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EVOLUTION OF ENERGY CONVERTERS FOR WIND TURBINES

A wind generator system requires a power conversion circuit called a power converter that is capable of regulating the generator frequency and line voltage. Several types of converter topologies have been developed over the past decades; each of them has its own advantages and disadvantages. Currently, there are mainly two converter topologies used in industrial wind turbines. Most of the proposed converters require line filters and transformers to improve the power quality and raise the voltage level accordingly. These heavy and bulky components add significantly to tower construction, turbine installation and maintenance costs. Recent advances in power semiconductors and magnetic materials have led to the development of new converter designs that could be a possible solution to reduce the size, weight and cost of power converters. This article provides an in-depth study of energy converter technology, ongoing research and development.

Keywords: wind generator; power converters; research and development; modern devices and materials.

Introduction

Wind energy has continued the worldwide success story as the wind power development is experiencing dramatic growth. According to statistical data the cumulative installed wind power capacity in 2014, 2017 and 2020 were 74.0, 158.86 and 282.43 GW respectively; almost doubled in every three years. The dynamic growth of wind power directly pushes the wind technology into a more competitive area. Therefore, it is essential for scientists and researchers to find out the effective technologies for the wind power generation systems. The variable nature of wind energy sources (in terms of the real power, reactive power, output voltage, and frequency) is a major challenging issue. The conversion of an input AC power at a given frequency and voltage to an output power at different frequency and voltage can be obtained with static circuits called power converters, containing controllable power electronic devices. Various power converters have been developed to fulfil the requirements of the wind power generation. Each of them has some advantages and some disadvantages. The traditional converter voltage level is in the range of 380–690 V due to the low generator voltage rating and the use of two-level converter topology. To reduce the electrical losses, a power frequency power-transformer is commonly used in wind power generation system (usually installed inside the turbine nacelle) to step-up the voltage to medium voltage level (e.g. 10–35 kV), as shown in Fig. 1. This heavy and bulky transformer significantly increases the weight and volume of the nacelle as well as mechanical stress of the tower. Nowadays components can handle higher current and voltage ratings, the power loss decreases and the devices become more reliable for the control of megawatt scale power thanks to the power electronics as a rapidly developing technology. The price is still decreasing, and power converters are becoming more and more attractive which means improving the performance of wind power generation systems. With the advent of new power semiconductor devices, different soft magnetic materials with high magnetic saturation flux density and low specific core loss are conceived to reduce the weight and volume of medium or high frequency-link [1].

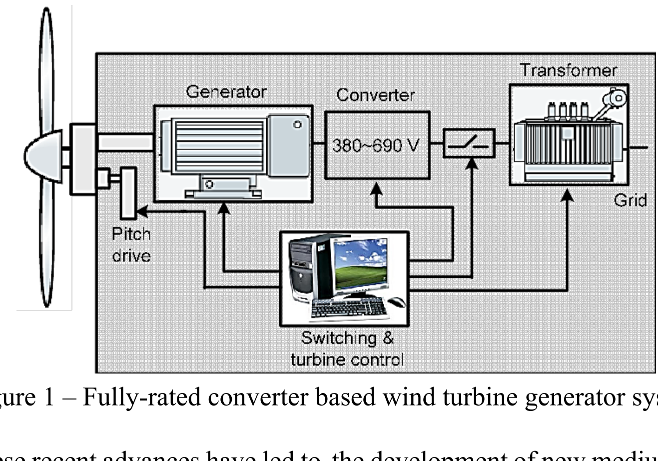

Figure 1 – Fully-rated converter based wind turbine generator system

These recent advances have led to the development of new medium voltage converter system, which would be a possible solution to eliminate the transformer of the wind turbine generator systems. This chapter aims to a comprehensive study of traditional converter technologies for wind turbine generator systems. In addition the challenges, current research and development trends, possible future directions of the research to develop new converter topology for future wind turbine are also considered in this chapter.

Materials and methods

2 Converters for wind turbine generator systems

In the last two decades different converter topologies have been investigated for power conditioning of wind turbine generator systems. All the proposed converters have some advantages and some disadvantages. Only diode rectifier based unidirectional converter and back to back bidirectional converter topologies are commonly used in the commercial wind turbine generator systems.

