Reactive power management of grid connected wind turbine driven PMSG using multilevel inverter based STATCOM

M.Kumanan, R.Bharani Kumar
MS (By Research) Scholar, Professor,
Department of EEE,
Bannari Amman Institute of Technology,
Sathyamangalam, Erode, TN, India
Ermkkeb2000@gmail.com,
bharanikumar.rbk@gmail.com

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Abstract

Wind energy conversion system installation is increasing throughout the world to meet the new demand and energy crisis. There are number of wind turbine generator technologies are available and installed. Out of which direct drive wind turbine driven permanent magnet generator is very attractive nowadays because no need of step up gears, less maintenance, absence of excitation source, operating at maximum power point region and higher efficiency. However the grid connected direct drive system suffers from the grid fault conditions. During grid fault chances for islanding of generator, to overcome this issue a multilevel inverter based STATCOM is proposed in this paper. The proposed STATCOM is simulated in the MATLAB/SIMULING and results are analysed to validate the theoretical studies.

Key Words: Direct drive Wind energy system, PMG, Wind turbine, STATCOM, Multilevel Inverter
1 Introduction

The electrical power demand in the world is increasing day by day. To meet out this rising energy demand. The resources of conventional fossil fuels are decreasing day by day and the resources will become extinct very soon. To overcome this issue most of the countries are focusing and utilizing available energy resources. Among the various alternative sources, Wind and Solar energy are gaining much importance. The estimated energy demand in the year 2030 will be 1791242 GW. To meet this energy demand the Indian government aims to utilize the renewable energy resources. By the end of the year 2025 the government aims to increase the wind energy capacity from 25 GW to 75 GW.[1] However, transmitting this power from remote location to the load side is an important task. Also renewable energy systems are mostly disconnected from the grid due to shortage of power transmission capacity, grid faults and power quality issues. To maintain the wind forms synchronism with grid over these issues, many solutions have been addressed in the literatures such as, mechanically switched capacitor bank and tap changing transformers are used for stability improvement and power quality improvement. However these devices suffers from poor power factor and not controlling the reactive power. FACTS devices particularly STATCOM has the ability to increase the voltage quality, accurate reactive power control and voltage regulation. The STATCOM is connected to the point of common coupling at which supplies reactive power or absorb the reactive power from the grid. Also the STATCOM inverter injects current to the grid at which cancel out the harmonic current.[2] Different types of wind turbine generates are connected to the grid such as wind turbine driven synchronous generator, cage induction generator, DFIG electrically excited synchronous generator, permanent magnet generator out of which recently the PM generator are very popular because of brushless operation, no rotor winding, small size, no rotor copper losses, less maintenance, and high efficiency. Because of these advantages, PMSGs are more suitable for variable speed wind energy conversion systems[3]. The main challenges in PMSG are voltage and frequency control under varying load conditions. The generated voltage of PMSG- systems can be controlled using static compensator (STATCOM). STAT-
COM is widely used in grid-connected and isolated supply systems for voltage and frequency control of PMG. In addition, it can be used for load balancing, harmonics elimination, load compensation, and reactive power compensation.[4] The multilevel converters are therefore emerging as an attractive one for STATCOMs and they have been used recently in practical installations.[5][6] By comparing various multilevel topologies in terms of the harmonic levels, losses and component costs, the cascaded multilevel converters are found to be the most suitable for applications requiring only reactive power exchange (STATCOMs). Converters with this topology are suitable in high-voltage and power system applications due to their modular structure, their ability to synthesize waveforms with better harmonic spectra.[7] The required high-voltage rating can be achieved by cascading (stacking) individual modules of a standardized low-voltage rating rather than custom building the power electronics for each application. The topology also permits the elimination of a converter transformer with further cost savings.

