begin{bmatrix} u_d & u_q & u_f \end{bmatrix}\begin{bmatrix} i_d & i_q & i_f \end{bmatrix}^T \quad (11)$$

The output power injected in the electric network characterized by P and Q in α-β axes is given by:

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (12)$$

where in α-β axes, *i*α and *i*β are the phase currents, *u*αand *u*β are the phase voltages. The apparent output power is given by:

$$S = \left(P^2 \quad Q^2 \quad H^2\right)^{1/2} \quad (13)$$

where H is the harmonic power.

3. Two-Level and Three Level Converters

The two-level converter is an AC/DC/AC converter, with six unidirectional commanded IGBT's *Sik*, used as a rectifier, and with the same number of IGBT's, used as an inverter. The rectifier is connected between an electric machine and a capacity bank. The inverter is connected between this capacity bank and a filter, which in turn is connected to an electric network. A three-phase symmetrical circuit in series models the electric network. The configuration of the system that will be simulated is shown in Figure 3.

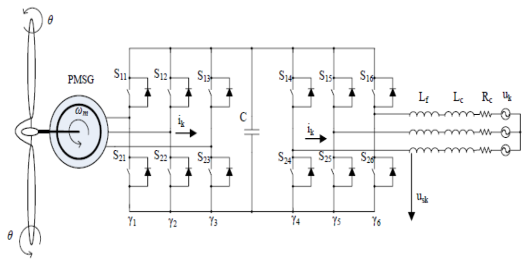


Fig. 3. Wind energy system with two-level converter

The groups of two IGBT's linked to the same phase constitute a leg *k* of the converter. For the two-level converter modelling we assumed that: 1) The IGBT's are ideal and unidirectional, and they will never be subject to inverse voltages, being this situation guaranteed by the arrangement of connection in anti parallel diodes; 2) The diodes are ideal: in conduction it is null the voltage between its terminals and in blockade it is null the current that passes through it; 3) The continuous voltage in the exit of the rectifier should always be *vdc* > 0 ; 4) Each leg *k* of the converter should always have one IGBT in conduction. For the switching function of each IGBT, the switching variableγ *k* is used to identify the state of the IGBT *i* in the leg *k* of the converter. The index *i* with $i \in \{1,2\}$ identifies the IGBT. The index *k* with $k \in \{1,2,3\}$ identifies the leg for the rectifier and $k \in \{4,5,6\}$ identifies the leg for the inverter. The two valid conditions for the switching variable of each leg *k* are as follows:

$$\gamma_k = \begin{cases} 1, S_{ik} = 1 \\ 0, S_{ik} = 1 \end{cases} \text{for } i \in \{1,2\} \text{ and } k \in \{1,---,6\} \quad (14)$$

The topological restriction for the leg k is given by

$$\sum_{i=1}^{2} S_{ik} = 1 \qquad k \in \{1,---,6\} \quad (15)$$

Hence, each switching variable depends on the conduction and blockade states of the IGBT's. The phase currents injected in the electric network are modelled by the state equation:

$$\frac{di_k}{dt} = \frac{1}{(L_c + L_f)}(u_k - R_c i_k - u_{sk}) \quad k = \{4,5,6\} \quad (16)$$

The output continuous voltage of the rectifier is modelled by the state equation:

$$\frac{dv_{dc}}{dt} = \frac{1}{C}\left(\sum_{k=1}^{3}\gamma_k i_k - \sum_{k=4}^{6}\gamma_k i_k\right) \quad (17)$$

Hence, (14) to (17) model the two-level converter.

