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High-Power Transformer-Less Wind Energy Conversion System with Permanent Magnet Wind Generator

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Abstracts

For grid integration, a low-frequency (i.e. 50 or 60 Hz) transformer is placed inside the nacelle of the offshore wind turbine to step-up the voltage to the grid voltage levels of 11–33 kV. The heave weight and large size of the step-up transformer significantly increase the weight and volume of the turbine. These penalties are critical in offshore applications, where cost of installation and regular maintenance are extremely high. As an alternative approach to achieve a compact and lightweight offshore and onshore wind turbine a medium voltage converter is proposed. The converter modules are cascaded to achieve medium voltage output. Each converter module is fed by a pair of generator coils with 90 phase shift to get the stable dc-link power. The power factor correction (PFC) circuit enables the generator to achieve unity power factor operation and the generator armature inductance is used as ac-side PFC boost inductance. At the grid-side, H-bridge inverters are connected in series to generate multilevel medium voltage output and the voltage-oriented vector control scheme is adopted to regulate the converter active and reactive power transferred to the grid. This new technology will enable transformer-less compact and lightweight turbine design, and has a great potential to be implemented in the future offshore wind farms and smart grid applications. The simulation is done by MATLAB/SIMULINK software.

Keywords: Cascaded H-bridge converter, high-power medium voltage converter, permanent magnet generator, transformer- less, wind power.

Introduction

The wind turbines use the kinetic energy of the wind and convert that energy into mechanical energy, which in turn can be converted into electricity by means of generator. The Wind energy touches the turbine blades and creating

Mechanical energy. The turbine shaft is connected to the Generator, producing alternating electric energy. The voltage level of a wind power converter is usually in the range of (380 to 690 V) due to generator voltage rating and voltage limitation of power electronics devices. Therefore, the power converter is connected to the grid via a step-up transformer to match the grid voltage level (10.5 to 35 kV) in the wind farm collection system. In this paper, a three phase 5-level output is obtained from the series connection of Cascaded Half H-Bridge Multilevel Inverter.

Most wind turbine generators generate electricity at a low voltage level of typically 380–690 V [1]. To integrate with medium voltage grid, a power frequency (50 or 60 Hz) transformer is used to step-up the voltage to 11–33 kV. In an offshore wind turbine power generation system this transformer is usually installed inside the nacelle together with other equipments, such as the generator and power converter as shown in Fig. 1, at a height of about 80 meters. This heavy and bulky transformer significantly increases the weight and volume of the nacelle as well as the mechanical stress of the tower. The weight and volume of a 0.69/33 kV, 2.6 MVA transformer are typically in the range of 6–8 tons and 5–9 m3, respectively [2]. These penalties are critical in offshore renewable energy applications, where the costs of installation and regular maintenance are extremely high. The installation cost is a fractional component of capital cost and it is estimated at 10% to 30% of the total cost [2]. In average, approximately 20% of the capital cost is associated with installation.

Hence, a step-up transformer-less, medium voltage converter based high power density turbine system has been attracting great attention for the future wind turbine power generation systems [3–5]. A new type of modular permanent magnet wind generator with a large number of isolated coils based system and multiple traditional generators based system have been proposed in [3, 4] and [5], respectively to eliminate the step-up transformer. These recent approaches require special generator or multiple traditional generators, which increases system control complexity, size and cost of installation and maintenance.

The converter modules (Full H-Bridge) are cascaded (17level) to achieve medium voltage output and the Inverse Sin PWM scheme is adopted to regulate the converter active and reactive power transferred to the grid. In Proposed System Each converter (Half H-Bridge) are cascaded to achieve medium voltage output. Each module is fed by a Constant DC voltage and the Phase shifted PWM scheme is adopted to increase the converter output voltage. In this paper each converter (Half H-Bridge) are cascaded to achieve medium voltage output. Each module is fed by a constant DC voltage and the Phase shifted PWM scheme is adopted to control the converter output voltage.

