International Journal of Electronic and Electrical Engineering.
ISSN 0974-2174, Volume 7, Number 4 (2014), pp. 357-364

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THD Reduction in PMSG Based Wind Energy System Using 17 Level Modular Multilevel Converter

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Abstract

The wind turbine, generator and converter are usually in the nacelle on the top of the tower, but the grid step-up transformer is placed at the bottom and Electric power is transmitted down by the generator through cables of high current rating which are expensive. For the THD reduction of WECS (Wind Energy Conversion System) 17 level MMC (Modular Multi level Converter) technique is used. The MMC is one of the most promising converter topologies for high-voltage applications, especially for high-voltage direct-current (HVDC) transmission systems. This study presents power electronics solution based on a PMSG (Permanent Magnet Synchronous Generator) design a MMC voltage source converter is developed to synthesize a high sinusoidal output voltage. In this system a LC Filter is used for the low order harmonic reduction. A set of simulation results conducted in MATLAB/Simulink environment are presented to verify the accuracy of the mathematical analysis.

Keywords: MMC, PMSG, WECS, LC Filter, Transformer, Rectifier, Harmonics, Inverter.

1. Introduction

WECS penetration is growing and the size of wind turbines also, especially for offshore applications where turbines in the range of 3-6 MW are now tested [1]. In order to comply with the more demanding grid codes in some countries with high wind power penetration (Denmark, Germany, Spain, UK, etc.) full- Scale back-to-back (BTB) converters are more and more used in [2].Replacing direct current (DC) machines and alternating current (AC) induction machines with permanent magnet (PM) machines has recently gained great interest. PM motors are gaining popularity wide variety of reasons. Because the excitation of a PM motor is provided by permanent magnets, brushes and slip rings are eliminated, resulting in a simple and rugged structure. So PMSG is used for power generation and one other reason to use the PMSG is that Permanent magnet excitation is current-free and lossless. For maximum power MPPT is used in this system. This system has 3MW capacity shown in fig.1

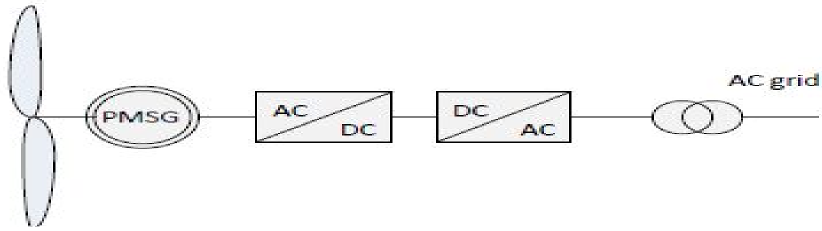


Fig. 1: Basic Structure of PMSG Based WECS.

MMC is used for the reduction of THD in output power of PMSG based wind energy system. In this IGBT is used as a switches. The main salient features of the MMC are the following[3], [4]:

It is structurally scalable and can theoretically meet any voltage level requirements.

It does not have the drawbacks of other multilevel converters. e.g., the capacitor voltage balancing task is relatively simpler and there is no requirement for isolated dc sources.

The MMC proposed in [5]-[8] is one of the most promising power converter topology for high power applications in the near future, particularly in HVDC links (e.g. transmission of offshore wind power, among others). Siemens has a plan of putting this converter into practical applications with the trade name "HVDC-plus".The typical structure of a MMC is shown in Fig. 2, and the configuration of a SubModule (SM) is given in Fig. 3. Each SM is a simple chopper cell composed of two IGBT switches (*T1* and *T2*), two anti-parallel diodes (*D1* and *D2*) and a capacitor *C*.

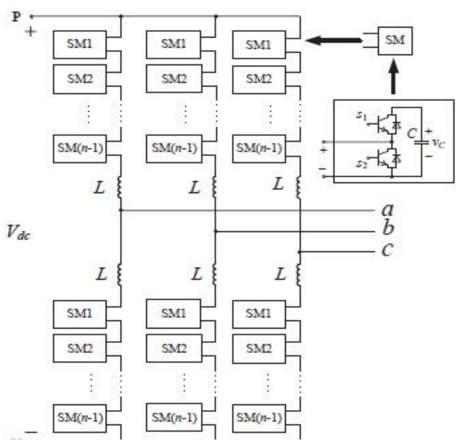


Fig. 2: Schematic of a three-phase Modular Multi-level Converter.

