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Modified Rectifier Topology for High Power PMSG Variable Speed Wind Turbine

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ABSTRACT*:* This paper presents the power electronic applications for wind energy systems. A new topology consists of two three phase diode bridge rectifiers and three naturally commutated thyristors is proposed. The proposed rectifier is used for the application of high power variable speed PMSG wind energy conversion system. The main advantage of the proposed rectifier are low cost, low power loss, simple control and highly reliable. The variable speed wind turbine has some prominent features than fixed speed and hence variable speed is used. The Maximum Power Point tracking algorithm is used for obtaining a maximized power output. The operating principle of the rectifier is elaborated. The rectifier and control operations are verified by MATLAB/ Simulink.

KEYWORDS*:*- Rectifier, Permanent magnet synchronous Generator, Wind energy Conversion system.

I. INTRODUCTION

The future trend in wind energy conversion systems is to increase the power capacity of wind turbines and generators to reduce the cost of generated electricity. The wind energy conversion system operates under two operating modes: fixed speed and variable speed wind turbines. The variable speed wind turbine has some advantages over the fixed speed wind turbines, they have ability to obtain maximum power from varying wind speed, higher overall efficiency audible noise at lower wind speed and lower mechanical stress [1]. Under variable speed operation the power converter in the system plays an important role in transferring the generator output power in the form of variable voltage variable frequency to the fixed voltage fixed frequency grid[2]. A typical PMSG based wind energy conversion system is shown in figure 1, in which a full capacity power converter is employed.

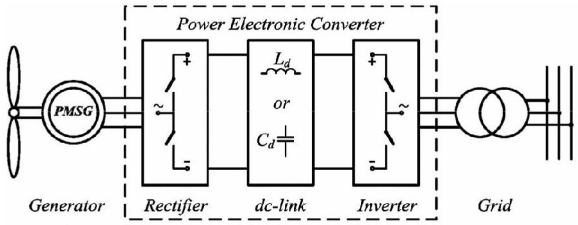

Figure.1. Typical structure of PMSG based wind energy conversion system.

The amount of energy obtained from a wind energy conversion system depends not only on the characteristics of the wind regime at the site, but it also depends on the control strategy used for the WECS[3]. The energy extracted from the wind is transferred from the generator to the dc-link by the generator side rectifier and then to the utility by the grid side inverter. The dc-link capacitor provides decoupling between the generator side and grid side converters. To achieve proper power control in the system, the dc-link has to be higher than the peak of the grid phase voltage[4]. There are many different controlled rectifier circuits, but the full power rating PWM rectifier is more expensive and complex. Also the rectifier generates higher switching losses and it is less efficient even though the input applied is the sinusoidal current[5]. The applications of voltage source inverter based power electronic systems for interfacing variable-voltage DC sources to the grid. A variable-speed wind power conversion system is used for illustration, where the VSI-based interface needs to convert a variable DC voltage to a nearly constant AC voltage with high-quality power[6]. The usage of synchronous generator, simple 3-phase diode rectifier with dc-dc chopper is more cost effective

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solution for ac-dc converter than 3-phase PWM converter[7]. The strategy combines the idea of Power Signal Feedback control and Input-Output Feedback Linearization method. As the results, the strategy can improve the dynamic response speed of WGS as well as the yield of wind energy in steady and dynamic state[8].

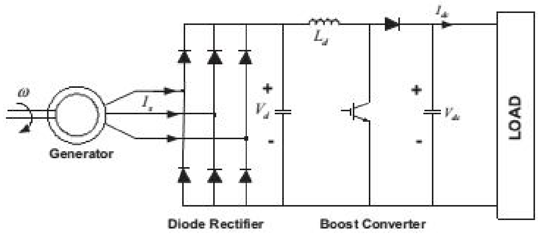

Figure.2. Diode bridge rectifier with dc-dc boost converter.

An uncontrolled diode bridge rectifier may be used as the generator side converter, but it is suitable for variable speed wind turbine system. In order to achieve a wind speed range, the grid side inverter is oversized to improve maximum power capture at variable wind speed but it leads to overcost and hence it can be reduced by adding a dc–dc boost converter between the diode rectifier and the inverter[9]. The proposed converter operation will be detailed in the following sections and the variable speed operation of the PMSG will be discussed.

