DUAL BRIDGE RECTIFIER FOR PMSG VARIABLE SPEED WIND ENERGY CONVERSION SYSTEMS

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Abstract - *A dual bridge rectifier topology consisting of two three-phase diode bridges and three individual thyristors is proposed for variable-speed PMSG wind energy conversion systems (WECS). The rectifier output voltage can be cascaded the input voltages of the PMSG by connecting the two diode bridges in series or parallel using thyristors. By properly controlling the thyristors in such a way that the conversion of wind energy is possible for variable wind speed. The proposed rectifier topology gives the maximum to double the output voltage of a single bridge rectifier. The rectifier advantages are low cost, low switching power loss and simple control.*

Key Words: **Wind Energy Conversion Systems (WECS), Permanent Magnet Synchronous Generator (PMSG), Wind Turbine Generator (WTG), Rectifier, Pulse generator, Thyristor.**

1. INTRODUCTION

Renewable energy resources, especially wind energy having great attention with the depletion of existing fossil fuel deposits and increasing concerns about CO_2 emissions. Since the late 1990's, variable speed constant frequency (VSCF) wind energy conversion systems (WECS) have been widely adopted in order to maximize wind energy utilization.

Wind turbine is of two types, one is fixed and the other is variable. The fixed type wind turbine has many drawbacks like reactive power, so the grid voltage level cannot be controlled. These drawbacks can be avoided by using variable speed wind turbines[1]. Advantages of variable speed systems: reduced mechanical stresses, higher overall efficiency, audible noise at low wind speed, the maximum output power from varying wind speed and improved power quality. But in variable speed wind turbine power electronic converters are needed which makes the variable speed operation promising. But the use of more components increases the cost of the system and switching losses.

Basically, a wind turbine is connected to a three-phase generator, such as synchronous generator and asynchronous generator, like doubly-fed induction generator (DFIG)[2] and direct-drive permanent magnet synchronous generator (PMSG). Direct drive-WECS has attracted more and more attention due to its advantages of high efficiency and high reliability. The permanent magnet synchronous generator (PMSG) converts the mechanical power from the wind turbine into output power of ac, which is then converted to dc power through a converter with a dc link to supply the dc load. To maximize the use of wind energy when the wind speed is below the rated speed, the maximum power point tracking (MPPT) of the system is used.

PMSG is used in low and medium power range in WECS. Advantages of PMSG over DFIG are it reduces maintenance cost due to brushless design, increases conversion efficiency. In a typical PMSG based WECS full power capacity AC-DC-AC power converter[3] is employed to covert the variable frequency variable speed generator output to the fixed frequency fixed voltage grid.

There are number of topologies are proposed earlier for power conversion and the most popularly used ones are back to back two level VSC[4], three-level neutral-point-clamped converter[5] [6] and multi-modular cascaded H-bridge converter[7]. The energy extracted from wind is transferred from the direct driven PMSG to the dc link by the generator side rectifier. The generator side converter is responsible for generator speed or torque control [8].There are several types of generator side converters such as PWM AC-DC rectifier on the generator side on which field oriented control (FOC) method can be implemented to control the WTG [8].

PWM rectifier is more expensive and complex for full power rating. Also, rectifier generates high switching losses and no significant benefits of efficiency. Instead of back-to-back PWM converters that involve numerous expensive active power switches and complex control, an uncontrolled diode rectifier is used as the generator side converter[9]. But it is only suitable for wind turbine systems equipped with pole changing WTG to achieve variable speed. By employing only diodes and naturally commutated thyristors, the proposed rectifier features low cost, low power loss and high reliability.

2. DUAL BRIDGE RECTIFIER TOPOLOGY

Proposed dual bridge rectifier topology consists of two sets of 3-phase diode rectifier bridges and three thyristors is as shown in Fig 1. Each diode rectifier is connected to the corresponding set of 3 phase winding and their outputs are connected in parallel. The two set of input windings are at 180° (electrical angle) phase displacement for the proper working of the rectifier. This can be done by rearranging windings under different pole pairs. Also, can be done by providing dual winding at the stator or using two PMSG's by providing three-phase winding to each generator. Then the output of the PMSG's should be at 180˚ phase shift.This arrangement is required for the natural commutation of the switches.This arrangement gives double the output power at half of the rate at wind speed by connecting in series.