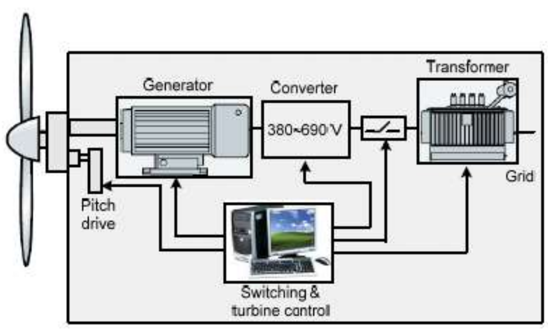

Fig. 1 Fully-rated converter based wind turbine system.

In this paper, a new medium voltage converter system with medium frequency (in the range of a few kHz to MHz) link is proposed to eliminate the heavy and bulky power frequency step-up transformer as shown in Fig. 2, which would be desirable for both onshore and offshore wind turbines. The proposed medium voltage converter based wind turbine power generation systems will have the following advantages:
(i) No requirement of special or multiple generator,
(ii) Inherent DC-link voltage balance due to single DC supply,
(iii) Direct gird connection without using transformer and filter
(iv) Overall compact and light weight system
(vi) Low installation and maintenance cost.

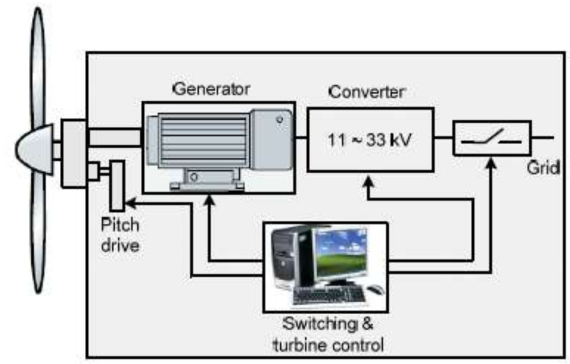

Fig. 2 Medium-voltage converter based proposed wind turbine system.

Design of proposed system

The cascaded H-bridge (CHB) topology has gained popularity for the medium voltage converter applications [6]. However, the CHB converter requires multiple isolated and balanced DC sources. In this paper, CHB converter based medium voltage converter is proposed for transformer-less grid connection of wind turbines. The medium frequency link is used to generate the isolated balanced multiple DC supplies for the CHB converter from a single low voltage commercially available traditional wind turbine generator. The large-number of CHB converter levels means that medium voltage attainability is possible to integrate the wind turbine generator into medium voltage network directly and also possible to improve the output power quality. However, the component number and control complexity increase linearly with the increase of level number. Considering the system performance, control complexity and cost, and market availability of the semiconductors.

Proposed system presents a modular permanent magnet wind generator and medium-voltage converter system, aiming to reduce the system current rating by cascading converter modules. Each module is fed from separate DC voltage, and an H-bridge inverter. Where three HW converter blocks are connected in series .Each HW converter blocks consists on DC voltage source. The sum of each HW converter block is connected to load. Here the output voltage is measured by using 3phase resistive load.

At the generator side, each converter module requires a stable voltage source input, where diode rectifier is used to give the input to the inverter. Each Converter block consists of two switches. The converter blocks are connected in series to increase the output voltage. The output of the Rectifier circuit is given to Cascaded

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H-bridge inverter. Where, 3 HWR blocks are connected in series to increase the output.

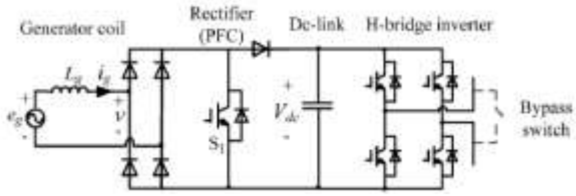

Fig 3. Configuration of the proposed system.

