Investigations on the use of multilevel converters in wind energy generation

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Abstract. This paper presents an analysis and simulation of a Wind Turbine Generator (WTG) driving a low speed Permanent Magnet Synchronous Generator (PMSG). The results of the tests are obtained by using the PSIM computer simulation program. The voltage source PWM inverter is used to interface the system with the electrical utility that is simulated in this paper as a resistive-inductive load.

1 Introduction

With the increase of energy demands, the need for a renewable energy source that will not harm the environment has also increased. Indications are made that the global energy demands will almost triple in the next decades. A cheap and versatile way to meet the future need is represented by the generation of electrical energy by using the power of the wind [1]. Utilities have the flexibility to accept a contribution of about 20% or more from wind energy systems [2]. For this reasons it is important to increase the performances given by the wind energy systems by modifying the design of the mechanical and electrical systems [3].

Such a solution is to use a permanent magnet synchronous generator (PMSG) that can operate at low speeds equivalent to those of the wind turbine instead of induction generators operating at high speeds. Different types of converters for synchronous generator output voltage control can be employed in order to get improved results on a local network or the national grid. Such systems have been developed for example by using conventional converters with two voltage levels and two NPC converters in rear to rear mounting [4]. Using multilevel converters the filtering element and the voltage requirements of the semiconductor devices are reduced while a high reliability is obtained.

In this paper an analysis is made by simulations using the specialized program PSIM of a Wind Turbine Generator (WTG) driving a low speed PMSG is presented. The system consists of a wind turbine, a permanent magnet generator, a special multilevel three phase rectifier and a multilevel voltage source inverter.

The rectifier is modeled in the Neutral Point Clamped (NPC) configuration and controlled using an indirect control strategy. The voltage source PWM inverter is used to interface the system with the electrical utility that is simulated in this paper as a resistive load. The inverter is the Five-Level Active-Neutral-Point-Clamped with Coupled-Inductors (5L-ANPC-CI) and is controlled using a PWM strategy.

2 The drive model

The mechanical scheme consisting of a wind turbine with a rated power output of 20 kW at the rated speed of 25 rpm, a gearbox with the ratio of 60/1 and a permanent magnet synchronous motor (PMSM) working as a generator is presented. The output of the PMSM represents the three-phase AC system feeding the NPC rectifier [Fig.1]. The two input terminals in the wind turbine model represent the wind speed and the angle of the propeller. Based on these values, the speed of the turbine and the output power are obtained. In this model the maximum output power is obtained for a wind speed of 25 rpm and a zero slope propeller.
The synchronous generator was selected with four poles to achieve a synchronism speed of 1500 rpm equivalent to 60 times the speed of rotation of the wind turbine. The output of the synchronous generator is feeding the NPC rectifier [5] that produces the DC voltage for the 5L-ANPC-CI inverter [6]. The properties of this new converter compared with a similar high performances structure are described in [7]. The inverter is supplying a local network modeled by a resistive-inductive load (Fig.2). The three phase rectifier block has as an input parameter the reference voltage value $U_{\text{ref}}$ which has the value equal to the dc voltage supply of the inverter. The inverter block has as an input parameter the modulation index.

The NPC rectifier control used is the indirect method with the compensation of the input voltage, while the inverter 5L-ANPC-CI is controlled with a sinusoidal PWM method. In Fig. 3 simulation results are presented considering the wind speed of 20 m/s, a 10° slope propeller, the reference voltage ($U_{\text{ref}}$) of 700V and the modulation index (M) of 0.9. The dynamic regime of the wind turbine can be observed until the propeller reaches the maximum speed equal to the wind speed. At this moment the turbine uses about 80% of the rated power and the generator reaches the speed of 1200 rpm. The dynamic regime is also influenced by the time until the DC output of the rectifier reaches the prescribed value given by $U_{\text{ref}}$ which in this case is 700 V.

3 Simulation results

In Fig. 3 (a) and (d) the output phase and line voltages respectively are presented. These voltages have a low harmonic distortion factor due to the increased number of voltage levels.
Fig 3 (b) contains the input dc voltage of the inverter that stabilizes after the generator speed reaches 1200 rpm as shown in Fig. 3 (e). In Fig. 3 (c) the current absorbed by the inverter is described, which is continuous.

![Figure 3: Simulation results at 80% of the rated power of the wind turbine: (a) phase output voltage $V_R$; (b) dc voltage $V_{DC}$; (c) rectifier output current $I_i$; (d) line output voltage $V_{RS}$; (e) PMSG speed $N_{gen}$.](image)

In Fig. 4 is presented a zoom of the previous figure after the DC voltage reached the reference voltage. The line voltage has nine levels for the five-level single arm inverter. In Fig. 4 (a) and (c) the output voltages and current on the local load are presented, while Fig. 4 (b) describes the current flow between the rectifier and the inverter. In Fig. 4 (d) the alternative voltage on phase A at the four poles generator output is presented. Through this indirect AC-DC-AC conversion the following advantages are obtained: voltage control, correction of the power factor and low harmonics content.

![Figure 4: Simulation results for the stabilized regime: (a) phase output voltage $V_R$ and the load current $I_R$; (b) rectifier output current $I_i$; (d) line output voltage $V_{RS}$; (e) PMSG output voltage $V_{Rg}$.](image)
In Fig. 5 the results of the simulations when the wind turbine operates at full power, at a wind speed of 25 m/s are described. The ANPC-CI inverter has a coupled inductor that increases the number of voltage levels and halves the current in half of the active devices.

The two currents through the inductor form the load current of the inverter and can be seen in Fig. 5 (a). Due to increase wind speed and hence of the wind turbine power the supply voltage of the rectifier can be increased which results in the production of more power in the local grid. In Fig. 5 (b) and (c) the line voltage with nine levels and the three phase sinusoidal currents system that results are described.

4 Conclusions

This paper presented a solution to increase the performances given by wind power generation using back-to-back multilevel structures. The simulations were performed using the PSIM software and described the advantages given by the special structures used. For the indirect conversion two special converters were used: the three-level NPC rectifier and the five-level ANPC-CI inverter. The output voltage harmonic content is low and therefore a small filter is required.

References