Variable Speed Wind Turbine System Based on PMSG and Improved ZVS FBTL DC-DC Converter

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Abstract— This paper analyzes a newly developed three level dc/dc converter is presented for wind energy conversion systems. The power generated from the permanent magnet synchronous generator is rectified and fed to the Improved ZVS FBTL converter. A passive filter to reduce the voltage stress and to improve the converter performance. ZVS technique to reduce the conduction losses in the switches. A voltage balancing control strategy is ensured for proper balancing of the input voltage fed to the converter. Whole wind energy conversion system control is to be done with PI controller.

Keywords— Variable speed wind turbine, PMSG, Three level DC-DC converter, ZVS technique, Passive filter, PI controller, Voltage balancing.

INTRODUCTION

Variable speed wind turbine can achieve maximum energy conversion efficiency over wide range of wind speeds. The turbine can continuously adjust its rotational speed according to the wind speed. In doing so the tip speed ratio can be kept at an optimal value to achieve the maximum power conversion efficiency at different wind speed. To make the turbine speed adjustable the wind turbine generator is normally connected to the utility grid through a power converter system. The converter system enables the control of the speed of the generator that is mechanically coupled to the rotor.

Power converters play a vital role in the integration of wind power into the electrical grid. The DC grid, with the advantages such as reactive power and harmonics seems to be promising solution of power collection system for the growing demand in the offshore wind power development. They also make it possible for wind farm to become active element in the power system. The offshore wind turbines may be directly connected into a DC grid to deliver DC power to a medium or high voltage network.

Multilevel converters can obtain high voltage level with low cost, easy available of low voltage devices which reduces the size and cost of the filters and increases the performance of the converter due to the characteristics of the staircase shaped outputs. And also the convenient way of reducing the voltage stress of the converter is by using the multilevel technology which is good one for high voltage and high frequency applications.

When the full bridge two level and half bridge three level converters were considered, the voltage change rate, dv/dt is high which caused large electromagnetic interference in the line connected to the grid. Normally, the voltage level of the dc network would be dozens of kilovolts which is much higher than the input voltage of the dc/dc converter. Hence, a medium frequency transformer (MFT) operated at hundreds of hertz to several kilohertz would be installed in the dc/dc converter. This not only ensures that the input voltage can be boosted to a desired high output voltage, but also achieves the isolation between source and grid.

Full bridge three level converters have a simpler circuit structure and less number of switching devices. Varying from other converter design a passive filter is introduced into the full bridge three level converters which improve the performance of the converter. This filter is used to reduce the stress in the medium frequency transformer. Moreover the voltage balancing control is not possible for two level converters and complicated for sub module based one. In order to reduce the voltage stress and the switching losses in the device, an improved ZVS (Zero Voltage Switching) full bridge three level DC-DC converter is proposed. The converter is capable of achieving zero voltage switching for all the power switches and the voltage stress is also reduced. Zero Voltage Switching means that the power to the load is switched on or off only when the output voltage is zero volts.

Zero Voltage Switching can extend the life of a controller and of the load being controlled. Varying from other converter design a passive filter is introduced which improves the performance of the converter. The alternating voltage which is obtained from the inverter is fed through the passive filter which reduces the stress and can effectively overcome the problems which occurs due to the non linear characteristics of the semiconductor devices which results in the distorted waveforms. This voltage is fed to the medium frequency transformer (MFT) which in turn steps up the voltage and is been fed to the converter which is essential for a power converter in high power applications. FBTL converter has simple circuit structure and less number of switching devices with improved dynamic response. In this project, an improved ZVS FBTL DC-DC converter is proposed with a voltage balancing control strategy. Wind Energy Conversion Systems (WECS) requires a generator to provide the required power. Many types of generators are available for WECS such as Squirrel Cage Induction Generator (SCIG), Wound Rotor Induction Generators (WRIG), Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG).

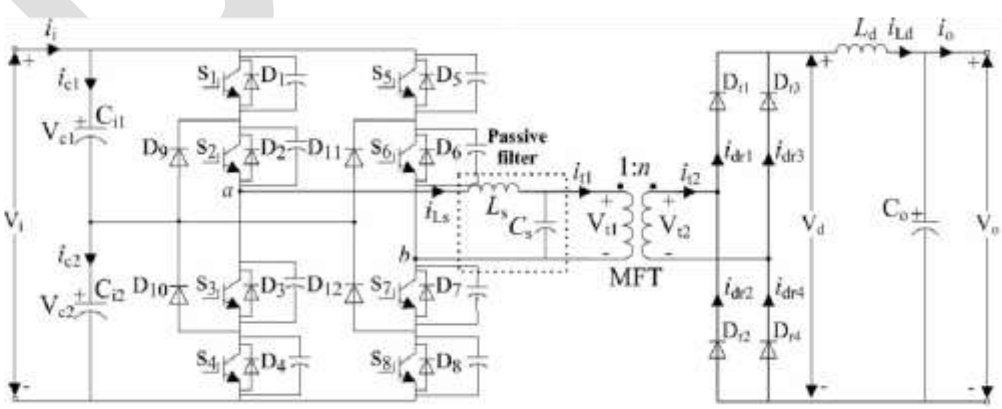
PMSGs are the majority source of commercial electrical energy. A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil.