2 MODELLING OF WIND ENERGY CONVERSION SYSTEMS

A. Wind Turbine Model
The captured mechanical power captured by wind turbine is expressed as

\[ P = \frac{1}{2} \rho v^3 A C_p(\lambda, \beta) \]  

Where \( \rho \) is the air density in kg/m\(^3\), \( A \) is the blade swept area in m\(^2\), \( v \) is wind velocity and \( C_p \) is the power coefficient of the wind turbine. The \( C_p \) can be expressed by,

\[ C_p(\lambda, \beta) = \frac{1}{2}(\lambda - 0.022\beta)^2 - 5.6)e^{-0.17\lambda} \]  

\[ \lambda = \frac{k \omega}{v} \]  

Where \( \beta \) is the blade pitch angle, \( \lambda \) is the tip speed ratio, \( R \) is the blade radius, \( \omega \) is the blade angular speed.

B. Permanent-Magnet Generator model
The p.u. d-q axis equivalent circuit model of the studied wind PMSG, where the q-axis is fixed on the machine rotor and rotates at rotor speed, can be expressed [6],

\[ v_{qs} = -r_s i_{qs} + \frac{p \lambda_q}{\omega_b} + \frac{\omega_r}{\omega_b} \lambda_d \]  
\[ v_{ds} = -r_s i_{ds} + \frac{p \lambda_d}{\omega_b} + \frac{\omega_r}{\omega_b} \lambda_q \]  

(3)  

(4)

Where,

\[ \lambda_q = - (X_{mq} + X_{ls}) i_{qs} = -X_q i_{qs} \]

\[ \lambda_d = - (X_{md} + X_{ls}) i_{ds} = -X_d i_{ds} + X_{md} i_m' \]

Where \( \lambda \) is the flux linkage, \( v_s \) is the stator winding voltage, \( i_s \) is the stator winding current, \( X_m \) is the magnetization reactance, \( X_l \) is the leakage reactance, \( i_m' \) is the magnetization current, \( \omega_r \) is the rotational speed, and \( \omega_b \) is the base speed.

3 CASCADED MULTILEVEL INVERTER

There are different types of multilevel inverter topologies are proposed in the literatures such as diode clamped, flying capacitor and cascaded topologies. The main aim of the diode clamped MLI is to use the power diodes at which to reduce the rating of the power switches. Here the voltage across each capacitor and power switch is only Vdc. However the diode clamped inverter having higher switching current stress and higher THD. In flying capacitor MLI capacitor is used instead of diodes to divide the input dc source voltages. Here the rating of each capacitor and power switches are Vdc. However the controlling of capacitor voltage is very difficult and also its weight and cost is more. The cascaded H-bridge MLI topologies having n-number of single phase H-bridge inverters connected in series to get the desired level of staircase waveforms. The cascaded h-bridge MLI having lower weight and also not requires diodes and requires less number of capacitors[9] [10]. Also the controller circuit is very simpler. Figure 2 shows the circuit diagram of seven level MLI for STATCOM applications. It consists of three h-bridges each having four IGBT power switches. Figure shows the pulse pattern for seven level inverter.
3.1 Modes of Operation

Mode I In this mode the switches S1 and S2 are turned ON of the upper H-bridge. Hence voltage Vdc is appears across the terminals of STATCOM as shown in Figure 3...
Figure 3. Equivalent circuit during model I Seven level Multilevel Inverter Topology

Mode II To maintain the switches S1 and S2 are in ON state and turn ON the switches S5 and S6, hence 2Vdc is appears across the STATCOM as shown in Figure 4.
Mode III

Similarly along with S1, S2, S5 and S6 the switches S9 and S10 are turned ON, no the voltage 3Vdc is appears across the STATCOM as shown in Figure 5. Figure 6 shows the pulse pattern for proposed multilevel inverter based STATCOM along with corresponding staircase wave form.
Figure 5. Equivalent circuit during model III Seven level Multilevel Inverter Topology
3.2 Fourier Series:
To realize the harmonic content present in the staircase waveforms if MLI a Fourier series is derived for seven level MLI and it is expressed in Equation 1.

\[ V(\omega t) = \sum_{n=1,3,5,\ldots}^{\infty} \frac{2V_{dc}}{n\pi} (\cos(n\theta_1) + \cos(n\theta_2) + \cos(n\theta_3)) \sin(\omega t) \quad (5) \]