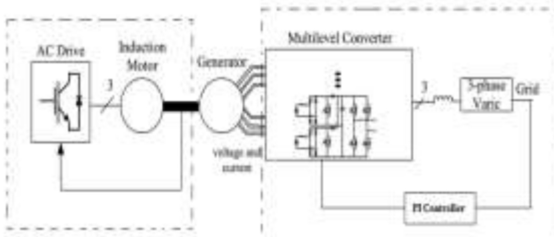

Fig. 4 Block diagram of the proposed system

Grid-side cascaded h-bridge converter

At the grid-side, the H-bridge inverters of each converter cell are connected in series to achieve medium voltage multilevel output, interfacing with the grid via the filter inductance as shown in Fig. 3. If assuming the dc-link voltage of each series-connected converter cell are the same (the dc-link voltage is regulated by the rectifier), then the cascaded H-bridge converter can be modeled as one voltage source converter and its output voltage is shared equally among the converter cells.

The cascaded H-bridge converter is regarded as a single voltage source converter. The modulation strategy must be developed to modulate the cascaded H-bridge converter the modulation of cascaded H-bridge inverter employs the so-called phase-shifted carrier PWM, where the carrier signal of each cascaded converter cell has a phase shift with each other by a certain degree and is compared with the common modulation signal. This modulation scheme can enable the converter to achieve multilevel voltage output when several converter cells are connected in series. It can also guarantee the equal power sharing between the cascaded cells, since the output voltage of each cell is the same (only has a small phase shift) and the current is the same (because they are in series).

A. Phase Shifted Carrier Pulse Width Modulation Technique (PSCPWM):

Fig.5 shows the Phase shifted carrier pulse width modulation. Each cell is modulated independently using sinusoidal unipolar pulse width modulation and bipolar pulse width modulation respectively, providing an even power distribution among the cells. A carrier phase shift of 180°/m for cascaded inverter is introduced across the cells to generate the stepped multilevel output waveform with lower distortion. The Phase Shifted Carrier PWM (PSCPWM), Figure 6, is a multicarrier modulation strategy that has all carrier waves phase shifted from each other. It is the standard modulation strategy for the Cascade Multilevel Inverter topology but is not exclusively for that topology.

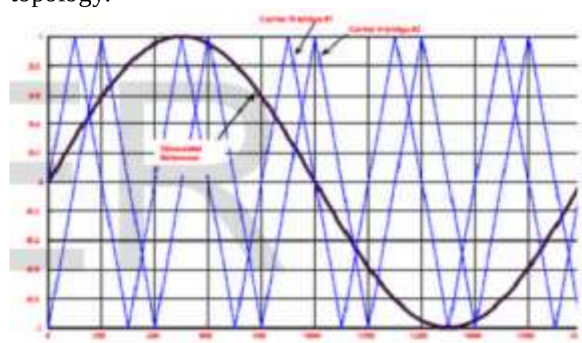

Fig.5 Phase shift carrier

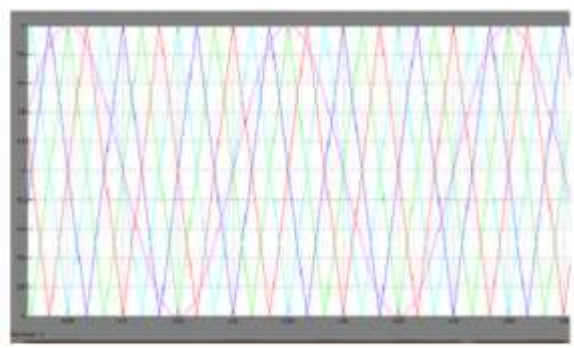

Fig.6 Phase shift carrier and reference signal

For a Cascade H-Bridge Multilevel Inverter with n number of full-bridge modules in each phase-leg there are also n number of triangular carrier waves. There is one triangular carrier wave for each full bridge module, phase shifted with 180/n in between them, with amplitudes the magnitude of the total DC voltage. The magnitudes for the carrier waves are modulated by the actual voltage level in the appropriate module. For the 5-level Cascade H-Bridge Multilevel Inverter with two modules there are two triangular carrier waves, one for each module. The modules create the two voltages with PSCPWM modulation. There are also two reference waveforms for the two legs in each inverter modules that are phase shifted 180° from each other. Both reference waves are compared with both carrier waves, one reference wave is for modulation of the left full-bridge module leg

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switches (dashed reference wave) and the other reference wave to modulate the right full-bridge module leg switches (solid reference wave). The triangular wave in Figure 6 is compared with the upper output voltage plot in Figure 6 (and the second triangular with the lower voltage plot). Close to 2ms in the plots it can be seen that the triangular wave crosses one reference wave downwards, controlling the right leg switches.

