Variable speed wind energy system based on a synchronous generator with a three level inverter

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Abstract. The aim of this paper is to show the application of a three level inverter as a grid interface for a variable speed wind energy conversion system. New megawatt wind turbines demand for the connection at higher voltage levels. Multilevel level inverters provide the solution for connecting these wind turbines at voltages over 1 kV. A variable speed wind energy conversion system based on a synchronous generator with a three level inverter has been completely modelled. Then, the dynamic performance of this wind energy conversion system has been studied by simulation. The simulation results show the appropriate behaviour of this system.

Keywords

Wind energy, variable speed wind turbine, three level inverter, synchronous generator.

1. Introduction

Wind energy has become very popular over the last years, mainly due to its great potential. However, the impossibility of regulating the primary energy makes it unreliable for supplying a particular demand.

Wind energy is a prominent area of application of variable speed generators operating on the constant frequency grid. Variable speed operation effectively uses the high inertia wind turbine as a flywheel during gusts. This helps to smooth power fluctuations and reduces stress on mechanical components such as shaft and gearbox.

Also, variable speed operation allows maximizing energy capture by the turbine. When connecting a wind energy conversion system (WECS) to the grid of constant frequency, regulation is accomplished by changing the speed of the system as a function of the wind velocity with the purpose of supplying the maximum power.

Early WECS were based on induction generators directly connected to the grid; hence the speed of these systems was quasi-constant. The evolution of power semiconductors has contributed enormously to variable speed WECS by interfacing the constant frequency of the grid to the variable frequency of the generator.

Nowadays the most popular variable speed WECS is based on a doubly fed asynchronous generator with a frequency converter supplying the rotor windings [1]. This is due to the fact that a small power converter is required to control the generator power. Nevertheless, new grid codes [2], related to the behaviour of the WECS during voltage sags, make difficult the implementation of doubly fed asynchronous generator in new wind farms [3].

Under these new specifications, the so-call full power converter system is more appropriate. This system is based on a synchronous generator connected to the grid through a frequency converter. The frequency converter can have different topologies, including a cycloconverter, but the one chosen here consists of a diode rectifier, a DC/DC boost converter and a three level PWM inverter (Fig. 1).

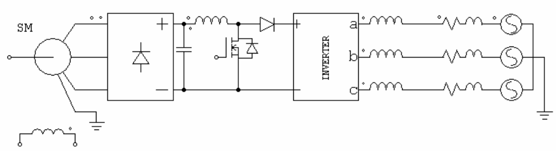

Fig. 1. Synchronous generator with full power converter.

The evolution of wind energy conversion systems shows a fast growth in power. Modern WECS are rated over 2 MW. With this power at low voltage (typically 690 V), high currents are obtained which nearly reach the current limit of modern IGBT's technology. In order to reduce the current in the IGBT's, a multilevel inverter topology is proposed, which allows connecting at a higher voltage and therefore reducing the current.

A three level neutral-point clamped (NPC) inverter [4] has been used (Fig. 2). The three-level inverter allows doubling the DC voltage and therefore connecting at double the AC voltage with half the current. Also for the same switching frequency, voltage harmonics are shifted at twice the harmonic frequencies of a two level inverter. The main disadvantage is that the double of IGBT's are required.

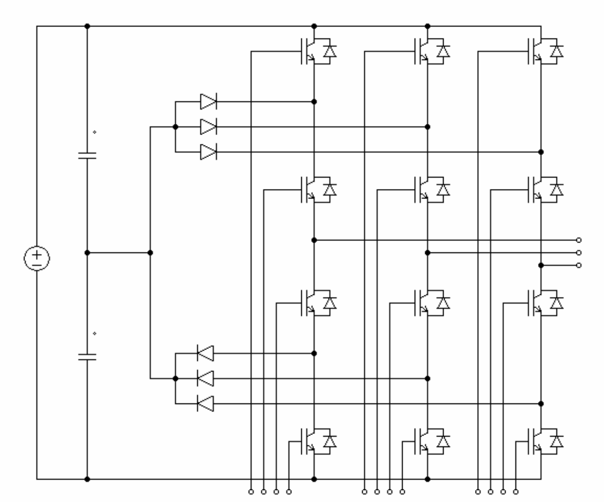

Fig. 2. Three-level NPC inverter.

The objective of this work is to show the dynamic performance of a variable speed WECS based on a synchronous generator with a three level inverter. Simulation results under different conditions will be given which demonstrate the viability of such system.

