An Advanced Full-Bridge Three Level DC-DC Converter with Voltage Balancing Control Technique for Wind Power Systems

K. Girija,  
Dept. of Electrical and Electronics Engineering, Siddharth Institute of Engineering and Technology, Puttur, Chittoor (D), Andhra Pradesh, India.

G. Seshadri,  
Associate prof, Dept. of EEE, Siddharth Institute of Engineering and Technology, Puttur, Chittoor (D), Andhra Pradesh, India.

Abstract—This paper presents an advanced full-bridge three level DC-DC converter and its control for wind power systems. A passive filter is used to improve the performance of the proposed converter. The presence of passive filter reduces the voltage stress of the medium frequency transformer in the AFBTL DC-DC converter. A modulation strategy is proposed for the AFBTC DC-DC converter, which provides two operating modes. Furthermore, a voltage balancing control of the wind turbine based on the AFBTL DC-DC converter in a DC-grid system is presented. Finally, the simulation results for the proposed AFBTL DC-DC converter with 1KW output power range is presented and obtained merely to the theoretical values.

Keywords- Full bridge three level (FBTL) converter, half bridge three level (HBTL) converter, permanent magnet synchronous generator (PMSG), DC-DC converter, wind turbine, voltage balancing control, pulse width modulation (PWM).

I INTRODUCTION

In general, the DC grid provides advantageous things such as absence of reactive power, harmonics and power factor, which gives an effective solution for the power collection system for the growing power demand in the present days. The offshore wind turbines are mostly connected to a DC grid to deliver DC power to a medium or high DC voltage networks. To minimize power delivery and the DC connection, a high efficient DC-DC converter is required. Generally, the voltage level of the DC network is much higher than the input voltage level of the DC-DC converter. For this reason, a medium frequency transformer (MFT) with a range of hundreds of hertz to several kilohertz operating frequency is used for the DC-DC converter. In addition to providing the boosted output voltage, it provides the galvanic isolation between source and grid.
There are many converter topologies which are widely used in the wind power systems as shown in Fig.1. The required number of switching devices for FB-two level inverter is very less compared to remaining three converter configurations. The switches used in the two level converter topology have to take the full DC-bus voltage, and then the voltage rate dv/dt becomes so high. Therefore it leads to large electromagnetic interference (EMI). As compared to two-level configurations, three-level configurations will provide benefits in the fields of power quality, electrical and thermal stress of semiconductors and number of switches required. The switches used in the three level converters will take only half of the DC-bus voltage, it provides less dv/dt ratio compared to FB two-level converter.

The basic FBTL converter has many advantages like reduced voltage stress of the switches, reduced filter size, improved dynamic response and it will be used for medium and high power conversions. Compared to HBTL, FBTL converter and submodules based (SMs) FBTL converter topologies can provide five-level output voltage to minimize the voltage steps and to reduce the dv/dt ratio.

For the p-level configuration, SMs-based FB converter requires 8(P-1) number of switches, which is more than 2(P-1) and 4(P-1) switches required in the basic HB and FB converters respectively. If we compare the FBTL with SMs based FBTL converter, FBTL converter requires less number of switches and easy to construct. With this reason, FBTL converter is preferred for wind power systems. In this paper, the isolated FBTL DC-DC converter is studied for high-power wind turbine systems as shown in Fig.2.

II PROPOSED CONVERTER

Fig.3 shows the structure of the IFBTL DC-DC converter having eight switches (S₁-S₈), eight freewheeling diodes (D₁-D₈), four clamping diodes (D₉-D₁₂), a medium frequency transformer, four rectifier diodes (D₁₃-D₁₄), a passive filter with Lₛ and Cₛ, an output filter inductor Lₜ, one output capacitor C₀ and two input voltage divided capacitors C₁₁ and C₁₂. C₁₁ and C₁₂ are used to split the input DC bus voltage Vᵢ into two equal voltages Vᵥ₁ and Vᵥ₂.

Apart from the FBTL DC-DC converter, a passive filter is inserted into the IFBTL DC-DC converter to improve the performance of the DC-DC converter as shown in Fig.3. This arrangement provides solution to overcome the problem that the nonlinear characteristics of semiconductor devices with distorted waveforms, harmonics and reduces the voltage stress of the MFT, which is important for the power conversion by converter in the high power applications.