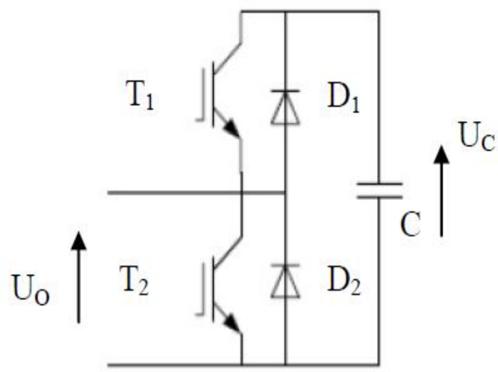


Fig. 3: Chopper cell of a Sub-Module.

2. System Description and Modeling

1. Wind Power: The first use of wind power was to sail ships in the Nilesome 5000 years ago. The Europeans used it to grind grainsand pump water in the 1700s and 1800s. The first windmillto generate electricity in the rural U.S.A. was installed in 1890 [9]. Today, large wind-power plants are competingwith electric utilities in supplying economical clean powerin many parts of the world.

A wind turbine extracts kinetic energy from the swept area of the blades. The power in the airflow is given by,

$$P_{air} = \frac{1}{2}\rho A v^3 \quad (1)$$

Where

ρ- Air density

A- Swept area of rotor, m^2

v- Upwind free wind speed, m/s

Although Eqn. (1) gives the power available in the wind the power transferred to the wind turbine rotor is reduced by the power coefficient, C_p:

$$C_p = \frac{P_{wind\ turbine}}{P_{air}} \quad (2)$$

Where,

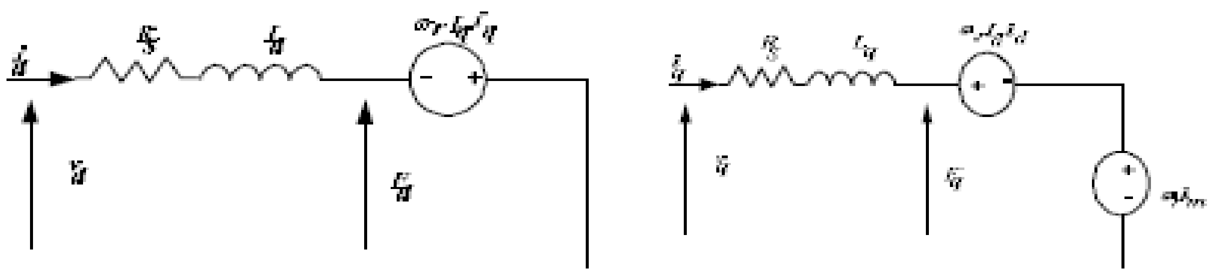
$C_p$is the power coefficient.

$$P_{wind\ turbine} = C_p P_{air} = C_p \frac{1}{2}\rho A v^3 \quad (3)$$

A maximum value of $C_p$is defined by the Betz limit, which states that a turbine can never extract more than 59.3% of the power from an air stream. In reality, wind turbine rotors have maximum $C_p$values in the range 25–45%.

It is also conventional to define a tip-speed ratio as

$$\lambda = \frac{\omega R}{v} \quad (4)$$



a)d axis b) q axis

Fig. 4: Equivalent circuit diagram of (PMSM) in “dq” frame.

2. Motor mode: The equivalent circuit of the machine in motor mode (PMSM) [10] along the axis “d” and q” is given in Figure 4

$$v_d = R_s i_d + L_d.\frac{di_d}{dt} - \omega_r.L_q.i_q \quad (5)$$

$$v_q = R_s i_q + L_q.\frac{di_q}{dt} + \omega_r.d.i_d + \omega_r.\lambda_m \quad (6)$$

Where vd ,vq , id and iq are the voltages and currents on the axis d and q of the stator respectively. Rs is the resistance of the stator windings, ωr is the angular velocity of the machine, λm is the maximum flux generated by the permanent magnet machine.

The e.m.f Ed and Eq on the d and q axis respectively are expressed by:

$$E_d = -\omega_r\lambda_q = -\omega_r.L_q.i_q \quad (7)$$
$$E_q = \omega_r\lambda_d = \omega_r.L_d.i_d + \omega_r.\lambda_m \quad (8)$$

The mechanical power developed:

$$P_m = \frac{3}{2}(E_d.i_d + E_q.i_q) = \frac{3}{2}(\omega_r.\lambda_d.i_d - \omega_r.\lambda_q.i_q) \quad (9)$$

The electromagnetic torque in a rotational reference:

$$\Gamma_e = \frac{P_m}{\omega_m} = \frac{P_m}{\omega_r}.(\frac{P}{2}) \quad (10)$$

Where P is the number of pole pairs and ω_m is the Mechanical speed.

3. Generator mode: As the PMSG machine is operated in generator mode [11]-[13], so the current in the stator winding will be in opposite direction. According to the dq plan, the equivalent diagram of the PMSG in generator mode is given in Figure 5.