This chapter gives the brief description of the papers reviewed for the literature survey. About 20 papers were referred for this project. The papers are based on; wind energy conversion systems have become a focal point in the research of renewable energy sources. The trend of wind energy conversion system is to increase the power capacity of wind turbines and generators to reduce the cost of generated electricity. In this chapter, the 20 papers are grouped under following category, such as study on induction generators, converters in variable speed wind turbines, harmonic reduction process and algorithms used.

II. PROPOSED RECTIFIER

The proposed rectifier consists of two three phase diode bridge rectifiers and three naturally commutated thyristors. The two diode bridge rectifiers are cascaded with the three thyristors in its respective input supply phases. The two diode bridge rectifiers are supplied by three phase power supply and it is displaced by 180 degree from the upper diode bridge rectifier. The diode rectifiers are in parallel. When all the thyristors are in off position, the proposed rectifier is in parallel and the output is the output of single diode bridge rectifier. When any one of the thyristor is in on position, the rectifier is in series and the output voltage is the output voltage of the two diode bridge rectifier.The proposed rectifier is shown in figure.3 below.

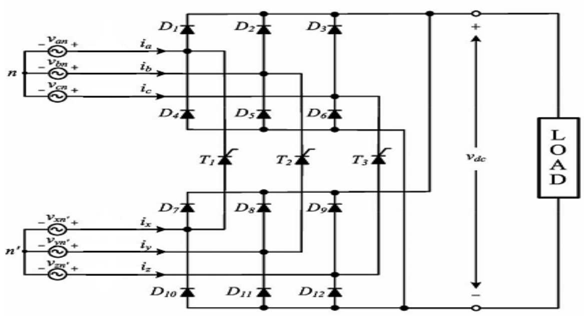

Figure.3. Proposed rectifier circuit.

Hence the uncontrolled diode bridge rectifier is used along with three naturally commutated thyristors are used; the proposed rectifier has the feature of low-cost. The operating principle of the rectifier in its different operating sections is explained in the following section.

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III. OPERATING PRINCIPLE

The operating principle of the proposed rectifier is explained using its input expressions and waveforms. The sources V_{an}, V_{bn}, V_{cn} and v_{xn}', v_{yn}', v_{zn}' are sinusoidal and can be expressed in the equation below.

$$V_{an} = \sqrt{2}V sin\omega t$$

$$V_{bn} = \sqrt{2}V sin(\omega t - \frac{2}{3}\pi)$$

$$V_{cn} = \sqrt{2}V sin(\omega t + \frac{2}{3}\pi) \text{ and}$$

$$V_{xn}' = \sqrt{2}V sin(\omega t + \pi)$$

$$V_{yn}' = \sqrt{2}V sin(\omega t + \frac{1}{3}\pi)$$

$$V_{zn}' = \sqrt{2}V sin(\omega t - \frac{1}{3}\pi)$$

The input voltage supplied to the proposed rectifier is shown in figure below.

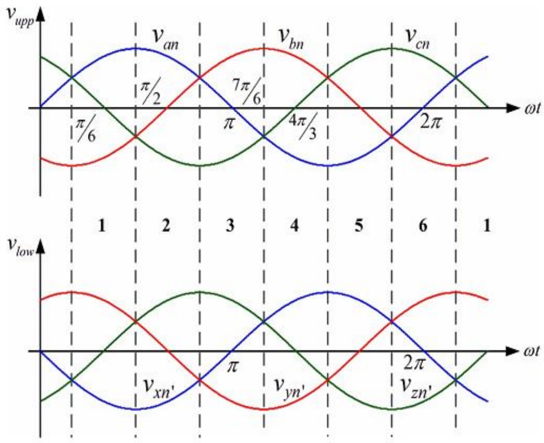

Figure.4. Input voltage supplied to the proposed rectifier.

The current path in each and every sections are elobrated using its circuit diagram. The current path in section 1 is explained using the input voltage supplied to the upper and lower diode bridge rectifiers. The maximum and minimum input phase voltages in the upper supply are v_{an} and v_{bn}, respectively; whereas for the lower supply, the maximum is v_{yn}' and the minimum is v_{xn}'. As illustrated in the figure below, the two diode bridges have separate current paths and maintain their own rectification when the thyristors are off. Assuming that we have an inductive dc load that behaves like an ideal current source, the rectifier's output voltage v_d is equal to the input line-to-line voltage v_{ab}.