2.1Diode rectifier based converter

In this converter system a variable frequency and variable magnitude AC power from the wind turbine generator is firstly converted to a DC power by a diode rectifier circuit and then converted back to an AC power at different frequency and voltage level by a controlled inverter. The diode rectifier (uncontrolled rectifier) based converter system transfers power in a single direction e.g. from generator to the grid. This type of power converter is normally used in a wound rotor synchronous generator (WRSG) or a permanent magnet synchronous generator (PMSG) based wind power generation system instead of an induction generator. In WRSG based system, to achieve variable speed operation the systems use an extra excitation circuit, which feeds the excitation winding of WRSG. The PMSG based wind turbine generator systems are equipped with a step-up chopper circuit. The step-up chopper adapts the rectifier voltage to the DC-link voltage of the inverter. Controlling the inductor current in the step-up chopper can control the generator torque and speed. The diode rectifier with step-up chopper based power conditioning system is illustrated in Fig. 2. The output voltage and input current of the diode rectifier and step-up chopper based converter system are shown in Figs. 3 and 4, respectively. The frequency spectrum of the output voltage of diode rectifier and step-up chopper based wind power conditioning system is depicted in Fig. 5. In this converter system the grid side inverter controls the active and reactive power delivered to the grid. The output voltage of this converter system is in the range of 380–690 V. Therefore, a step- up transformer is commonly installed inside the nacelle to feed-in the energy into an medium voltage grid. Many power semiconductor vendors such as Semikron, ASEA brown boveri (ABB), IXYS, and Mitsubishi Electric produce devices specially designed for this type of converter in a module form, all the devices in a single pack, which reduces the cost and complexity of the power conditioning system. Semikron developed SKS 660F B6U+E1C+B6CI 250 V06 and IGDD6-4-426-D3816-E1F12-BL-FA modules for diode rectifier based power conditioning systems. According to the internal circuit configuration the SKS 660F B6U+E1C+B6CI 250 V06 module is suitable for PMSG based wind turbine generator systems and IGDD6-4-426-D3816-E1F12-BL-FA module is suitable for WRSG based wind turbine generator systems. Mitsubishi Electric developed CM100MXA-24S module with this converter topology which can be used for both WRSG and PMSG based wind turbine generator systems.

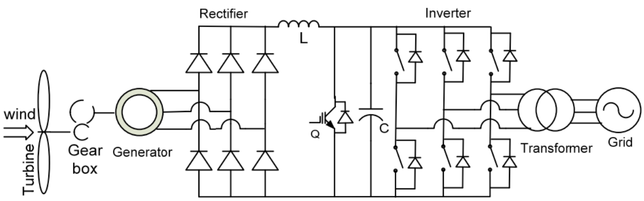

Figure 2 – Diode rectifier based converter topology

Although it is a cost effective choice, the power quality of this converter system is critical to the selection. A summary of advantages and disadvantages is presented as below:

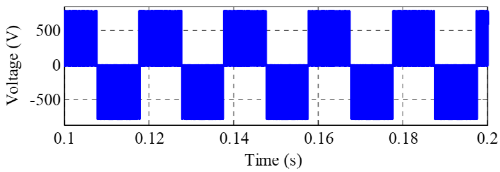

Figure 3 – Output voltage of diode rectifier based converter, where inverter switching frequency is 2 kHz

Advantages:

Low system production cost and

Simple to implement

Disadvantages:

Diode rectifier produces a large amount of harmonics (input current), which affects the performance of the utility system

Higher harmonic losses (output voltage) and

Unidirectional power handling capability

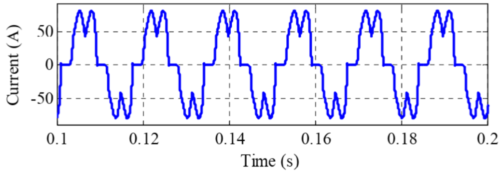

Figure 4 – Input current of diode rectifier based converter

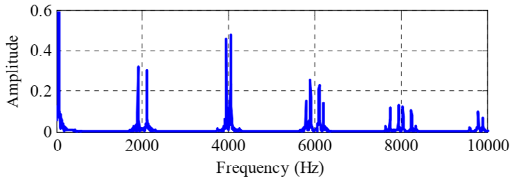

Figure 5 – Output voltage frequency spectrum of diode rectifier based converter system

