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Low Distortion Boost Rectifier Discontinuous Conduction Mode with Peak Current Mode Control for Wind Power Systems

O. Carranza[1], E. Figueres[2], G. Garcerá[2] and L. G. González[3]

[1] Escuela Superior de Cómputo, Instituto Politécnica Nacional
Av. Juan de Dios Bátiz S/N, 07738, D. F. (Mexico)
Phone number:+52 5557296000 ext 52022, e-mail: ocarranzac@ipn.mx

[2]Grupo de Sistemas Electrónicos Industriales del Departamento de Ingeniería Electrónica, Universidad Politécnica de Valencia, Camino de Vera S/N, 7F, 46022, Valencia (Spain)
Phone number:+34 963879606, e-mail: efiguere@eln.upv.es, ggarcera@eln.upv.es

[3] Departamento de Ingeniería Electrónica y Comunicaciones, Universidad de los Andes
Merida, (Venezuela)
Phone/Fax number:+34 963879606, e-mail: lgerardo@ula.ve

Abstract. This work presents a Three-Phase Boost Rectifier with peak current mode control operated in Discontinuous Conduction Mode working as the input stage of wind power systems based on Permanent Magnet Synchronous Generators with variable speed operation. It is shown that the DCM operation significantly reduces the Total Harmonics Distortion of the currents in the Permanent Magnet Synchronous Generator, so that the vibrations and mechanical stress of the generator is minimized. The characteristics of the DCM Boost rectifier are studied considering: 1) The resistance in series of the inductors; 2) The modeling and adjustment of the current injected control yielding a stable loop; 3) The design of an input filter that reduces the switching noise in the currents of the generator.

The Three-Phase Boost Rectifier with input filter under study, with the following values:

- Output Power of the generator: P = 2 kW
- Output Voltage of the rectifier: V_o = 800 V.
- Output voltage range of the generator: V_{ab}= 104 - 416 V_{rms}
- Inductance of one phase of the generator: L_{ga}=L_{gb}=L_{gc}=25 mH
- Resistance of one phase of the generator: R_{ga}= R_{gb}= R_{gb}= 5 Ω
- Number of poles: n_p = 12
- Nominal Current: I_{nom} = 4.87 A_{rms}
- Speed Range of the generator: n_m = 150 – 600 rpm

Fig. 1 shows the Bode Diagram of the transfer function from the control voltage to the inductor current, $G_{ic}(s)=i_L(s)/v_c(s)$, for values of the modulation index (m_c) between 2 and 7, with n_m = 600 rpm, L = 750 μH, P = 2 kW and R_i = 0.01 Ω.

In Fig. 1 it is observed that for m_c = 2 and m_c = 3 the current loop is unstable because the phase of $G_{ic}(s)$ undergoes a positive phase transition corresponding to complex conjugated highfrequency poles. This means that the closed loop poles are located in the complex right half plane, yielding an unstable current loop. With $m_c \geq$ 4, it is observed that the control loop is stable because the phase transition of $G_{ic}(s)$ is negative. Selecting m_c= 4, resulting F_m = 0.1666 for this rectifier.

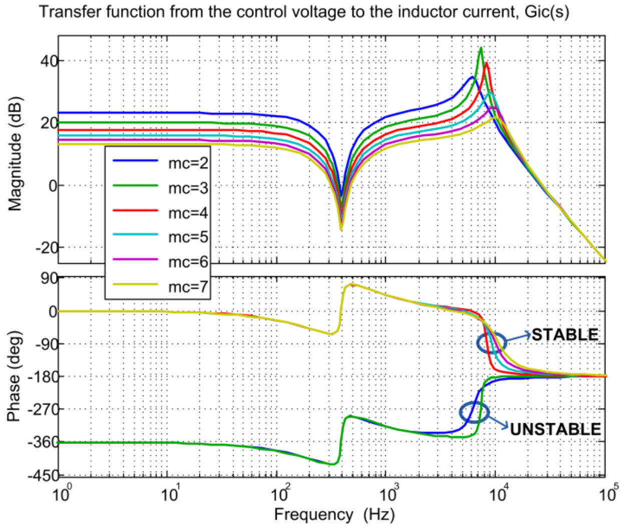

Fig. 1. Transfer Function of the Inductor´s Current in relation of the Control Voltage Gic(s).

After the design of the input filter and PCC control, the behavior of the system has been simulated by means of PSIM software. The complete circuit is shown in Fig. 2.

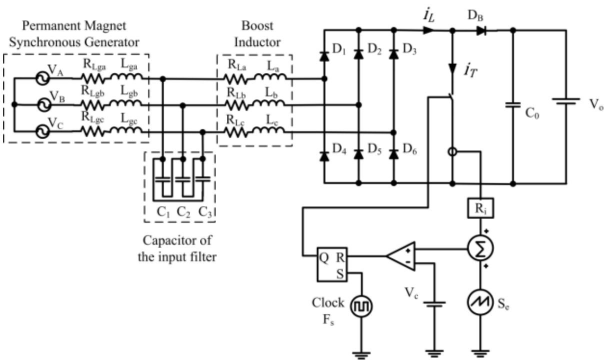

Fig. 2. Three Phase Boost Rectifier in DCM with input filter and PCC Control.

