Study of Harmonic Mitigation in PMSG Wind Turbine Energy Conversion Systems

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Abstract. Reduced magnet price has made synchronous generators with permanent magnet synchronous generator (PMSG) an attractive alternative in the last couple of decades. Permanent magnet synchronous generators (PMSG) applied to wind energy conversion system (WECS) using variable speed operation is being used more frequently in wind turbine application. Variable speed systems have several advantages over the traditional method of operating wind turbines, such as the reduction of mechanical stress and an increase in energy capture. To allow the variable speed operation of the PMSG WECS a conventional passive harmonic trap filter with a bulky capacitor associated with a voltage source current controlled inverter (VS-CCI) is used. This simple scheme introduces a high intensity low frequency current harmonic content into the PMSG and consequently increases the total loses in it. Subsequently, decreases the power capability of the system. This paper presents a comparative simulation study between three different approaches applied to harmonic mitigation in PMSG WECS.

Keywords: Wind energy, Harmonic component, PMSG, Rectifiers, Harmonic Trap Filter.

1 INTRODUCTION

Now a day's worldwide energy crisis is one of the great problem. The interest in renewable energy has been revived over last few years, especially after global awareness regarding the ill effects of fossil fuel burning. The amount of energy captured from a WECS depends not only of the wind at the site, but depends of the control strategy used for the WECS and also of the conversion efficiency. Permanent magnet synchronous generators (PMSG) on wind energy conversion system (WECS) with variable speed operation are being used more frequently in low power wind turbine application. Variable speed systems have several advantages such as the reduction of mechanical stress and an increase in energy capture. In order to achieve optimum wind energy extraction at low power fixed pitch WECS, the wind turbine generator (WTG) is operating in variable-speed variable-frequency mode. The rotor speed is allowed to vary with the wind speed, by maintaining the tip speed ratio to the value that maximizes aerodynamic efficiency. The PMSG load line should be matched very closely to the maximum power line of the WTG. MPPT control is very important for the practical WECS systems to maintain efficient power generating conditions irrespective of the deviation in the wind speed conditions. To achieve optimal power output, a sensor-less scheme including a wind turbine model was developed by Tan et al in. The developed wind turbine model will be used in this work in order to evaluate the different harmonic mitigation approaches. To build the first one a classical three phase bridge rectifier (BR) associated to a bulky capacitor is used and the second stage may be implemented by two types of converters schemes Voltage source current controlled inverter (VS-CCI) and Line commutated inverter (LCI) as shown in

Fig. 1. This paper has the main focus in the first energy conversion stage the AC-DC converter, which is responsible by an injection of a high harmonic current content into the PMSG. These currents circulating into the machine will generate losses. Using these approaches is possible to minimize the current harmonic content.

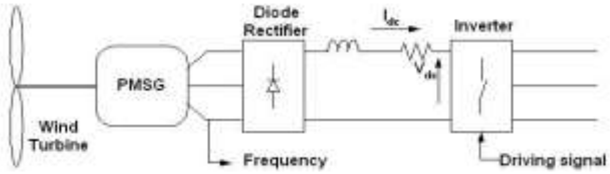

Figure 1. Wind Energy Conversion System.

A software simulation model developed in using PSIM® software, which allows easy performance evaluations, is used to estimate the behaviour of these three different schemes associated with the PMSG WECS. Simulation results showed the possibility of achieving maximum power tracking, output voltage regulation and harmonic mitigation simultaneously.

2 WIND TURBINE SYSTEM

The In a wind turbine system, the kinetic energy in the wind is converted into rotational energy in a rotor of the wind turbine. The rotational energy is then transferred to a generator, either directly or through a gearbox for stepping up the rotor speed. The mechanical energy is then converted to electrical energy (variable-frequency, variable-voltage) by the generator. From the generator, the electrical energy is transmitted to a utility grid either directly or through an electrical energy conversion stage that produces constant-frequency, constant-amplitude voltage suitable for interface to the utility. The entire system is shown in Fig. 1. A brief description of each element of the system is given below. The output power of the wind turbine is given by the following equation. $P_m = \frac{1}{2} C_p(\beta,\lambda)\rho A V^3$ (1)

C_p =	Performance coefficient	Dimension less
ρ =	Air density	kg/m^3
A =	Turbine swept area	m^2
V =	Wind speed	m/s
β =	Blade pitch angle	degree
λ =	Tip speed ratio of the rotor blade	Dimension less

The C_p curve for the wind turbine used in this study is shown in Fig. 2. The wind turbine output mechanical torque is affected by the C_p.

