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A Review on Back-to-Back Converters in Permanent Magnet Synchronous Generator based Wind Energy Conversion System

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Abstract

This paper presents a review on the application of back-to-back converters in the field of permanent magnet synchronous generator (PMSG)-based wind energy conversion systems (WECS). The wide applications of the back-to-back converters are power conditioning devices, micro grid, high voltage direct current (HVDC), and renewable energy systems. The intention is to present an overview about the design considerations taken by various researchers in back-to-back converters in the field of WECS and recent developments on it. Generally the configuration of back-to-back converters used are 12 pulse voltage source converters (VSC), 12 pulse current source converter (CSC), and nine (9) pulse voltage source converter.

Keywords*: back-to-back converter, voltage source converters (VSC), current source converters (CSC), permanent magnet synchronous generator (PMSG), wind energy conversion systems (WECS)*

1. Introduction

The applications of power electronics devices in the field of power systems are making a great impact for power conditioning [1-4], HVDC, Renewable energy systems [5], [6-9], and Micro Grid integrations to the power grid. The impact of back-to-back converters in the field of power systems made the system more reliable and made a way to synchronize the renewable energy sources to the grid. The design of back-to-back converters is broadly classified as voltage source converters and current source converters[10-11]. The voltage source converters (VSC) have the common dc link with capacitor and similarly the current source converters (CSC), [12-13] has dc link with the inductor. The both VSC and CSC have its own advantages and disadvantages. Depends on the requirement of the system, the converter source type and design configuration is chosen by various researchers in this field.

The most common design, configuration employed is 12 pulse VSC and CSC based back-to-back converters, 12 pulse VSC based back-to-back converters supported by DC to DC converter with ultra-capacitor connected across the DC link, 9 pulse VSC based back-to-back converter. The design constraint, while implementing the back-to-back converters is to maintain the constant DC link voltage. The base model for the development of the back-to-back converter is a 3 phase diode rectifier connected to the 6 pulse VSC inverter. Based on this model the researchers done an extensive research and modeled the efficient back-to-back converter designs.

2. Classification of Back-to-Back Converter

The back-to-back converter is classified, based on the converter type and design aspects used by various researchers in the field of power systems. The Figure 1 shows the classification of the back-to-back converter.

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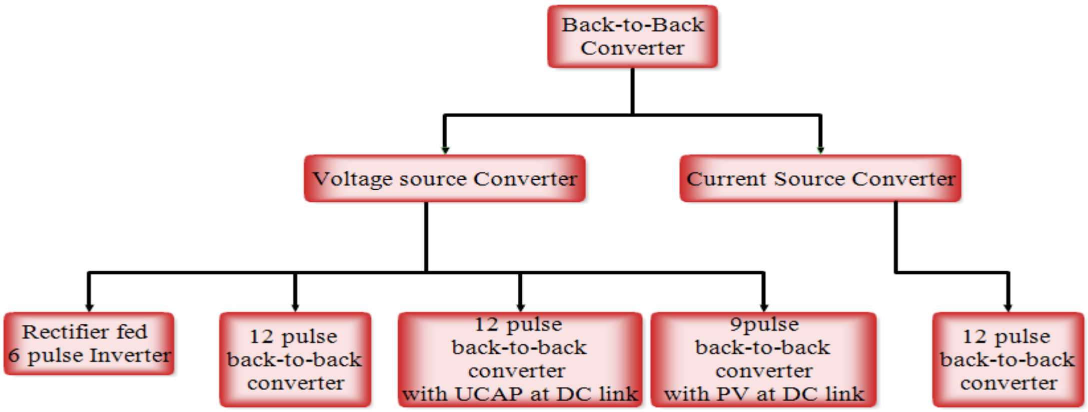

Figure 1. Classification of back-to-back converters in power systems field

2.1. Voltage Source Converter

2.1.1. Diode Rectifier with 6 Pulse Voltage Source Inverter

The basic model of back-to-back converter consists of 3 phase diode rectifier and inverter. This type of converters widely used in the PMSG based wind energy conversion systems and HVDC, [17-20], [21-25] . The controlling part is inverter alone and dc link capacitor is bulky and has a short life span. In this model the output voltage has more ripples. This model cannot be used as the back-to-back inverter applications, like power conditioning devices and micro grid synchronization with power grid. The Figure 2 shows the configuration of diode rectifier with 6 pulse voltage source inverter.