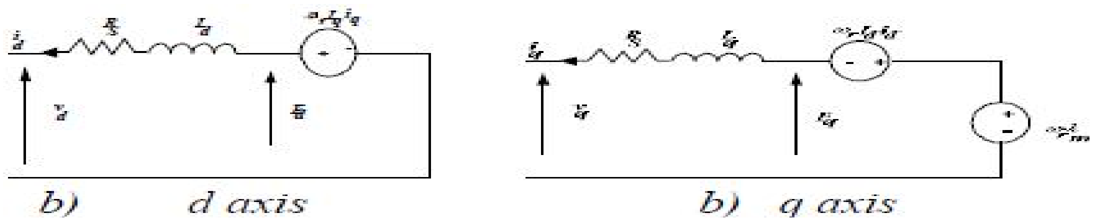


Fig. 5: Equivalent circuit diagram of the (PMSG) in "dq" frame.

$$v_d = -R_s.i_d - L_d.\frac{di_d}{dt} + \omega_r.L_q.i_q \quad (13)$$

$$v_q = -R_s.i_q - L_q.\frac{di_q}{dt} - \omega_r.L_d.i_d + \omega_r.\lambda_m \quad (14)$$

EMF Equations-

$$E_d = \omega_r.L_q.i_q \quad (15)$$

$$E_q = -\omega_r.L_d.i_d + \omega_r.\lambda_m \quad (16)$$

Mechanical Power-

$$P_m = \frac{3}{2}.\omega_r.(\lambda_m.i_q + i_d.i_q.(L_q - L_d)) \qquad (17)$$

Electromagnetic Torque

$$\Gamma_e = \frac{P}{2}.\frac{P_m}{\omega_r} = \frac{3}{2}.(\frac{P}{2}).(\lambda_m.i_q + (L_q - L_d).i_d.i_q) \qquad (18)$$

3. Multi-Module Structure and Operation - Three-Phase MMC:

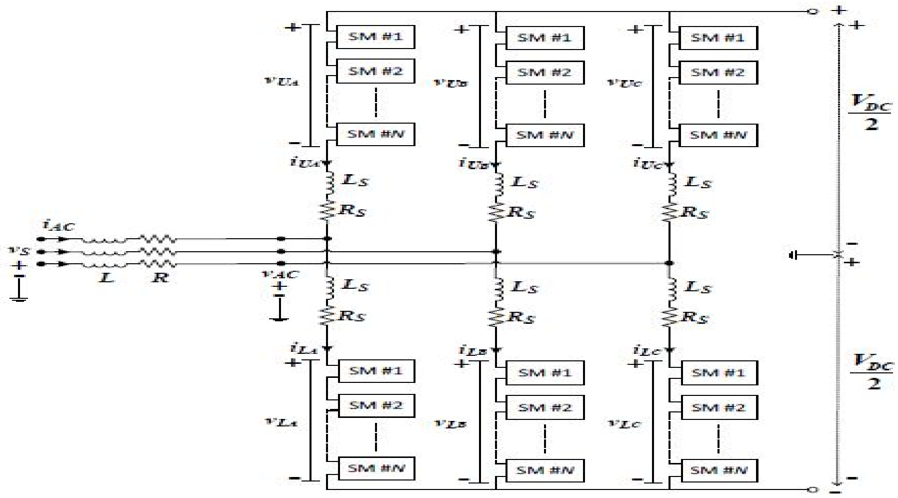


Fig. 6: Three phase MMC.

The operation of the three phase MMC is essentially the same as the single phase version as shown in fig.6. The equations developed in the previous section apply to the other two phases of the converter with, of course, the expected phase-shift between them. One notable difference is that there is now a possibility for current to circulate through phases without appearing at either the AC or DC terminal.

4. Modeling and simulation of the system-

In this system WECS and a 17Level MMC is connected to reduce the THD of the output power.

