

## A Control Circuit Small Wind Turbines with Low Harmonic Distortion and Improved Power Factor

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**Abstract.** This paper presents the application of average current mode control to reduce the THD<sub>i</sub> and increase the PF in a Three-Phase Boost Rectifier driving a small wind turbine. It is used as input stage of small wind turbines with permanent magnet synchronous generators operating at variable speed. The Boost Rectifier's output is connected to an inverter which feeds the energy to a distribution power grid. The operation in discontinuous conduction mode allows significantly reducing the Total Harmonic Distortion of the current in the small wind turbine. However, it is necessary to add an input filter so that the switching ripple doesn't arrive to the small wind turbine. It is evaluated the convenience of the current sensors placement in the DC side of the rectifier or at the output of the generator. The results demonstrate that it is better to place the sensors in the output of the generator, because it is achieved smaller THD<sub>i</sub> and higher PF.

Average Current-Mode Control (ACC) is proposed to indirectly regulate the PMSG torque, because the generators currents are proportional to the electromagnetic torque. The ACC principle is to measure the average current of the power inductor or some other current in a point where it is reflected the average current of the power inductor, so that it can be less sensible to the commutation noise in the measure of the current. ACC is suitable to implement a source of regulated current.

Three-Phase Boost Rectifier studied with the two points where the average current can be measured, and with the following values:

- Output Power of the generator:  $P = 2 \text{ kW}$
- Output Voltage of the rectifier:  $V_0 = 800 \text{ V}$ .
- output voltage range of the generator:  $V_{ab} = 104 - 416 \text{ V}_{\text{rms}}$
- Inductance of one phase of the generator:  $L_{ga}, L_{gb}, L_{gc} = 25 \text{ mH}$

- Resistance of one phase of the generator:  $R_{ga}, R_{gb}, R_{gc} = 5 \Omega$
- Number of poles:  $n_p = 12$
- Nominal Current:  $I_{\text{nom}} = 4.87 \text{ A}_{\text{rms}}$
- Range of speeds of the generator:  $n_m = 150 - 600 \text{ rpm}$

The control loop structure of ACC [6] for this converter is shown by Fig. 1.  $R_i$  is the current sense gain,  $F_M$  is the modulator gain and  $G_s(s)$  is the current compensator [6].

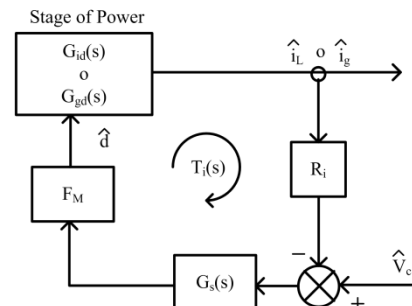


Fig. 1. Scheme of Average Current Mode Control.

The compensator  $G_s(s)$  is designed to stabilize the current control loop,  $T_i(s)$  with a phase margin larger than  $50^\circ$  and a gain margin larger than  $10 \text{ dB}$ .

After designing the input filter and the ACC controllers, we implement the system in PSIM to evaluate their large signal behavior. The ACC implementation when the current is measured directly in the DC side of the rectifier is shown by Fig. 2.

The ACC scheme when the generator currents are measured, is shown by Fig. 3. Note that only two currents are sensed, because the PMSG currents are a balanced

system. The signal processing has been implemented by means of a C Script Block of PSIM, in a similar way that it will be implemented in the experimental prototype.

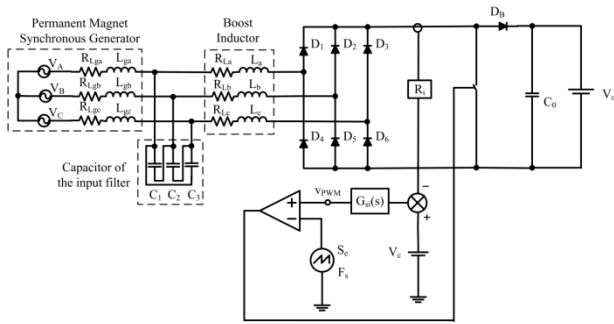


Fig. 2. Three Phase Boost Rectifier DCM with ACC Control and measuring directly in the DC side of the rectifier.