2.2 Back to back converter

The controlled rectifier and controlled inverter based converter is called back to back converter consisting of two conventional pulse width modulated (PWM) voltage source inverters (VSIs). It differs from the diode rectifier based converter for the rectification stage, where the diode rectifier with chopper circuit is replaced by controlled rectifier as shown in Fig. 6. The controlled rectifier gives the bidirectional power flow capability, which is not possible in the diode rectifier based power conditioning system. Moreover, the controlled rectifier strongly reduces the input current harmonics and harmonic losses. The output voltage and input current waveforms of a back to back converter are illustrated in Figs. 7 and 8, respectively. The grid side converter enables to control the active and reactive power flow to the grid and keeps the DC-link voltage constant, improving the output power quality by reducing total harmonic distortion (THD). The generator side converter works as a driver, controlling the magnetisation demand and the desired rotor speed of the generator. The decoupling capacitor between grid side converter and generator side converter provides independent control capability of the two converters. A simulation analysis of back to back converter based wind turbine generator system was carried in [2]. The harmonic spectrums of the back to back converter are shown in Fig. 9. Due to some special features this converter topology has received great attention recently. Many power semiconductor manufacturers such as Semikron, ASEA brown boveri (ABB), Hitachi, Siemens, IXYS, and Mitsubishi Electric produce components in a module form, all the devices in a single pack; suitable for this converter, which makesthe converter compact and lightweight. As an example, Semikron developed SKS C 120 GDD 69/11-A3A WA B1B module for power conditioning of synchronous and double-fed generator based wind power systems. The back to back converter can be used for PMSG and squirrel cage induction generator (SCIG) based wind power generation systems. Siemens employs back to back converter for power conditioning of SCIG based wind turbine generator systems. The voltage rating of the most common generators is usually in the range of 380–690 V except that Repower employs 6.6 kV DFIG. Therefore, converter voltage level is also in the range of 380–690 V due to the low generator voltage rating and the use of two-level converter topology. In order to integrate the wind turbine with local medium voltage grid a step-up transformer is normally installed inside the nacelle of the wind turbine. In the last two decades a lot of research and development have been reported to improve the performance of this converter. New control schemes were proposedto improve the performance of inverter section [3, 4] and field programmable gate array (FPGA) based reconfigurable control strategy has been proposed [5]. An integrated control strategy of back to back converter has been developed for direct drive PMSG based wind turbine systems [6].

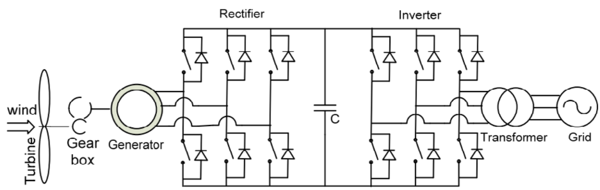

Figure 6 – Back to back converter based wind turbine generator system

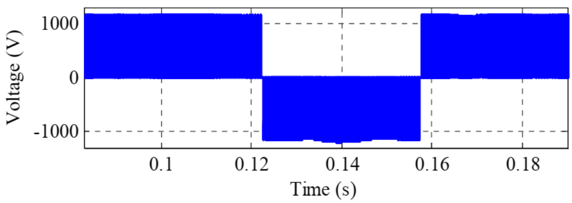

Figure 7 – Output voltage of back to back converter

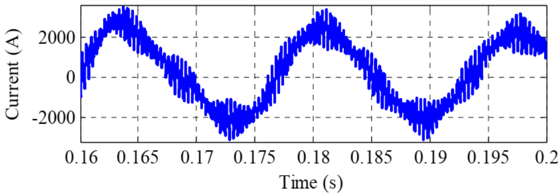

Figure 8 – Input current of back to back converter

Recently, the back to back converter has also attracted significant interest for partial rating converter applications, where the wind turbine system employs doubly-fed induction generator (DFIG). The block diagram of DFIG based wind turbine generator system with back to back converter is shown in Fig. 10.

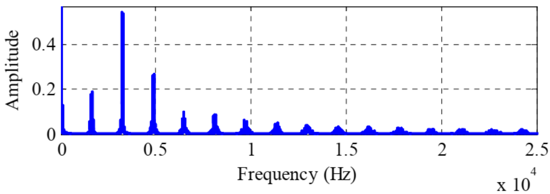

Figure 9 – Frequency spectrum of the output voltage of back to back converter

Several manufacturers such as ABB, Repower, Vestas, GE Wind, and Ecotecnia currently employ DFIG concept for modern wind turbine systems. To obtain sub- and sup-synchronous speed operations the rotor side converter must be able to handle slip power in both directions. When the turbine speed is below the synchronous speed, the power input to the system through the stator winding is balanced by subtracting a small portion of power from the system through the rotor circuit. On the other hand when the shaft speed is above the synchronous speed the power is balanced by adding a small portion of power to the system through the rotor circuit [7]. To improve the performance of the back to back converter based wind turbine generator system several literatures have proposed different control topologies.