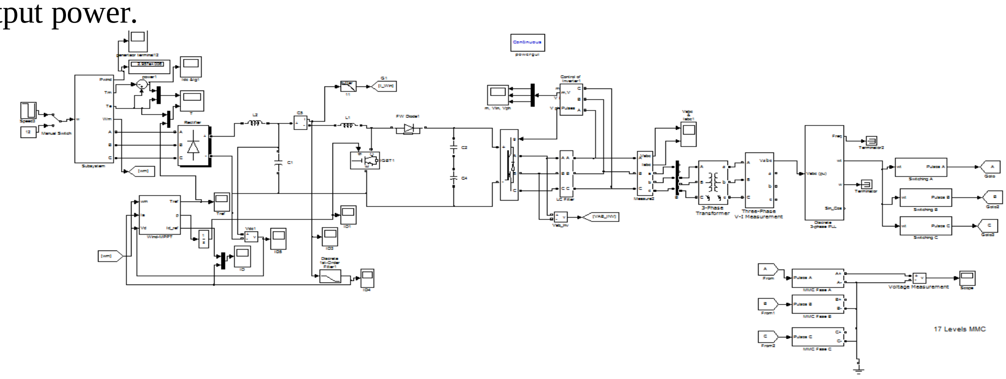


Fig. 7 MATLAB/Simulink Model

The output power of the PMSG is 2.957 MW. After gaining the power it converts in dc voltage through a rectifier. MPPT is used for the maximum power and then after MPPT the converted output voltage is boosted by a Boost converter. A Bridge rectifier is used for the conversion of DC voltage in AC. LC filter eliminates the low order harmonics and THD of output voltage is reduced upto 1% by using 17 Level MMC.

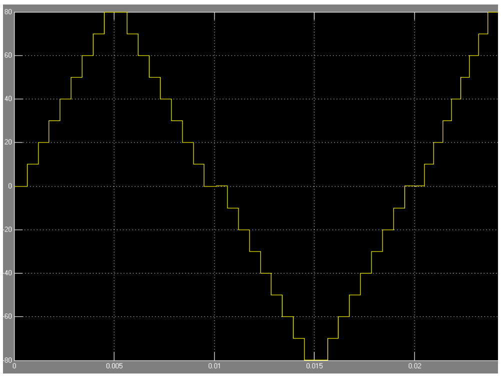


Fig. 8: Output waveform

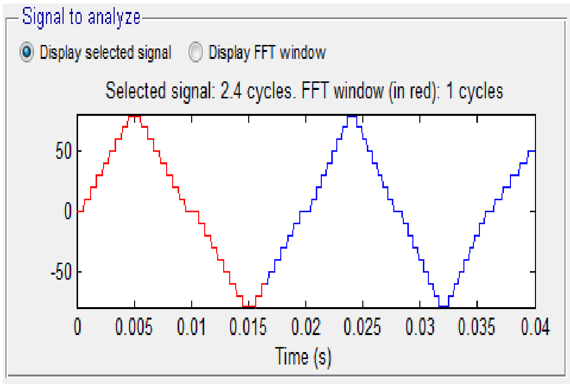


Fig. 9: FFT Window.

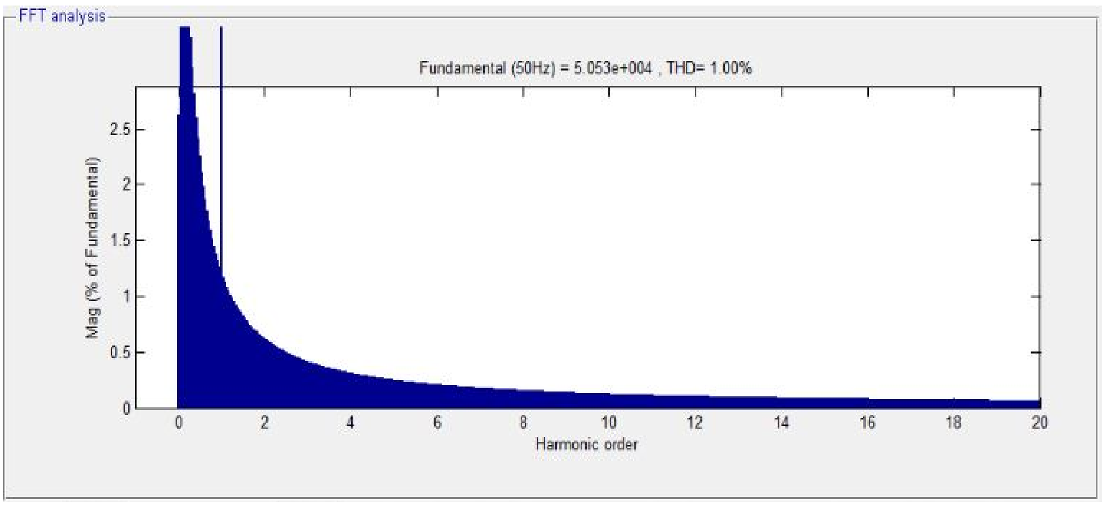


Fig. 10: THD analysis.

5. Conclusion

This paper has demonstrated the implementation of a model of the MMC on WECS using PMSG device. A new concept is introduced in this paper by using LC Filter and 17 Level MMC. By this concept output voltage THD is reduced upto 1%. LC filter reduces low order harmonics. The SMs are switched at very low switching frequency (260 Hz) resulting in very high efficiency. In order to ensure a high apparent switching frequency, all SM are interleaved by providing a shift delay for the carrier.

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