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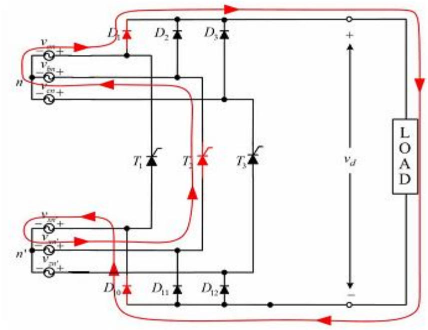

Figure.5. Section 1 Operation.

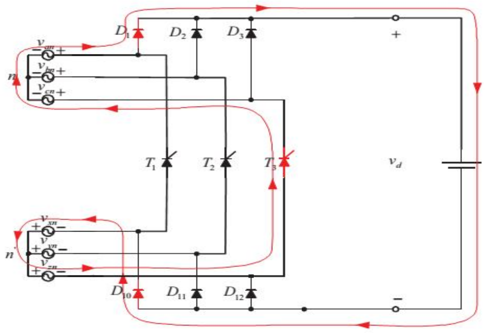

Figure.6. Section 2 Operation

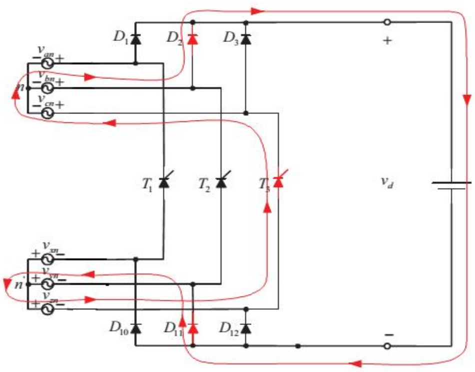

Figure.7.Section 3 peration.

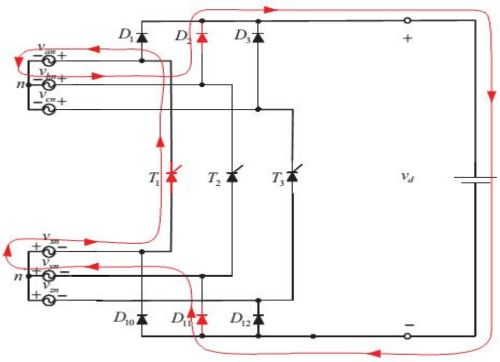

Figure.8. Section 4 Operation.

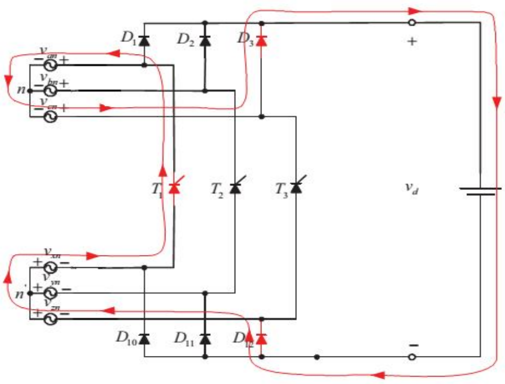

Figure.9. Section 5 Operation

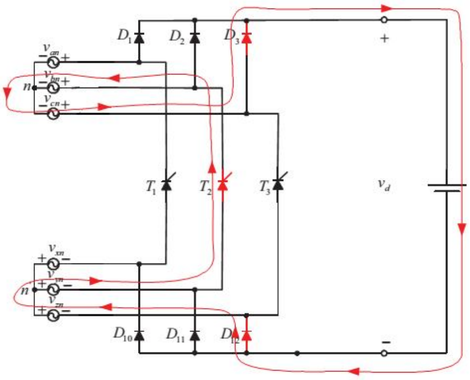

Figure.10. Section 6 Operation

The thyristor T2 connect the minimum voltage phase in the upper supply phase b and the maximum voltage phase in the lower supply phase y is turned on at any time within Section 1, the two diode bridges are forced into a series connection through the thyristor. The dc voltagevdthen becomes the sum of $v_{ab}$and v_{yx}, equaling to $2v_{ab}$ in magnitude.

A. CURRENT PATH IN VARIOUS SECTIONS

Figure 5-10 shows the current path in all the six sections when individual thyristor is on. In section 1, Figure 5 shows that the two sets of diode rectifiers are connected in serial when T_2 is on. Two diode rectifiers are shown in series in

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Figure 5. In the upper rectifier devices, $D_1$and D_5, are on, and the rectifier supplies the voltage v_{ab}. In the lower rectifier devices, D_8 and D_{10}, are on The thyristor T_2 is forward biased by the voltage, vd. After T2is triggered, the load is supplied by v_{ab} and v_{yx} in series, which is two times of vab. Similar operations will occur in other sections.