Previously, the development and design of DFIG, using an inverter in the rotor circuit with a vector control circuit, was described [8].

In order to improve the fault ride-through capabilities and crowbar dynamics of the system an internal model control controller has been proposed in [8].

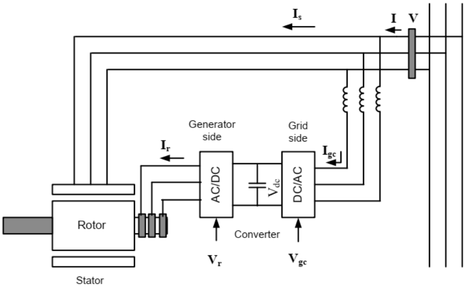

Figure 10 – DFIG based wind turbine generator system with back to back converter

Conclusions

The back to back converter is a bidirectional power converter.

The DC-link voltage can be boosted to a level higher than the amplitude of the grid line to line voltage in order to achieve full control of the grid current

The capacitor between the inverter and rectifier makes it possible to decouple the control of the two inverters, allowing the compensation of asymmetry on both the generator side and the grid side.

The component costs are low (commercially available in a module form).

Disadvantages:

The presence of the heavy and bulky DC-link capacitor increases the costs and reduces the overall lifetime of the system

Another important drawback of the back to back converter is the switching losses. Every commutation in both the grid inverter and the generator inverter between the upper and lower DC-link branch is associated with a hard switching and a natural commutation

The back to back converter consists of two inverters, so the switching losses might be even more pronounced

The high switching speed to the grid may also require extra EMI-filters, and

The combined control of the controlled rectifier and inverter is quite complicated.

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Эволюция преобразователей энергии для ветровых турбин

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Жел генераторы жүйесі генератор жиілігі мен желінің кернеуін реттеуге қабілетті қуат түрлендіргіші деп аталатын қуатты конверсиялау тізбегін қажет етеді. Соңғы онжылдықта түрлендіргіш топологияның бірнеше түрі жасалды; олардың әрқайсысының өзіндік артықшылықтары мен кемшіліктері бар. Қазіргі кезде өндірістік жел турбиналарында негізінен екі конвертерлік топология қолданылады. Ұсынылатын түрлендіргіштердің көпшілігі қуат сапасын жақсарту және кернеу деңгейін сәйкесінше көтеру үшін желілік сүзгілер мен трансформаторларды қажет етеді. Бұл ауыр және көлемді компоненттер мұнара құрылысына, турбинаны монтаждау мен қызмет көрсету шығындарына айтарлықтай қосады. Жартылай өткізгіштер мен магниттік материалдардың соңғы жетістіктері қуат түрлендіргіштерінің көлемін, салмағын және құнын төмендету үшін мүмкін шешім бола алатын жаңа түрлендіргіш конструкцияларын жасауға әкелді. Бұл мақалада энергия түрлендіргіштің технологиясы, жүргізіліп жатқан зерттеулер мен әзірлемелер терең зерттелген.

Кілтті сөздер: жел генераторы, күштік түрлендіргіштер, зерттеулер мен әзірлемелер, заманауи аспаптар мен материалдар.

Система ветрогенератора требует схемы преобразования энергии, называемой преобразователем мощности, которая способна регулировать частоту генератора и напряжение в сети. За последние десятилетия было разработано несколько типов топологий преобразователей; у каждого из них есть свои достоинства и недостатки. В настоящее время в промышленных ветряных турбинах используются в основном две топологии преобразователей. Для большинства предлагаемых преобразователей требуются сетевые фильтры и трансформаторы для улучшения качества электроэнергии и соответствующего повышения уровня напряжения. Эти тяжелые и громоздкие компоненты значительно *увеличивают расходы на строительство башни, установку турбины и техническое обслуживание. Последние достижения в области силовых полупроводников и магнитных материалов привели к разработке новых конструкций преобразователей, которые могут стать возможным решением для уменьшения размера, веса и стоимости преобразователей энергии. В этой статье содержится углубленное исследование технологии преобразования энергии, текущие исследования и разработки.*

Ключевые слова: ветрогенератор; силовые преобразователи; исследования и разработки; современные приборы и материалы.

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