2. Description of the system

The WECS consists of a synchronous generator and a frequency converter. The generator has a three phase stator winding and a separated excitation winding. The main characteristics of the generator are given in Table I.

Table I.- Generator rated characteristics

Power	1500 Kw
Frequency	50 Hz
Speed	1500 rpm
Voltage	690 V

Generator excitation is controlled in order to achieve a constant voltage/frequency ratio. Under this specification, the generator power can be controlled through the control of the DC current. This current control is accomplished by means of the DC/DC booster control (Fig. 3).

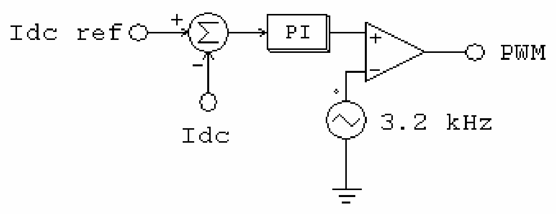

Fig. 3. DC/DC booster current control.

In the scheme of Fig. 3, DC current reference is set-up in order to achieve the wind turbine maximum power tracking through the optimal power-speed characteristics of the turbine [5].

Finally, the inverter control has the purpose of achieving constant DC voltage and regulating power factor at the point of common connection (PCC).

The main characteristics of the inverter and the grid at the PCC are given in Table II.

Table II.- Grid connection data

Grid voltage	1200 V
Grid frequency	50 Hz
Short circuit power	30 MVA
DC voltage	2000 V
Switching frequency	5 kHz
Inverter capacitors	0.5 mF
Inductive filter	0.15 mH

The inverter control is based on a decoupled control of the active and reactive power. From these references a current control scheme is used to obtain voltage reference for PWM. The modulation strategy consists of comparing the reference voltage with a carrier triangular signal (Fig. 4).

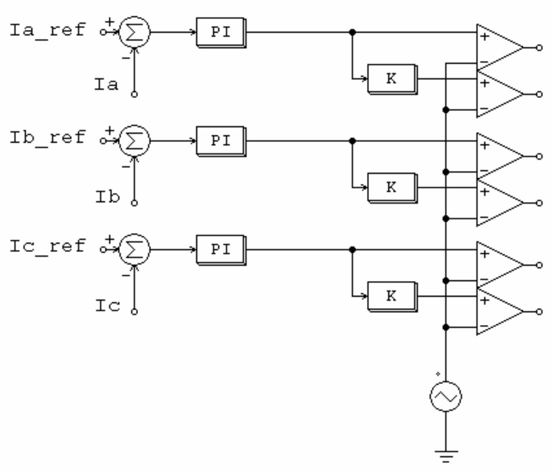

Fig. 4. Three-level pulse width modulation scheme.

3. Simulation results

In the following simulation studies, the wind turbine has not been modelled because it is out of the scope of this work and it does not contribute to the results of the studies of this work. Therefore, in this work the generator is driven by a speed controlled drive. Nevertheless, a detailed model of the wind turbine can be found in [6].

Two different sets of simulation results are going to be presented. The first one shows the response of the WECS to a power step. While, the second one shows the response of the WECS to a rotational speed step.

For the first simulation study, rotational speed is kept constant at 1500 rpm. A power step from 500 kW to 1000 kW is applied at t=7s. Fig. 5 shows power as measured at the PCC. Reference power is achieved with a good dynamic response. Fig. 6 shows generator current and Fig. 7 shows a detail of generator current and voltage between t=9s. and t=9.1s. It should be noted that frequency is 50 Hz as correspond to a rotational speed of 1500 rpm. Finally, Fig. 8 shows a detail of voltage and current at the DC link between t=9s. and t=9.1s.

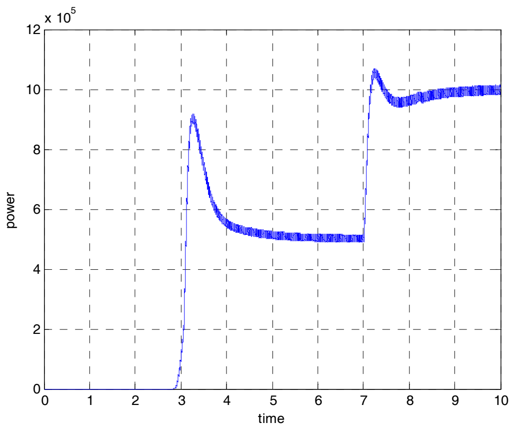

Fig. 5. Generator power.