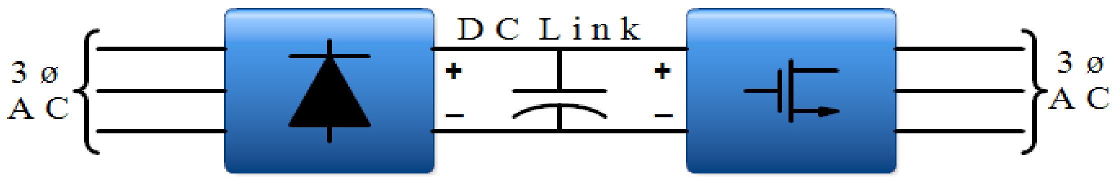

Figure 2. Diode Rectifier with 6 Pulse Voltage Source Inverter

2.1.2. Back-to-Back 12 Pulse Voltage Source Converter

The 12 Pulse back-to-back voltage source converters have two converter modules connected to the common DC link capacitor. These types of converters are widely used in, wind energy conversion systems, power conditioning devices like [25-26] unified power quality conditioner micro grid integration into the power grid. The advantage of this design is, it has capable of making power flow in both directions. This advantage makes the model more suited for power conditioning devices. The capacitor is bulky and it doesn't provide natural protection for short circuit. Also it doesn't provide constant DC link voltage. Figure 3. shows the configuration of 12 pulse back-to-back voltage source converter.

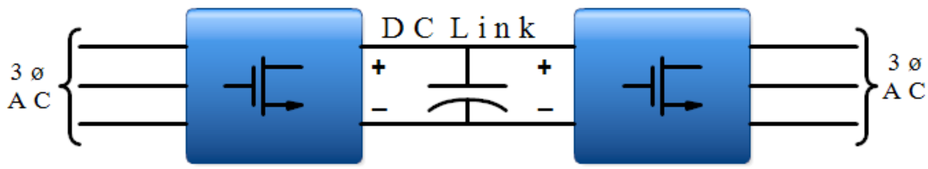

Figure 3. Back-to-Back 12 Pulse Voltage Source Converter

2.1.3. Back-to-Back 12 Pulse Voltage Source Converter with DC-DC converter and Battery/UCAP

Maintaining of constant DC link voltage in the back-to-back converters is essential, in order to provide the constant supply to the inverter side [41-43]. Here the constant DC link voltage is achieved by DC-DC converter with Battery (or) Ultra Capacitor (UCAP), which is connected across the DC link capacitor. Some researchers use renewable energy sources, instead of Ultra Capacitor to maintain the constant DC link voltage. Figure 4 shows the configuration of 12 pulse back-to-back voltage source converter with DC-DC converter and Battery/UCAP.