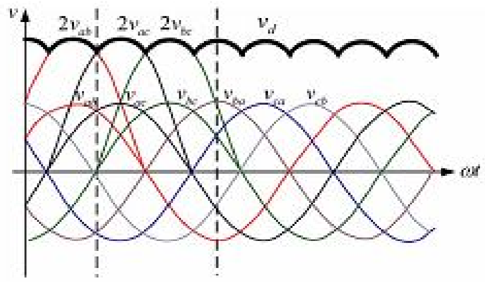

Figure.11. Rectifier output voltage for $\alpha=0^0$.

IV. MPPT CONTROL FOR VARIABLE SPEED PMSG WECS

The simplified system diagram of a variable-speed PMSG wind turbine using the proposed rectifier as the generator-side converter is illustrated in Figure.12. Under normal operating conditions, the VSI is responsible for maintaining a constant dc voltage while regulating the grid side power factor as. The whole system consists of two identically rated PMSGs which are directly coupled to the rotor shaft of the wind turbine. Each PMSG is feeding one of the two inputs of the rectifier. By adjusting the mechanical angles of the generators during installation, the 180º phase displacement requirement on the rectifier input voltages can be satisfied easily. It is worth noting that due to the distinctive structure of the rectifier, the power rating of the two PMSGs is approximately half that of the system's rated power, such that the ratings of the generator-side and the grid-side converters.

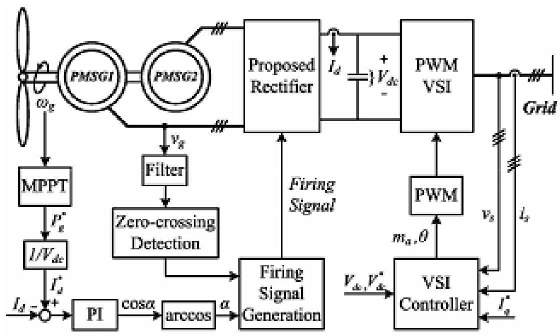

Figure.12. Proposed rectifier in variable speed WECS application.

V. SIMULATION RESULTS

A simulation model in matlab/simulink has been constructed to verify the rectifier operation, as shown in Figure 14. The proposed rectifier and its MPPT control for variable-speed operation are designed. The simulink model is shown in figure 13 below.

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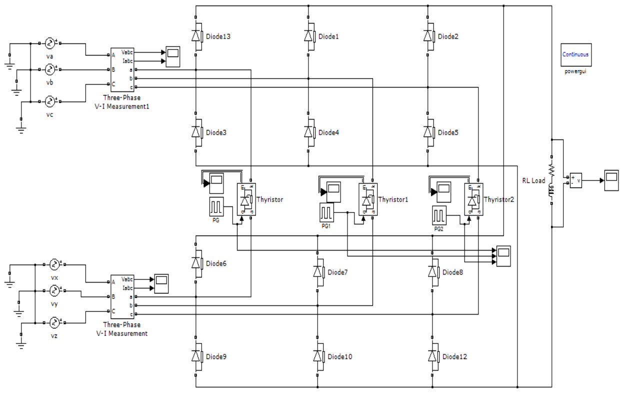

Figure.13. Simulation diagram for proposed rectifier.

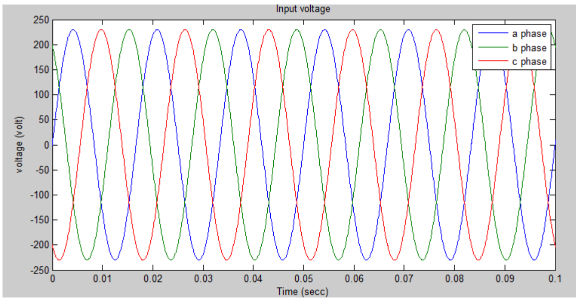

Figure.14. Input voltage supplied to the upper diode bridge rectifier.

The simulink block consists of two three phase diode bridge rectifiers supplied with three phase supply and cascaded by three thyristor. Its supply voltages for the upper diode bridge rectifier are shown in figure 14

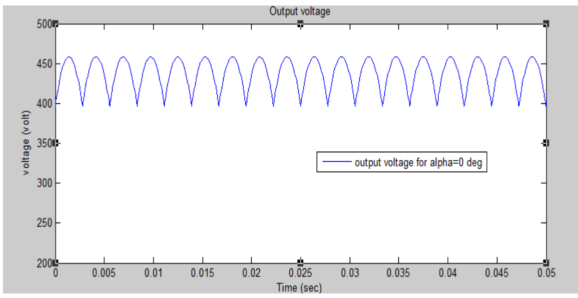

Figure.15. Simulation result of the rectifier for $\alpha=0^{0}$.