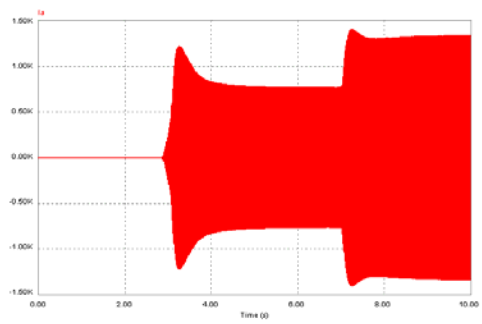

Fig. 6. Generator current.

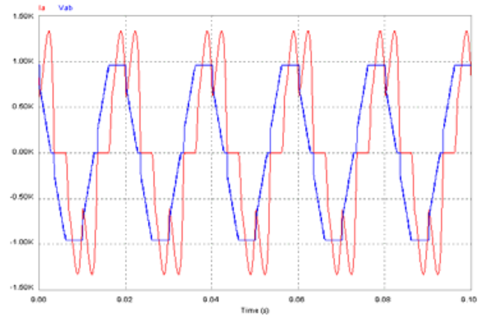

Fig. 7. Detail of generator current and voltage.

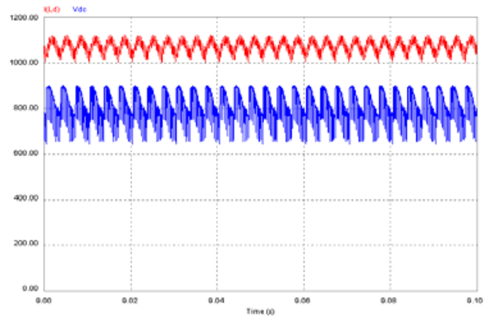

Fig. 8. Detail of current and voltage at the DC link.

For the second simulation study, power reference is kept constant at 500 kW. A speed step from 1500 rpm to 1800 rpm is applied at t=7s. Fig. 9 shows rotational speed. It should be noted that speed response is related to the speed control loop implemented to drive the generator. The purpose of this simulation study is, therefore, to demonstrate the response of the power controller to a speed variation due, for example, to a strong wind gust. Fig. 10 shows power response, which exhibits a good damping of such a strong disturbance. Fig. 11 shows generator current and Fig. 12 shows a detail of generator current and voltage between t=14s. and t=14.1s. The detail shows that frequency is 60 Hz as correspond to a rotational speed of 1800 rpm.

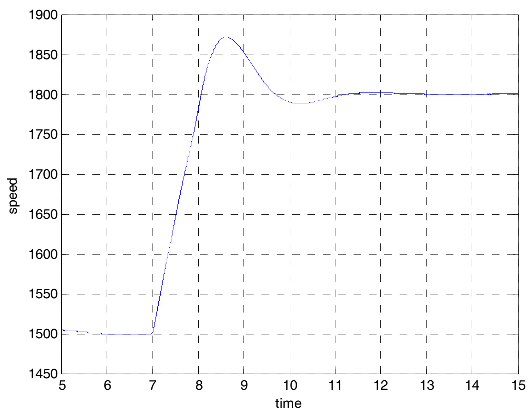

Fig. 9. Rotational speed.

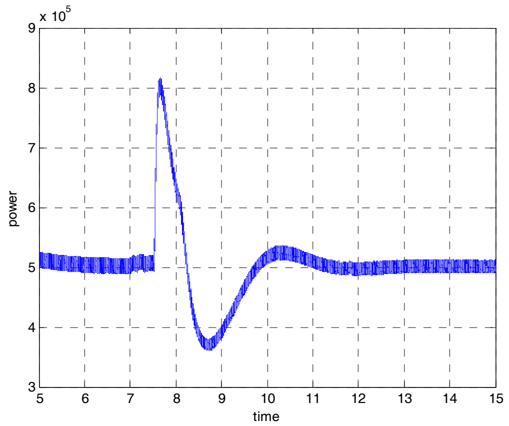

Fig. 10. Generator power.

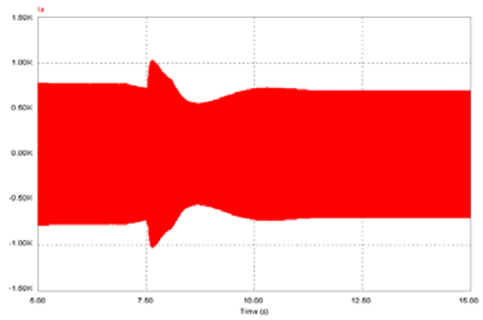

Fig. 11. Generator current.