IMPROVED ZVS FBTL CONVERTER

Improved ZVS FBTL DC/DC converter, is composed of eight switches (S1–S8), eight freewheeling diodes (D1–D8), four clamping diodes (D9–D12), an MFT, four rectifier diodes (D*r*1–D*r*4), a passive filter (L_s and C_s), an output filter inductor L_d, an output capacitor C_o, and two voltage divided capacitors (C_{i1} and C_{i2}).These capacitors are used to split the dc voltage V_i into two equal voltages V_{c1} and V_{c2}. Different from the FBTL DC/DC converter, a passive filter is inserted into the Improved ZVS FBTL DC/DC converter as shown to improve the performance of the DC/DC converter which can effectively overcome the problem that the nonlinear characteristics of semiconductor devices results in distorted waveforms associated with harmonics and reduce the voltage stress of the MFT, which is very significant for the power converter in the high power application.

MODULATION STRATEGY

The switches S1–S8 are switched complementarily in pairs with a pulse width modulation (PWM), i.e., pairs S1–S3, S4–S2, S5–S7, and S8–S6, respectively. The duty cycle for S1 is *D*. The way of phase shifting the PWM for other switch pairs results in the different operation modes. The modulation strategy also includes the voltage balancing control for IFBTL dc/dc converter.



International Journal of Engineering Research and General Science Volume 4, Issue 2, March-April, 2016
ISSN 2091-2730

OPERATION MODE I

The PWM waveform for the pairs S8–S6, S5–S7, and S4–S2 lags behind that for pair of S1–S3 by $(D - D_c)\ T_s/2$, $T_s/2$, and $(D - D_c + 1)T_s/2$ respectively as shown in Fig. 2.7(a). T_s is the switching cycle. The overlap time between S1–S3 and S8–S6 is $D_cT_s/2$, which is also for S4–S2 and S5–S7. D_c is defined as the overlap duty ratio.

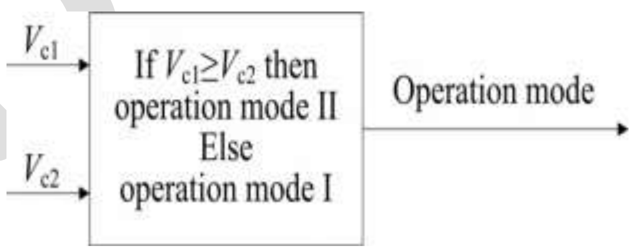
OPERATION MODE II

The PWM waveform for pair S8–S6 leads before that for pair S1–S3 by $(D - D_c)\ T_s/2$, and the PWM waveform for pairs S4–S2 and S5-S7 lags behind that for the pair S1–S3 by $(1-D+D)T_s/2$ and $T_s/2$, respectively. The overlap time betweenS1–S3 and S8–S6, and between S4–S2 and S5–S7 is also both $D_cT_s/2$. The main difference between the two operation modes is the capacitor charge and discharge situations in each half cycle. In operation mode I, capacitor C_{i2} discharges more energy than capacitor C_{i1} in each half cycle while capacitors C_{i1} and the C_{i2} exchange their situations in operation mode II. In operation mode II, capacitor C_{i1} discharges more energy than capacitor C_{i2} in each half cycle. The two operation modes can be alternatively used for the adaptive voltage balancing control.

The steady-state operations of the converter under the proposed modulation strategy are explained with the assumption that $C_{i1} = C_{i2}$. In one cycle T_s under operation modes I and II, respectively. Voltages V_{ab}, V_{t1}, V_{t2} and currents i_{Ls}, i_{t1}, i_{t2} are all periodic waveforms with period T_s. Currents i_{c1}, i_{c2} and i_{Ld} are with the period $T_s/2$. Owing to the passive filter in the Improved ZVS FBTL dc/dc converter, the performance of voltages V_{t1} , V_{t2} and currents i_{t1}, i_{t2} associated with the MFT is effectively improved, which is significant for the Improved ZVS FBTL dc/dc converter in the applications of the medium-voltage and high-power system. The charge and discharge situations (i_{c1} and i_{c2}) of capacitors C_{i1} and C_{i2} are the main difference between the operation modes I and II, which would affect the capacitor voltages V_{c1} and V_{c2}. The other performances of the converter are nearly the same.