Where
- \( n \)-harmonics order number
- \( \theta \) are the switching angles

Optimisation of switching angles using ANT COLONY. From the Fourier series analysis, the fifth and seventh order harmonics are very dominant. Also design of filter circuit for lower order harmonics is very difficult also increases the size and cost of the filters. To avoid the filter requirements the notch angles should be optimised, here ANT colony optimisation techniques is used to optimise the notch angles [8]. After the optimisation, the switching angles are found out that \( \theta_1=13, \theta_2=29 \) and \( \theta_3=51 \). These switching angles are completely removed the fifth and seventh order harmonics from the staircase waveforms as shown in Figure. First the transcendental equations are converted into polynomials. Then the variables are taken to form the four equations. Consider

\[ \cos \theta = x; \]
\[ \cos(5\theta) = 5 \cos \theta - 20 \cos^3 \theta + 16 \cos^5 \theta; \]
\[ \cos(7\theta) = -7 \cos \theta + 56 \cos^3 \theta - 112 \cos^5 \theta + 64 \cos^7 \theta; \]
\[ \cos(11\theta) = -11 \cos \theta + 220 \cos^3 \theta - 1232 \cos^5 \theta + 2816 \cos^7 \theta - 1024 \cos^{11} \theta; \quad (6) \]

4 RESULTS AND DISCUSSION

Figure 7 shows MATLAB model of CMLI. This model contains three phase programmable voltage source, rectifier bridge, CMLI circuit,
with upper and lower triggering circuit and three phase V-I measurement. Fig.4.2 shows MATLAB model of the upper triggering circuit. This circuit serves to produce triggering pulses for the switches. The Fig 4.1 having the three single phase H-Bridge inverter, each inverter bridge having the four MOSFET rating of IRF840. The pulse to the MOSFET is designed according to the Figure 6.

Figure 7 Simulation model of cascaded MLI
The Figure 8 shows the pulse pattern for the MOSFET switches of the seven level cascaded MLI. The pulse duration for switches T1, T2, T3 and T4 is 83.4%. The pulse duration for switches T5, T6, T7 and T8 is 66.6%. The pulse duration for switches T9, T10, T11 and T12 is 50%. Figure 9 shows the output voltage of the simulated cascaded MLI for the input battery voltage of 100V. The output voltage of each level consists of 100V. The total peak voltage of 300V.
Figure 9 Pulses positive group switches

Figure 9 output voltage waveform for seven level cascaded MLI

Figure 10 Shows the harmonic profile of the seven level cascaded MLI. It clearly shows that the total harmonic distortion around 14.27%. the third order harmonics magnitude is only 5.2% and 5th order harmonics is 8.2% the all other harmonics are below 4%.
5 CONCLUSION

A STATCOM with multilevel inverter topology is suggested for voltage and frequency regulation of wind turbine PMSG system. When compared with conventional two level inverters, the multilevel structure allows to raise the power handling capability in the conversion process and also it has very low THD profile. By proper adjustment of PWM pulses, it can control both reactive power exchange, voltage and frequency control. To optimize the switching angles a ANT colony optimization technique is used. Theoretical study of MLI based STATCOM is verified with simulation studies. The proposed MLI based STATCOM with wind turbine PMG is modelled in the MATLAB/ Simulink. a.
Fig. 1. Procedures for developing a model of health education program for 5-year-old children using 3D animated fairy tales.

Fig. 1. Example of a figure caption. (figure caption) Figure Labels: Use 8 point Times New Roman for Figure labels. Use words rather than symbols or abbreviations when writing Figure axis labels to avoid confusing the reader. As an example, write the quantity Magnetization, or Magnetization, M, not just M. If including units in the label, present them within parentheses. Do not label axes only with units. In the example, write Magnetization (A/m) or Magnetization (A m⁻¹), not just A/m. Do not label axes with a ratio of quantities and units. For example, write Temperature (K), not Temperature/K.

References