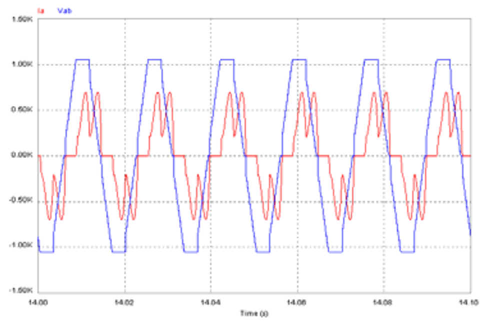

Fig. 12. Detail of generator current and voltage.

Finally, the response of the three level inverter is going to be shown in the following figures. Fig. 13 shows the inverter currents and the grid voltage of phase ‘a’ when delivering 1000 kW with unity power factor. It should be noted that voltage and current in phase ‘a’ have the same angle.

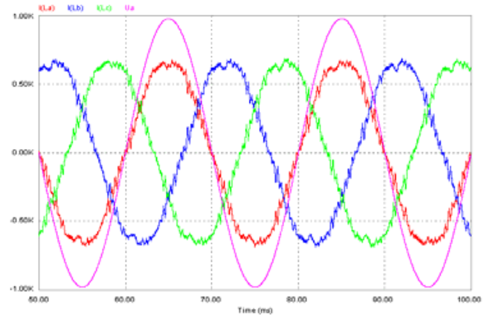

Fig. 13. Inverter currents and grid voltage (P=1000kW and cosφ=1)

Fig. 14 shows voltage between phases ‘a’ and ‘b’ at the inverter terminals and voltage in one of capacitors of the DC link.

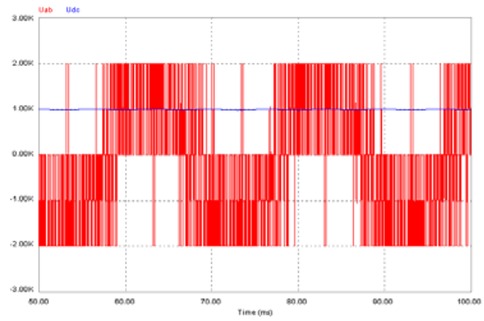

Fig. 14. Inverter output voltage and input voltage in one capacitor.

Fig. 15 shows the dynamic response of the inverter currents when the inverter is delivering 1000 kW and a step of reactive power command from 0 to 500 kVAr is applied. Voltage of phase ‘a’ is also represented for reference. Then, it should be noted that current and voltage are in phase before the step command is applied and current leads voltage after the step command is applied.

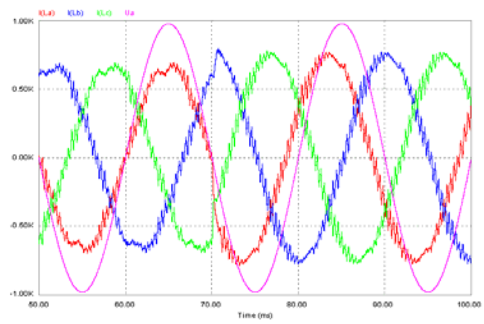

Fig. 15. Inverter currents response to a step of reactive power command.

Fig. 16 shows the active and reactive power deliver by the inverter. It should be noted the decoupled control of active and reactive power, and the fast response of the reactive power control loop.

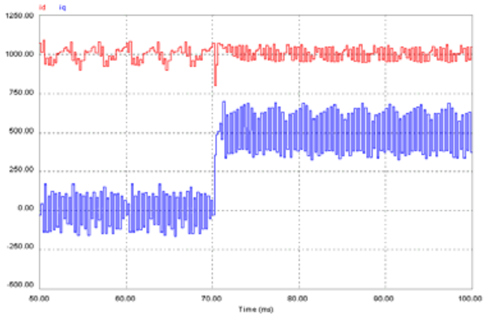

Fig. 16. Inverter active and reactive power.

4. Conclusion

A variable speed wind energy conversion system has been presented which is based on a synchronous generator with a frequency converter based on a three level inverter. Multilevel inverters allow connection to higher grid voltages and produce higher frequency harmonics for the same switching frequency. Simulation results show the viability of such a WECS and demonstrate the good dynamic performance of the system.

Acknowledgement

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