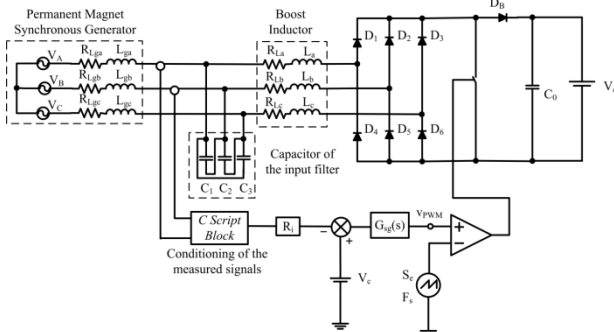


Fig. 3. Three Phase Boost Rectifier DCM with ACC Control and measuring in the output generator

The values obtained until moment are:

- Boost Inductance of one phase:  $L_a, L_b, L_c = 375 \mu\text{H}$
- ESR of the Boost inductors:  $R_{L_a}, R_{L_b}, R_{L_c} \approx 100 \text{ m}\Omega$ .
- Capacitance of the filter:  $C_1, C_2, C_3 = 2.2 \mu\text{F}$ .
- Current sensing gain:  $R_1 = 0.1 \Omega$ .
- Slope of the PWM ramp:  $S_e = 5 \text{ V/ms}$ .

## 1. Results

The performance of the proposed control loops have been evaluated by means of the PSIM 7.0.5 software [7].

Fig. 4 shows both current and voltage in one of the generator phases when the current is measured directly in the DC side of the rectifier.

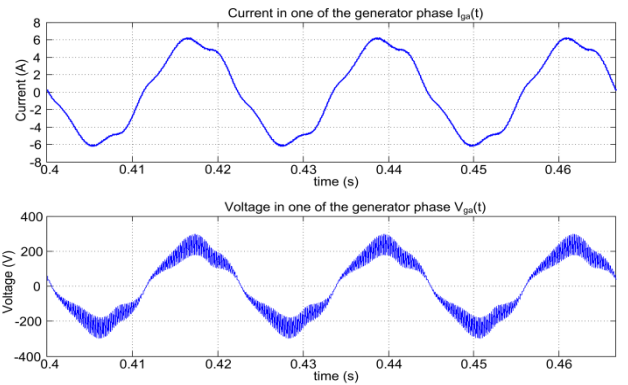


Fig. 4. Current and Voltage of one phase of a Three-Phase Boost Rectifier DCM with ACC Control when the current is measured directly in the DC side of the rectifier.

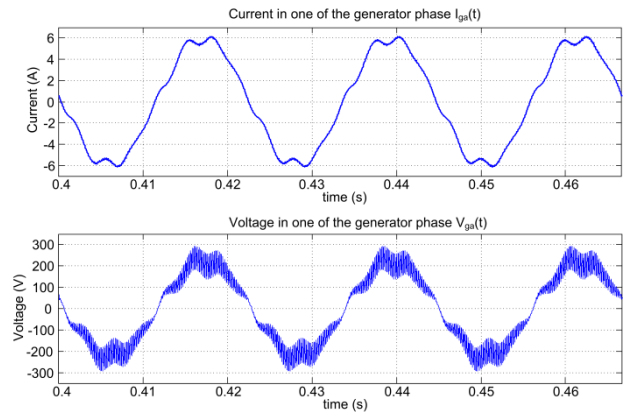


Fig. 5. Current and Voltage of one phase of a Three-Phase Boost Rectifier DCM with ACC Control when the current is measured in the generator.

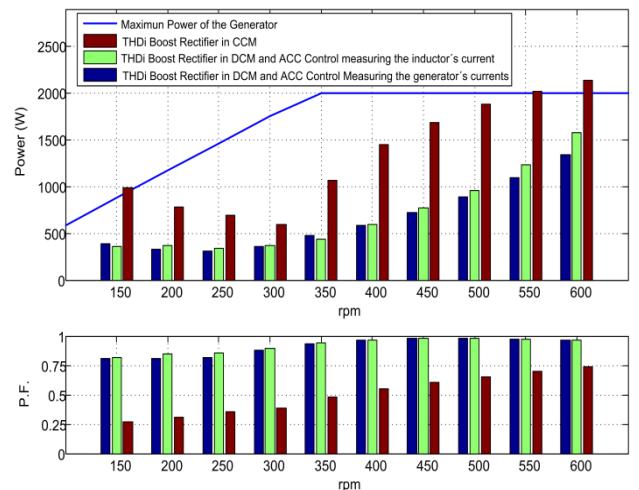


Fig. 6. Comparison of the measured THDi and PF in DCM and CCM

Fig. 6 shows the measured generator THDi and PF of the PMSG in the whole speed operation range. The maximum power of the generator, which is limited by the nominal current at low speeds, is also shown. In Fig. 6 it is shown that both THDi and PF significantly improve when the Boost Rectifier is operated in DCM, with regard to CCM.

Note that the improvement of the THDi and PF values is better when the current is sensed directly at the output of the generator.

## 2. Conclusion

In this paper it has been presented the application of average current mode control to a Three Phase Boost Rectifier applied to small wind turbines. In the implementation of the ACC control it has been devoted special attention in determining the most appropriate place to measure the current. From the analysis, it is obtained that the most appropriate place to measure the current is in the generator. With this, approach the rectifier achieves low THDi and a high PF, in comparison with the Boost Rectifier operating in CCM.