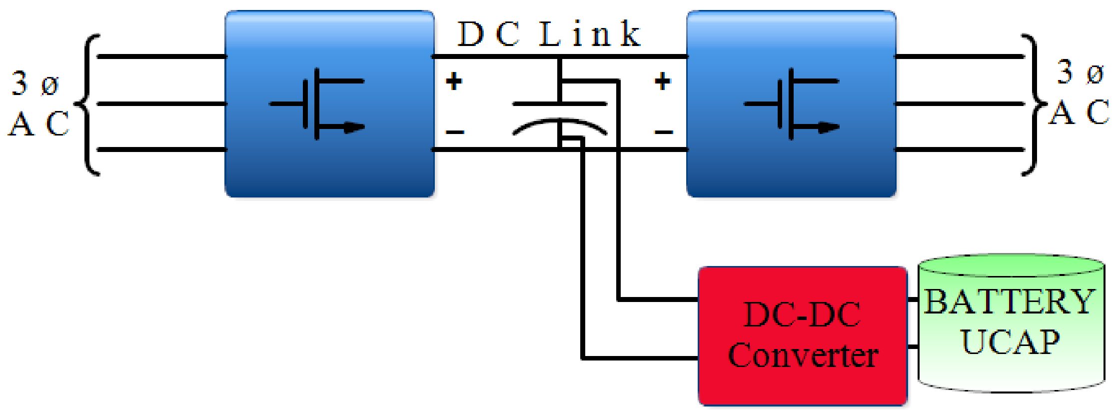

Figure 4. Back-to-Back 12 Pulse Voltage Source Converter with DC-DC converter and BATTERY/ UCAP

2.1.4. Back-to-Back 9 Pulse Voltage Source Converter

Harmonics plays a major role in the constraint of power electronics devices. If there is more number of switches, it produces switching loss also. This may reduce the efficiency of the device.

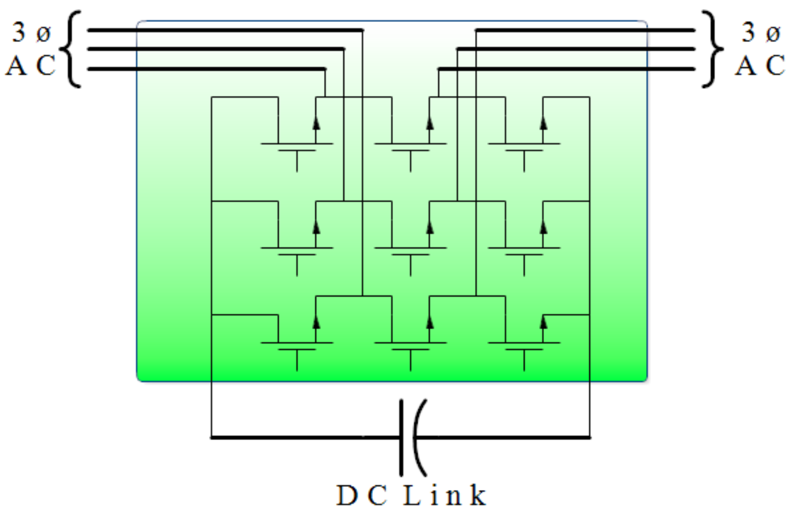

Figure 5. Back-to-Back 9 Pulse Voltage Source Converter

In order to overcome these problems, researchers had designed a new model of back-to-back converters which contains 9 switches [22-24], [53] instead of 12 switches. This model is widely used in the power conditioning devices and in some cases used as a dual output inverter. Depends on the application, it can be used with reduced losses and less number switches. Figure 5 shows the configuration of 9 pulse back-to-back voltage source converter.

2.2. Current Source Converter

2.2.1 Back-to-back 12 Pulse Current Source Converter

Recently the research of current source converters [14-15], [55] in the field of power systems increased and more recent developments were done by various researchers. The main advantage of current source converters is it act as a first order filter and provides natural protection on short circuit. This configuration consists of two 3 phase converters, which are connected to the common DC link reactor.

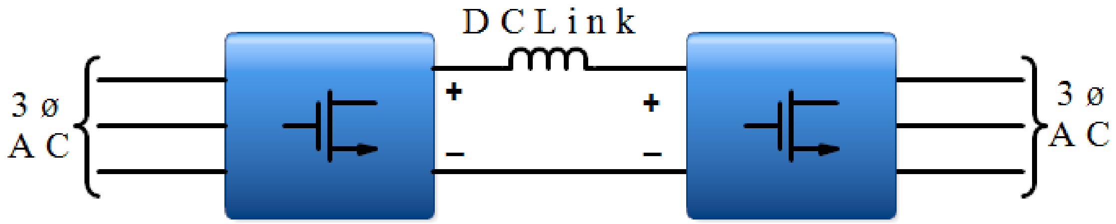

Figure 6. Back-to-Back 12 Pulse Current Source Converter

This model is widely used in Power conditioning devices , HVDC transmission, and wind energy conversion systems. For making this model more efficient many researchers has worked towards current source converters. Figure 6. shows the configuration of Back-to-Back 12 Pulse Current Source Converter.

3. Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion Systems (WECS)

3.1. PMSG WECS based on the Diode Rectifier Bridge and Inverter

A simple topology of a wind energy conversion system consists of a [31-32], [36], [44], 54] diode bridge rectifier, with a DC link to an inverter. This type of converter is simple and reliable, but the power factor of the PMSG [46] is low. The other problem is that, if the output voltage of the rectifier is lower than the grid, it cannot be synchronized with the grid. Figure 7 shows the configuration of PMSG WECS based on the Diode Rectifier Bridge and Inverter.

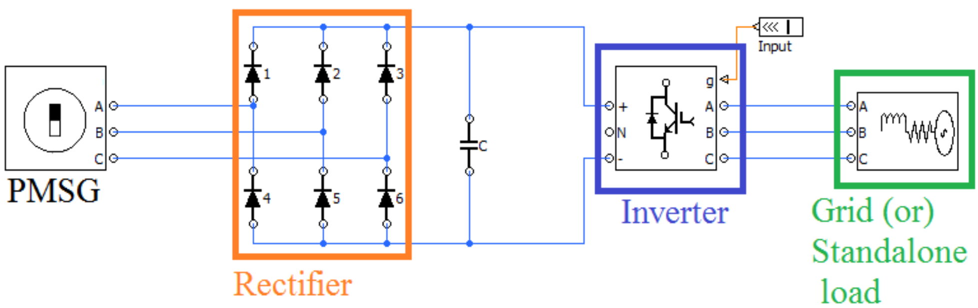

Figure 7. PMSG WECS based on the Diode Rectifier Bridge and Inverter

3.2. PMSG WECS Based on Back-to-Back Converter

The characteristics of the back-to-back converter [27-30], [33], [34], [56] are that the converter needs active devices at both rectifiers and the grid side of the inverter. The advantages of this model are both the rectifier and inverter bridges are controllable. The major disadvantage of back-to-back topology is that, the control strategy is complex and expensive due to need of 12-channel Pulse Width Modulation signals for the rectifier and the inverter. In a practical system, the control algorithm requires more processors like Micro-Controller Units, Digital Signal Processor, and Field Programmable Gate Array to control. Figure 8 shows the configuration of PMSG WECS Based on Back-to-Back Converter.

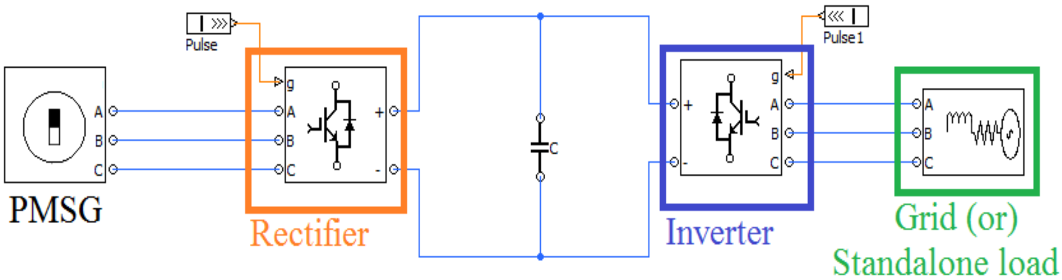

Figure 8. PMSG WECS Based on Back-to-Back Converter

3.3. PMSG WECS Based on Diode Bridge Rectifier, Boost Converter with Battery and Inverter

A topology with Rectifier and DC-DC converter (Boost Converter) is employed along with the Battery in the DC link to maintain the constant DC link voltage [37-39], [45], [47-49], [52]. The advantages of this model are DC link voltage is maintained constant. The major disadvantage is, it requires battery storage for maintaining the constant DC-link and the number of controlled parameter is also increased. In a practical system, the control algorithm requires more processors like Micro-Controller Units, Digital Signal Processor, and Field Programmable Gate Array to control. Figure 9 shows the configuration of PMSG WECS Based on Diode Bridge Rectifier, Boost Converter with Battery and Inverter.