The proposed rectifier is used for the application of high power PMSG variable speed wind turbine and hence for the application purpose the three phase PWM inverter is designed in MATLAB and the output phase voltages are obtained. The structure of the PWM inverter is shown in figure 15.

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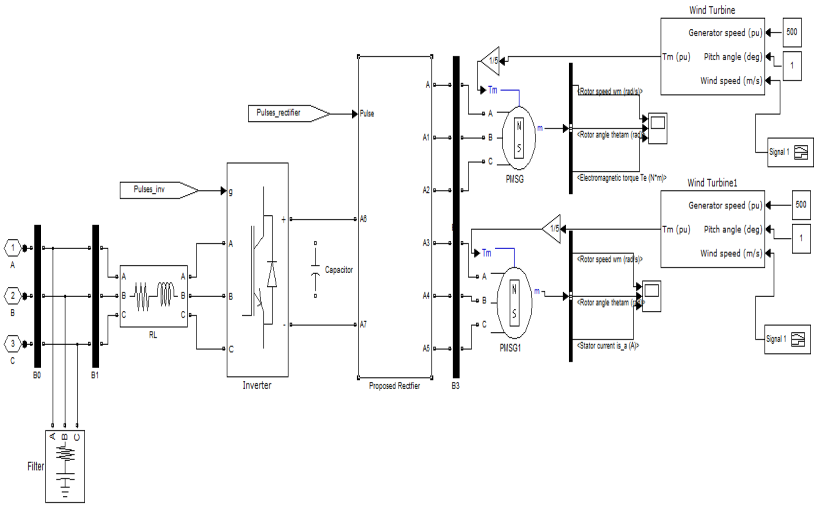

Figure.16. Simulated design of WECS.

Fig 16 shows the design of WECS and the output for WECS is shown below

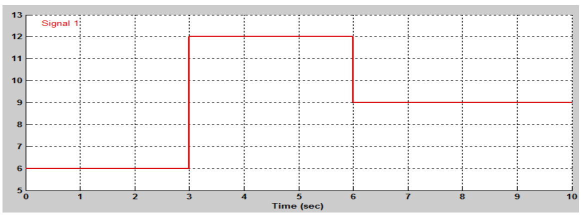

Figure.17. Wind speed to the wind turbine.

Hence the system is the variable speed wind energy conversion system, the input wind speed applied to the system is shown in figure 17

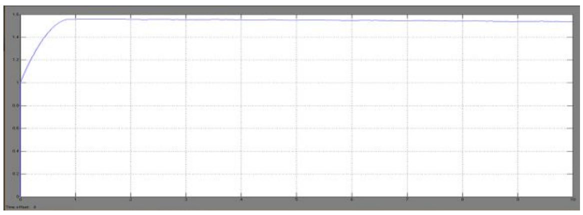

Figure.18. Generator speed of conversion system.

The output of the permanent magnet synchronous generator is in the form of rotor speed, rotor angle,electromagnetic torque and stator line current. These output waveforms are shown in figure. 18

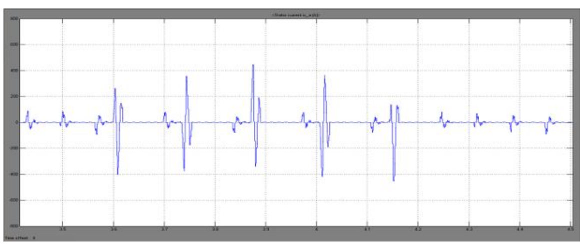

Figure.19. Line current produced as output.

These are the output voltage and current waveforms obtained from the proposed rectifier and the application of wind energy conversion system

VI. CONCLUSION

This paper presents a rectifier topology particularly suitable for variable-speed high-power PMSG wind turbine applications. Built with diodes and thyristors, the rectifier features low cost, low commutation power losses and high reliability. The operating principle of the proposed rectifier is explained using MATLAB; a simple optimum power control strategy is adopted for the rectifier to extract maximum power from the wind. It was demonstrated by simulation results that the rectifier can properly control the permanent magnet generators to achieve variable-speed operation within wind velocity region from about half to full rated value.

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