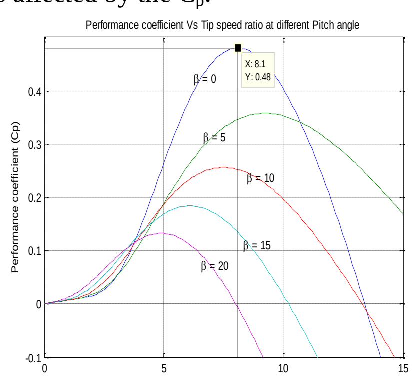

Figure 2. Power coefficient vs. Tip speed ratio with β=0, 5, 10, 15, 20 degree

In order to maximize the aerodynamic efficiency, the T_e of the PMSG is controlled to match with the wind turbine T_m to have maximum possible C_{pmax}. With a power converter, adjusting the electrical power from the PMSG the T_e may be controlled, therefore the rotor speed can be controlled. To operate at maximum power at all wind speeds, the electrical power output from the power converter controller must be continuously changed compensating wind speed variation conditions to have the system always matched on the maximum power locus. From the power curve of the wind turbine, it is possible to operate the wind turbine at two speeds for the same power output. Theoretical models for generators producing power from a wind turbine have been previously developed. The outer rotor 20kW CRESTA PMSG described in [1] is used in this WECS mathematical model. Unlike the three systems described above a WEG-PMG employs a synchronous generator. To avoid complexities in the field excitation system it uses permanent magnet poles. Use of permanent magnet facilitates reduction of pole size and consequently reduction of the synchronous speed of the generator by increasing the number of poles. As a result the WEG-PMG does not need a gear. The grid interface in the case of WEG-PMG is an asynchronous link. With an asynchronous grid interface the problem of armature voltage regulation demands a variable speed operation of the prime mover. As such a pitch-controlled WT is essential for this system because unlike an induction machine the PMG does not have a command on speed on its own. Though it is costlier than a stall-regulated WT owing to sophisticated control mechanism, the overall power conversion efficiency of the pitch-controlled WT is superior to that of a constant speed stall regulated one. The power loss in the grid interface of a WEG-PMG is expectedly higher than that of a WEG-DOIG of equal capacity because the former delivers the entire load current through the asynchronous link unlike the latter. The complete grid connected sensor-less PMSG WECS scheme using a well-known three-phase six-pulse bridge rectifier and two bulky capacitors are shown in Fig. 3