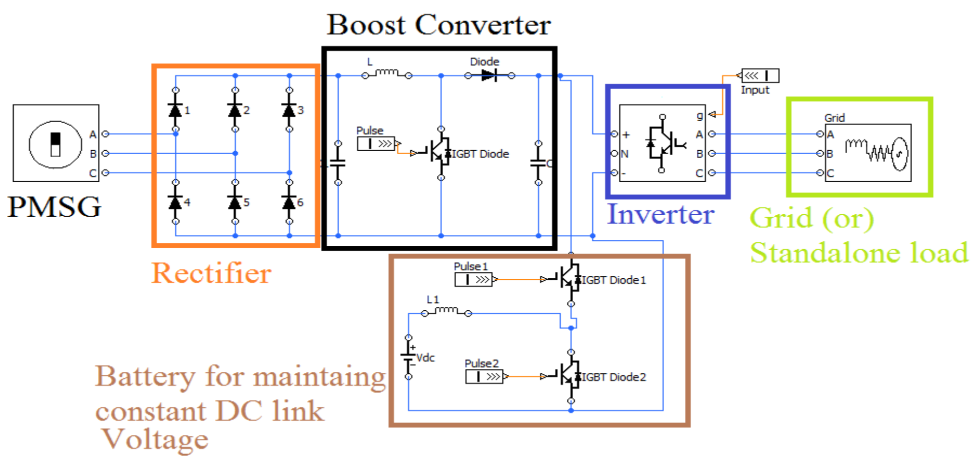

Figure 9. PMSG WECS Based on Diode Bridge Rectifier, Boost Converter with Battery and Inverter

Table 1. Comparison of PMSG WECS models

PMSG WECS based on	No of Controllable switches	Control algorithm and Implementation	Implementation Cost	Efficiency
Diode Rectifier Bridge and Inverter	6	Simple	Low	Low
Back-to-Back Converter	12	Complex	High	High
Diode Bridge Rectifier and DC Chopper with Battery and Inverter	9	Complex	High	High
Diode Bridge Rectifier,Buck Boost Converter and Inverter	7	Simple	Less	High

4. Controller for Back To-Back Converter

For making the efficient and controlled operation controller part is necessary for the power electronics devices the widely used control algorithm is synchronous reference frame theory in which the three phaseco-ordinates (abc) is converted to two co-ordinates (dq0) and based on the requirements the error signal is calculated by comparing with the reference source [10-11], [16], [21], [35], [50-51]. The Transformation matrix form abc to dq0 is given in equation (1). The Inverse Transformation matrix dq0 to abc is given in equation (2). The hardware implementation is done using DSP and FPGA kits using the same algorithm for various types of applications.

$$\begin{bmatrix} i_a \\ i_b \\ i_C \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} cos\theta & -sin\theta & \sqrt{\frac{1}{2}} \\ \cos(\theta - \frac{2\pi}{3}) & -\sin(\theta - 2\pi/3) & \sqrt{\frac{1}{2}} \\ \cos(\theta + \frac{2\pi}{3}) & -\sin(\theta + 2\pi/3) & \sqrt{\frac{1}{2}} \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} \mathrm{i_d} \\ \mathrm{i_q} \\ \mathrm{i_0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + 2\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta + 2\pi/3) \\ \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} \end{bmatrix} \begin{bmatrix} \mathrm{i_a} \\ \mathrm{i_b} \\ \mathrm{i_c} \end{bmatrix} \quad (2)$$

5. Conclusion

A comprehensive review on the different model configurations of back-to-back converters in the field of PMSG based wind energy systems is reported in this paper. The performance, efficiency and implementation cost of the each model is analyzed The recent developments are based on the high efficient converters with reduced number of switches and high efficient converters for power conditioning devices, High voltage direct current transmission, and renewable energy conversion systems. Different model configurations of back-to-back converters have been addressed. These devices have wide area of applications inthe field of power systems and the various design configurations are classified in this paper. The review on back-to-back converters in PMSG based WECS will serve as reference guide for the researcher for the further development of the high efficient systems.

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