Fig.2. Block diagram of the wind turbine connected to a dc grid.
III OPERATION PRINCIPLES

For the successful operation of proposed FBTL DC-DC converter an advanced pulse width modulation technique with two operating modes is proposed and is discussed as below.

A. PROPOSED MODULATION STRATEGY

A PWM technique is used to conduct the switches $S_1$-$S_8$ complementally in pairs, i.e., pairs $S_1$-$S_3$, $S_4$-$S_5$, $S_6$-$S_7$ and $S_8$-$S_6$ respectively. The duty cycle for $S_1$ is $D$. The way of phase shifting the PWM for other switch pair’s results in the different operating modes as described below.

1) Operating Mode I:

The PWM waveform for the switch pairs $S_6$-$S_8$, $S_5$-$S_7$ and $S_4$-$S_2$ lags behind the pair $S_1$-$S_3$ by $(D-D_c)T_s/2$, $T_s/2$ and $(D-D_c+1)/2$ respectively as shown in Fig. 4(a). The term $T_s$ represents the switching cycle. The overlap time between the switch pairs $S_1$-$S_3$ and $S_6$-$S_8$ is $D_cT_s/2$ and is also same for $S_4$-$S_2$ and $S_5$-$S_7$. The term $D_c$ is nothing but the overlap duty ratio.

2) Operating Mode II:

In this mode of operation, the PWM waveform for the pair $S_8$-$S_6$ leads another pair $S_1$-$S_3$ by $(D-D_c)T_s/2$ and the waveforms of remaining pairs $S_5$-$S_7$, $S_4$-$S_2$, $S_6$-$S_8$ and $S_5$-$S_7$ lags the pair $S_1$-$S_3$ by $(1-D+D_c)/2$ and $T_s/2$ respectively as shown in Fig 4(b). The overlap time between the group of pairs $S_1$-$S_3$, $S_6$-$S_8$ and $S_5$-$S_7$, $S_1$-$S_3$ is same and its value is $D_cT_s/2$.

The main difference between the above mentioned operation modes is change in charge and discharge positions of capacitor in each half cycle as shown in Fig 4.
In mode I, input capacitor $C_{i2}$ in each half cycle as shown in Fig 4b. These two operation modes can be used alternatively for the adaptive voltage balancing control.

**B. PROPOSED VOLTAGE BALANCING CONTROL TECHNIQUE**

In this chapter, a voltage balancing control technique is proposed for the AFBTL DC-DC converter, which can be analyzed by alternating operating modes I and II.

- **In operation mode I:**

  As shown in Fig 4a, capacitor currents $i_{c1}$ and $i_{c2}$ are same with time period of $T_s/2$. The charge and discharge positions for capacitors $C_{i1}$ and $C_{i2}$ in each half cycle is common for states A, C and E. In stage B, current $i_{c2}$ is more than $i_{c1}$, where $i_{c2}$ is very less than $i_{c1}$ in stage D as shown in Fig 4a. The periods of stages B and D are $(D-D_t)T_s/2$. For example if $V_{c1}=V_{c2}=V_i/2; C_{i2}$ will provide more energy to the load than $C_{i1}$ in the first half cycle during the mode I operation. The situation in the second half cycle is similar to the first half cycle. Consequently, voltage $V_{c1}$ is higher than $V_{c2}$ as shown in Fig 4a, which result in the situation that $V_{c1}$ is greater than $V_{c2}$ in mode I operation.

- **In operation mode II:**

  Operation is same compared to mode I, the charge and discharge positions of capacitors $C_{i1}$ and $C_{i2}$ in stages A, C and E are same during the first half cycle. The only difference is that current $i_{c2}$ is less than $i_{c1}$ in stage B during mode II operation as shown in Fig 4b, which is complement to that in operation mode I. The value of periods for stages B and D are a common value and is equal to $(D-D_t)T_s/2$. For example, if $V_{c1}=V_{c2}=V_i/2; C_{i1}$ will provide more energy to the load than $C_{i2}$ in the first half cycle in mode II operation. Here also the situation in the second half cycle is common to first half cycle. Therefore, $V_{c1}$ is less than $V_{c2}$ in mode II operation as shown in Fig 4b.