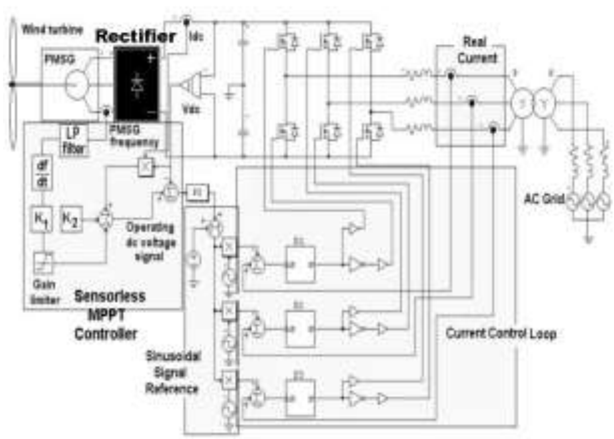

Figure 3. Implemented sensor-less VS-CCI WECS

3 HARMONIC ANALYSIS OF PMSG

Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind is a renewable resource because it is inexhaustible[7]. It is a result of the sun shining unevenly on the earth. Since wind turbine output is proportional to the cube of the wind speed, the wind turbine generator output fluctuates due to wind speed variations. The loading characteristic of the PMSG WECS can be easily simulated by connecting an adjustable load resistor to the PMSG and rectifier terminal. In order to extract the peak power from the WTG at a given wind speed, the WECS has to match closely to the maximum power curve. First of all it is necessary to understand why this study is important. Therefore, a briefly remark of the problem is presented. A study case is presented showing the PMSG output currents at full load condition (20 kW resistive load) using a conventional BR shown in Fig. 3, which is normally employed in PMSG WECS. The wind speed in this case is 12 m/s. Harmonic characterization of these abnormal currents is obtained and the results are presented in the following section. In order to evaluate the quality of current and voltage an objective study was made using the Fourier analysis. The harmonic content and the total harmonic distortion (THD) of the output PMSG current and voltage were obtained, the results are summarized in Fig. 4 and Fig. 5.

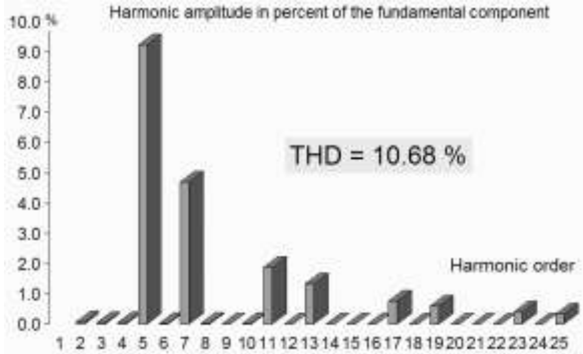

Figure 4. Harmonic content of the PMSG output current.

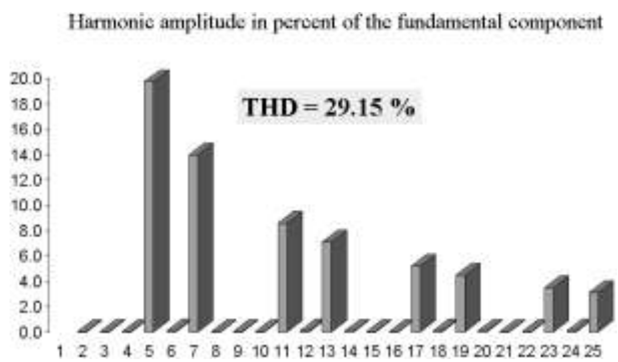

Figure 5. Harmonic content of the PMSG output voltage.

4 PASSIVE HARMONIC TRAP FILTER

The classical passive trap filters are always associated with the idea of harmonic mitigation. Also the PFC and the PWM_{REC} schemes will need high frequency filters to mitigate the high frequency current ripple generated by them selves. Looking for this classical power electronics problem a first design could be to use passive HTF as shown in Fig. 6. In fact, a reduction of the 5th and 7th harmonic may be enough to turn the THD to acceptable levels. A design of two trap filters was made to minimize the 5^{th} and 7^{th} harmonic at nominal power.

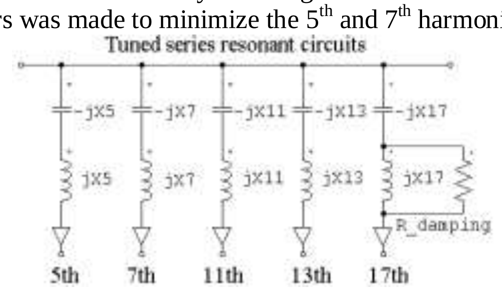

Figure 6. Passive harmonic trap filters.

The simulated results are shown in figures 7 to 10. A remarkable improvement in the current and voltages waveforms was obtained using this simple solution. Figure 9 shows the PMSG output currents and the line to line output voltage (divided by 5), which are almost sinusoidal. A current THD less than 2.5% was obtained as shown in Fig. 8.

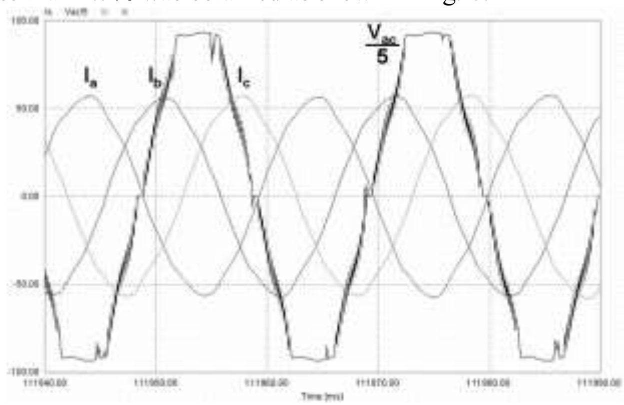

Figure 7. Three-phase PMSG output currents and output line to line voltage div. by 5 using 5th and 7th harmonic trap filters.