VOLTAGE BALANCING CONTROL STRATEGY OF IFBTL CONVERTER

The switches S1–S8 are switched complementarily in pairs with a pulse width modulation (PWM), i.e., pairs S1–S3, S4–S2, S5–S7, and S8–S6, respectively. The duty cycle for S1 is D. The way of phase shifting the PWM for other switch pairs results in the different operation modes. The modulation strategy also includes the voltage balancing control for IFBTL dc/dc converter.

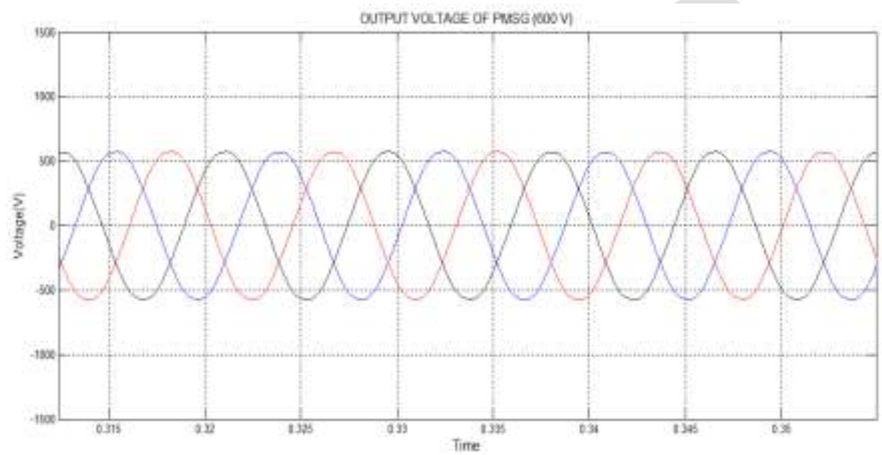


SIMULATION AND TEST RESULTS

Simulation for the permanent magnet synchronous generator fed improved full bridge three level dc/dc converter for wind energy conversion systems is done using MATLAB Simulink. The power generated in the turbine is fed to the grid through an improved full bridge three level dc/dc converter which is used for high and medium power application.

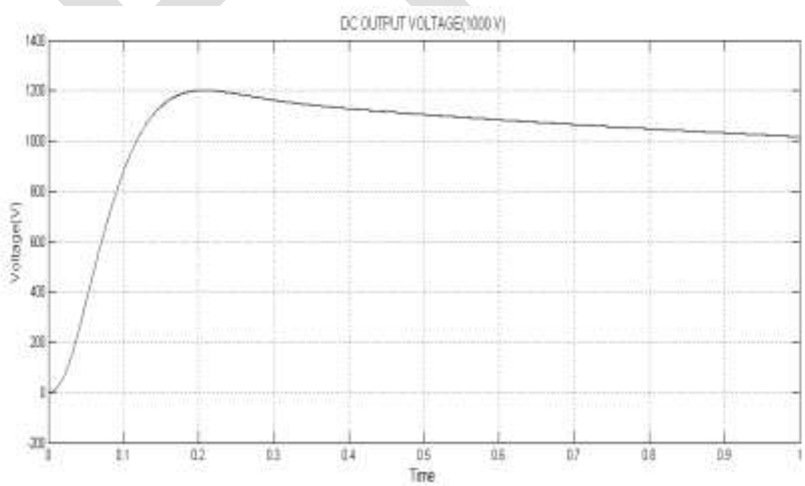
OUTPUT VOLTAGE FROM GENERATOR

Output voltage of 600 V AC is generated from PMSG and is fed to the bridge rectifier.



DC OUTPUT VOLTAGE

DC output voltage of 1000 V obtained from simulation from the Improved ZVS FBTL converter and this stepped up voltage is given to the DC grid.



CONCLUSION

This project has presented the control of the Improved ZVS FBTL dc/dc converter for the wind turbine system to facilitate the integration of wind turbines into a dc grid by transferring power through Improved ZVS FBTL converter efficiently by minimizing the losses. The converter is designed with variable speed wind turbine and PMSG and also the overall control is done using PI controller and simulated using MATLAB simulink.

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