  Based on the above mentioned analysis, $V_{c1}$ would be higher than $V_{c2}$ in operation mode I, $V_{c1}$ would be lesser than $V_{c2}$ in operation mode II. A control strategy is proposed for the capacitor voltage balancing as shown in Fig 5. Where, a capacitor is used with two input voltages $V_{c1}$ and $V_{c2}$. If $V_{c1} > V_{c2}$, the mode of operation in the next half cycle is selected as II. On the other hand, the mode I operation is selected in the next half cycle when $V_{c1}$ is less than $V_{c2}$.

**IV SIMULATION RESULTS**

In this chapter, the simulation results obtained for the proposed system are given for 1KW output power. They are given for various parameters as shown below.

**Fig. 5** Block diagram of the proposed voltage balancing control for AFBTL DC-DC converter.

**Fig. 6** Simulation diagram for the proposed three leveled DC-DC converter configuration.
Fig. 7. Basic Input voltage ($V_i$)

Fig. 8. Voltage across the input capacitor $C_1$ ($V_{c1}$)

Fig. 9. Output voltage obtained from the three level converter.

Fig. 10. Transformer secondary winding voltage ($V_{t2}$)

Fig. 11. Load voltage ($V_o$)
Fig.12. Load current (I₀)

Fig.13. Delivered power to the load (P₀)

These are the results associated with the proposed three leveled DC-DC converter using voltage balance control technique. In this model, the voltage obtained from three leveled converter is given to the primary of transformer winding and then it is stepped down to an AC voltage as shown in Fig. 10. Finally the voltage obtained at the secondary can be inverted to DC in order to synchronize the DC grid. The magnitude of output power can be calculated from the product of output voltage and output current and from the simulation results it is clear for the 1KW output power configuration.

V CONCLUSION

This paper has presented the role of the AFBTL DC-DC converter for the wind power system. The modulation strategy with two operating modes I and II is proposed for the AFBTL DC-DC converter. The proposed operation modes I and II are discussed very clearly. A voltage balancing control technique is given for the proposed AFBTL DC-DC converter, where the alteration of mentioned operating modes can maintain the balanced capacitor voltage. With the use of modulation technique and passive filter, the voltage stress of the transformer is effectively reduced, which is very important in the medium voltage and high voltage applications. A simulation type of 1KW AFBTC DC-DC converter is tested and obtained good results for recommending it to the real time applications.

VI REFERENCES


K. Girija received B.Tech degree in Electrical and Electronics Engineering from Jawaharlal Nehru Technological University, Anantapur, India in 2012. Currently she is pursuing M.Tech in power electronics at Siddharth Institute of Engineering and Technology, Puttur, India. Her research interests are inverters and their development in power electronics.
**P. Chandrasekhar** received B.Tech, degree in Electrical and Electronics Engineering from SV University, Tirupathi, India, M.B.A from SV University, Tirupathi and M.Tech degree in Electrical power systems from Jawaharlal Nehru Technological University, Anantapur, India in 1993, 1996, 2007 respectively. Currently he is working as an associate professor in the department of Electrical and Electronics Engineering at Siddhartha Institute of Engineering and Technology, Puttur, India. His research interests include Power systems and power electronics.

**K. Sarbham** received B.Tech degree in Electrical and Electronics Engineering from JNTU Hyderabad. M.Tech degree in “Power Electronics and Industrial Drives” from Sathyabhama University, Chennai. Currently he is with department of Electrical and Electronics Technology, Puttur, India. His research interests include Power Electronic Devices and their performance improvement.

**G. Seshadri** received B.Tech degree in Electrical and Electronics engineering from JNTUH in 2005, M.Tech degree in Power System and Control and MBA from S.V.University, Tirupathi, India in 2008, 2013 respectively and currently he is doing Ph.D in S.V.University and Currently he is working as an Associate Professor in the department of Electrical and Electronics Engineering, Siddharth Institute of Engineering and Technology, Puttur, India. His research interest is Power Systems. He is life member of ISTE.