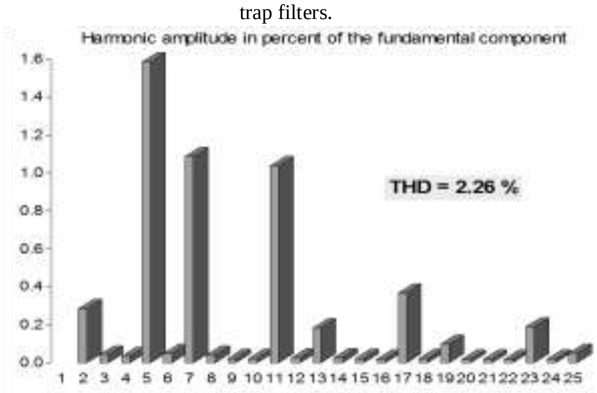

Figure 8. Harmonic content of the PMSG output current using 5^{th} and 7^{th} harmonic trap filters.

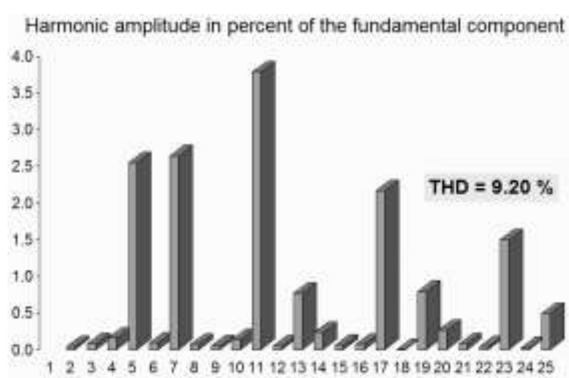

Figure 9. Harmonic content of the PMSG output line-to-line voltage using 5^{th} and 7^{th} harmonic trap filters.

The voltage THD was drastically reduced from 29.15% to 9.20%. On the other hand its RMS value has increased from 293 V to 343 V respectively. This happens because the comparison parameter chosen was the constant power output (20 kW). The resistive load is adjusted in order to keep the power output constant. Once the harmonic core losses are related with the harmonic content of the voltage [5, 6] this characteristic can not be neglected. The study of the active power filters applied to PMSG WECS is out of the scope of this paper. However, is under study at the moment. In figure 11 the PMSG output line to line voltage div. by 5 is shown in the frequency domain.

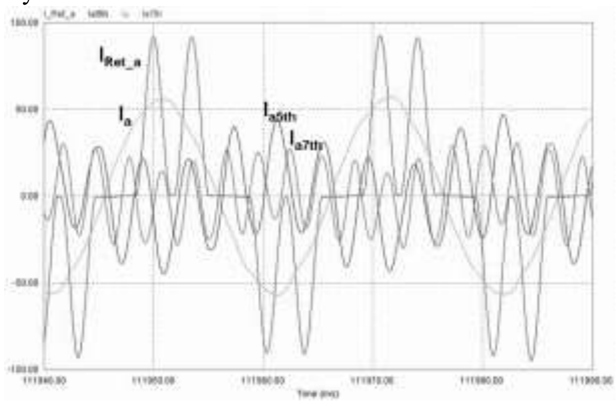

Figure 10. PMSG output, bridge rectifier and 5th and 7th harmonic trap filters current at 20 kW.

5 CONCLUSION

In this paper, three well-known harmonic mitigation solutions were applied to PMSG WECS AC to DC conversion. Harmonic trap filters are easily implemented by passive components but they are normally implemented with bulk components. Notwithstanding the HTF presented good THD results, the HTF are a matched solution for a specific operation point (wind speed and output power). The voltage THD was drastically reduced from 29.15% to 9.20%. On the other hand its RMS value has increased from 293 V to 343 V respectively.

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BIOGRAPHY

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