The simulated values are:

- Boost Inductance associated to each phase: L_a, L_b, L_c = 375 µH
- Resistance in series associated to the Boost inductor in each phase: R_{La}, R_{Lb}, R_{Lc} ≈ 100 mΩ.
- Capacitance of the filter: C_1, C_2, C_3 = 2.2 µF.
- Current sense gain: R_i = 0.01 Ω.
- Slope of the stabilization ramp: Se = 22.503 V/ms.

Results

The simulation results have been obtained by means of PSIM 7.0.5 [6].

Fig. 3 shows the generator phase current of a Boost Rectifier working in CCM vs. the same current of a DCM Boost rectifier with the designed PCC and input filter, with input filter and peak current-mode control, simulated by PSIM^{TM} with n_m = 450 rpm and P = 2 kW. It is observed that the proposed DCM operation with input filter and PCC reduces both the low frequency and the switching harmonics.

Fig. 4 shows the comparative behavior of the THD_i and the PF seen by the generator with a boost rectifier in CCM and in DCM with the previously designed input filter. The variations of the generator voltage and frequency as a function of the generator speed in rpm have been considered. The maximum power of the generator is also shown in its speed range. Both the THD_i and the PF improve significantly in the whole speed range when the Boost Rectifier operates in DCM with input filter.

Fig. 5 shows the response of the current in one of the generator phases to a control voltage step. This step produces a variation of the generator output current from 2.16 to 4.28 A_{rms}, which is clearly stable.

Conclusion

In this paper it has been presented the design and analysis of a Three Phase Boost Rectifier applied to Wind Power with Permanent Magnet Synchronous Generators. The study of peak current mode control of the rectifier output current shows a high power factor of the system, and a low Total Harmonic Distortion of the generator output current. The maximum THD_i is 15%. Another important parameter is the adjustment of the stabilization ramp slope, so that the current loop is stable, because the input filter modifies the transfer function from the duty cycle to the inductor current.

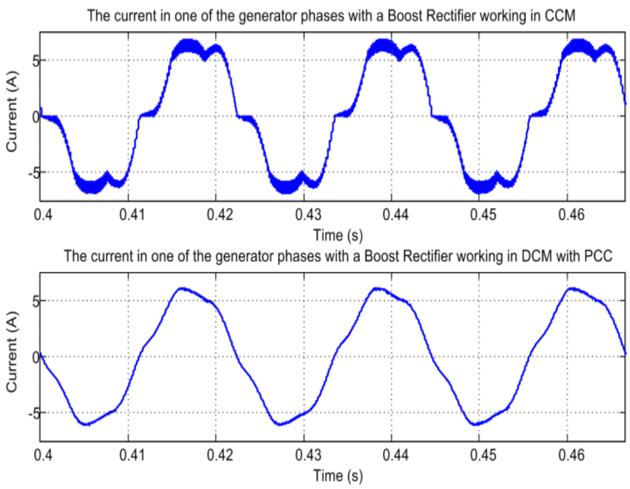

Fig. 3. Generator phase current of a Boost rectifier working in CCM vs. DCM with input filter.

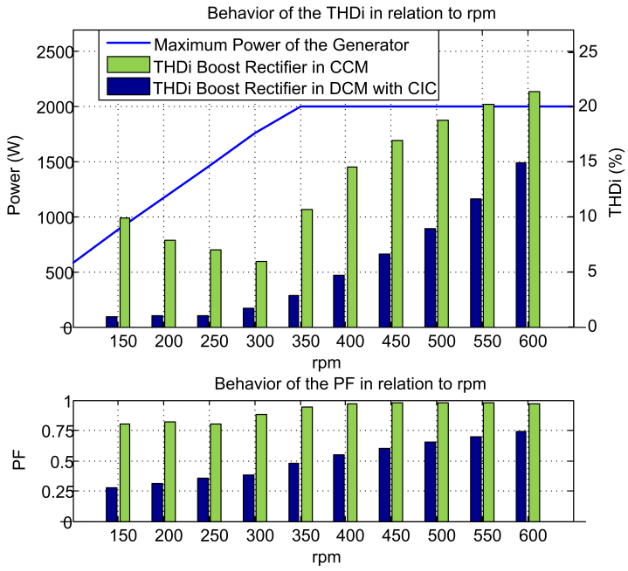

Fig. 4. The comparative behavior of the THD_i and the PF seen by the generator with a boost rectifier.

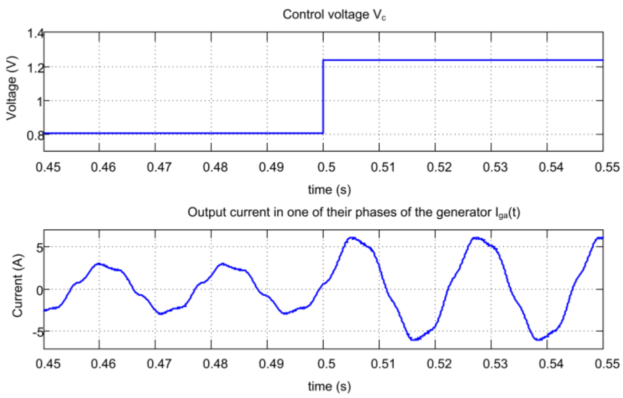

Fig. 5. Output current in one of their phases of the generator with variations of the control voltage.