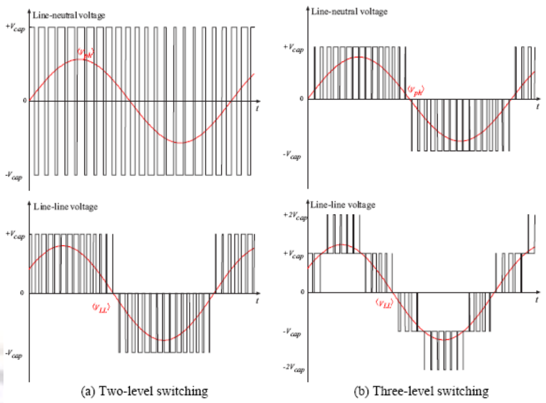
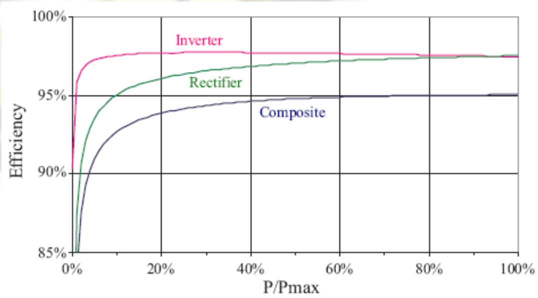


Fig.4. Comparison of PWM waveforms for a) Conventional two level switching b) Three level switching

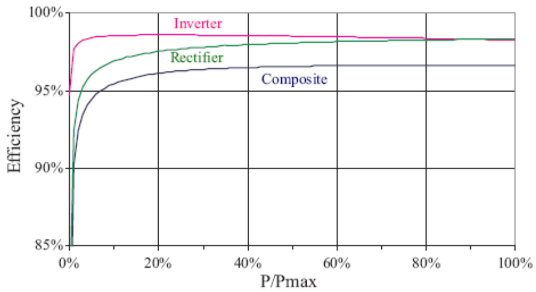
Figure 4 compares waveforms of conventional pulse width modulation (PWM) of two level switching voltage and three level switching voltage. In the two level switching voltage waveform, the line-neutral voltage is switched between two voltage levels: positive Dc bus voltage and the negative DC bus voltage. While in the three level switching voltage waveform, the line-neutral voltage is switched among voltage levels of positive voltage of DC bus, negative voltage of the bus voltage and the mid-point voltage of DC bus. The major disadvantages of the multilevel conversion are its complexity of bus bar interconnection. A larger number of semiconductor devices are required. As the number of voltage levels increases, the bus bar structures of the multilevel DC link converter become more complex and difficult to fabricate. The capacitor voltage balancing problem in the multilevel converter is also an eminent disadvantage. Several solutions have been proposed to overcome this problem.

2- Level DC Link Converter



(a)

3- Level DC Link Converter



(b)

Fig.5. Efficiencies of 3-phase Dc link Converters a) two level switching b) three level switching

The switching technique employed for the converter giving the pattern of the voltages across the link capacitor. The waveforms based on PWM switching technique for the conventional two level and three level switching from the figure.5 shows that the converter efficiencies are dominated by the efficiencies of the rectifier parts of the converters. In addition, at lower operating power or lower operating voltage, the efficiencies of the rectifier parts decrease more rapidly than those of the inverter parts. Because the voltage produced by the generator is proportional to the wind speed, the reduced voltage produced by the generator under low wind speed conditions causes the rectifier parts to work harder in stepping up the voltage magnitude. This requires grater proportion of the indirect power. In the rectifier portion of the DC link system, the indirect power consists of energy that is first stored in the inductors and later released to the DC link. In contrast, the direct power consists of power flows directly from the input side to the output side, without going through the intermediate step of being stored. Hence the indirect power conversion incurs additional losses.

4. Matrix Converter

The matrix converter is an AC/AC converter, with nine bidirectional commanded IGBT's *Sij*. It is connected between the electric machine and a second order filter, which in turn is connected to an electric network. The second order filter is an inductive load that avoids the interruption of the output currents. A three-phase active symmetrical circuit in series models the electric network. For the matrix converter modelling we assumed that:
1) the diodes are ideal: in conduction it is null the voltage between its terminals, and in blockade it is null the current that passes through it; 2) the elements of the command matrix of the converter are bidirectional switches in voltage and current; 3) the command variables *Sij* for each *i* has for one *j* the value one, i.e. only one switch is in conduction in order to achieve continuity in the current in each phase; 4) the command variables *Sij* for each *j* has for one *i* the value one, i.e. only one switch is in conduction in order to achieve continuity in the voltage between the phases [10]. The configuration of the system that will be simulated is shown in Figure 2. The IGBT's commands *Sij* are given in function of the on and off states as follows:

$$S_{ij} = \begin{cases} 1, (on) \\ 0, (off) \end{cases} \quad i, j \in \{1, 2, 3\} \qquad (18)$$