Simulation Results

The simulation is done by MATLAB/SIMULINK software. Once the wind speed reaches cut-in speed and the dc-link voltage is regulated to 1400 V, the grid-side contactor will close and the cascaded H-bridge converter starts to operate and control the active and reactive power fed into the grid

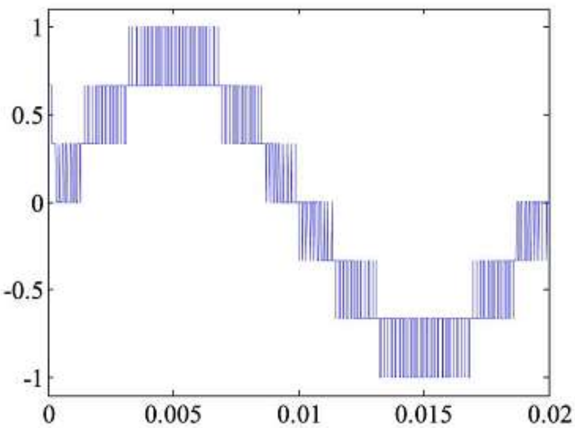

Fig.7 output voltage of the cascaded H-bridge inverter with three stages (seven levels)

Fig. 8 shows the grid voltages and currents during three-phase symmetrical grid voltage dip (20%). As seen, the converter output current increases to maintain the active power transfer. If a larger voltage dip happens, the converter current may reach the limit and the generator-side rectifier should reduce the power output and the generator speed may increase.

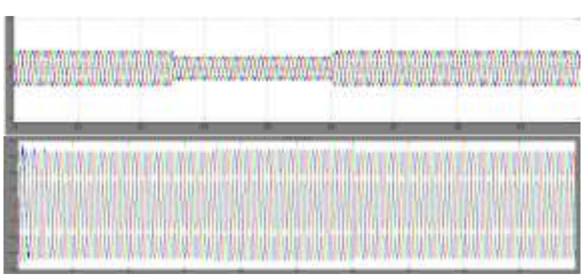

Fig. 8 grid voltage and current during 20% voltage dip

Fig 9 and 10 shows the output of simulation of proposed system. Phase shifted PWM technique is used to control the switching sequence of MLI.

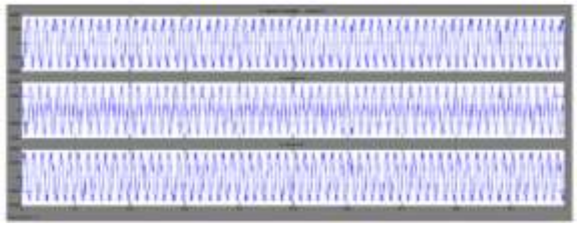

Fig.9 Simulation Output for High voltage Converter 3.39KV

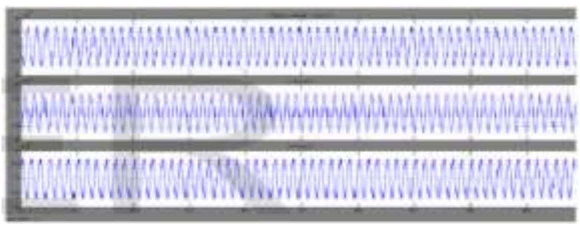

Fig. 10 Simulation Output for High Voltage Converter 6.78KV

Conclusion

Proposed System has presented a permanent magnet wind generator and high-power converter system, which increases the converter output voltage by cascading converter modules. This system can reduce the cable losses and associated cost for cables and connections by reducing the current, which provides a solution for the power conversion of large wind turbines. 3 phases Half H bridge Converters are used to increase the output level and the Phase Shifted vector-controlled cascaded H-bridge converter can successfully transfer power from the generator to the load with independent active power and reactive power control ability.

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