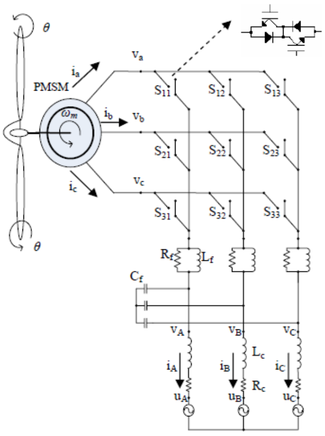


Fig. 6. Wind energy system with matrix converter

The assumptions in 3) and 4) are given by restrictions (19) on commands *Sij*:

$$\sum_{j=1}^{3} S_{ij} = 1 \qquad i \in \{1, 2, 3\}$$
$$\sum_{i=1}^{3} S_{ij} = 1 \qquad j \in \{1, 2, 3\} \qquad (19)$$

The vector of output phase voltages is related to the vector of input phase voltages through the command
matrix, as follows:

$$\begin{bmatrix} v_A \\ v_B \\ v_c \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = [S] \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (20)$$

The vector of input phase currents is related to the vector of output phase currents through the command matrix, as follows:

$$[i_a \quad i_b \quad i_c]^T = [S]^T [i_A \quad i_B \quad i_C]^T \qquad (21)$$

Hence, (18) to (21) model the matrix converter.

Matrix converters do not require intermediate energy storage and have lower switching losses. Although the matrix converter has six additional switching devices, compared to the back-to-back, two-level, DC-link converter, the absence of the DC-link capacitor may increase the efficiency of the converter. Also, the power semiconductor devices in the matrix converter are switched at average voltages lower than those in the two-level, DC-link converter. The major disadvantage of the matrix converter is the limitation of the voltage gain ratio, which leads to poor semiconductor device utilization. Another drawback is the large number of semiconductor devices required to make the matrix converter functional. Although devices with smaller current rating can be employed, they still lead to a large number of gate driver circuits. In addition, with the absence of the DC-link, there is no decoupling between the input and output sides. Any distortion in the input voltage is reflected in the output voltage at different frequencies; as a consequence, sub harmonics can be generated. Many soft-switching techniques have been proposed to improve the efficiency of the matrix converter.

5. Conclusion

The increased wind power penetration in power systems networks leads to new technical challenges, implying research towards more realistic and physical models for wind energy systems. This paper presents a more realistic modelling of generator, power electronics converter used in wind power systems. Mainly three power converter topologies integrating wind power with the electrical grid: two-level, three level and matrix converters are discussed in depth with its ample scope in wind energy sector in India. Technical comparison between the two level, three level and matrix converter are also given.

References:

[1] J. M. Carrasco et al., “Power-electronic systems for the grid integration of renewable energy sources: a survey”, IEEE Trans. on Industrial Electronics, Vol. 53, No. 4, pp 1002-1016, August 2006.
[2] J. A. Baroudi, V. Dinavahi and A. M. Knight, “A review of power converter topologies for wind generators”, Renewable Energy, Vol. 32, No. 14, pp 2369-2385, November 2007.
[3] R.Melicio,V. M. F. Mendes and J.P.S. Catalao, “Wind energy systems and power quality: Matrix versus Two level Converters”
[4] K. Ghedamsi, D. Aouzellag and E. M. Berkouk, “Matrix Converter based variable speed wind generator system” , Journal of Electrical and Power Engineering 2(1), 39-49,2008
[5] Thomas Ackermann, “A book on wind power in power systems” John wiley & Sons,Ltd. pp 53-77.
[6] Siegfried Heier, “A book on grid integration of wind energy conversion systems” John wiley & Sons,Ltd. pp 199-214.
[7] R. Erickson, S. Angkititrakul, and K. Almazeedi, “A New Family of Multilevel Matrix Converters for Wind Power Applications: Final Report”, pp 15-25, December 2006.
[8] Ren 21-Renewable2011 Global Status Report, pp 16-21