By turning ON/OFF the thyristors the diode rectifier bridges can be connected either in series or in parallel. This arrangement gives double the output power at half of the rate at wind speed by connecting in series. By Comparing with the pole changing technique, two sets of windings can be achieved by reconfiguration of generator windings with additional cost. Even though more devices are involved in the converter but the rating of the devices is only half of the converter rating hence the cost of the converter is reduced and also there are no high frequency switches and the switching losses are reduced.

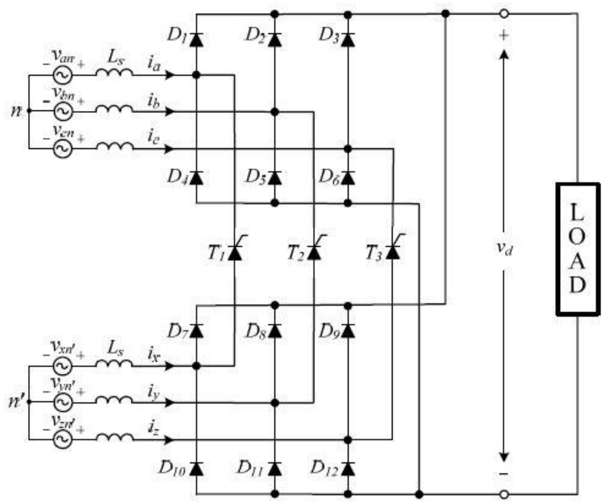


Fig -1: Dual Bridge Rectifier Topology

3. CONVERTER OPERATION

Either a PMSG with dual stator windings or two PMSG's each connected to one set of three-phase winding is used as the AC power supplies of the rectifier. Assuming the two input power supplies for the dual bridge rectifier is equal in magnitude and 180˚ phase displacement with each other, such that the instantaneous voltages of sources v_{an}, v_{bn}, v_{cn} and v_{xn} , v_{yn}, v_{zn} are sinusoidal and are expressed as

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

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

$$v_{cn}=\sqrt{2}V \sin(\omega t + \tfrac{2}{3}\pi)$$

$$v_{xn}=\sqrt{2}V \sin(\omega t + \pi)$$

$$v_{yn}=\sqrt{2}V \sin(\omega t + \tfrac{1}{3}\pi)$$

$$v_{zn}=\sqrt{2}V \sin(\omega t - \tfrac{1}{3}\pi)$$

Working of the dual bridge rectifier can be explained by the switches ON and OFF of the thyristor.During normal operation, the thyristors are OFF and the bridges are connected in parallel, the rectifier's output voltage is same as the output of the single diode bridge. Whenever the wind speed reduces than the rated speed, the thyristor switches are turned on at the right instants of time.Then the two bridges are connected in series and gives the double the output voltage at half of the rated wind speed.

When the thyristors are turned ON doubled the output voltage obtained is due to the constraint of connecting the two three-phase inputs at 180˚ displacement with each other. Since the input to the bridges at 180˚ phase difference, the voltage at the both leads are not same. At one end the voltage will be higher than the other. At an instant only one switch will be in forward biased and the other two will be in reverse biased.

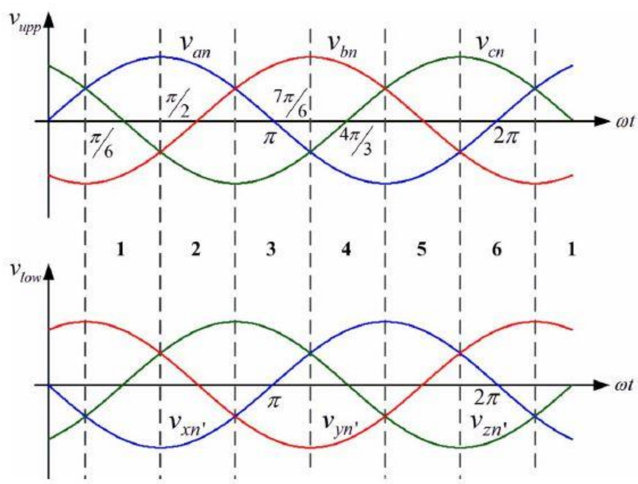


Fig – 2: Rectifier source voltage waveforms

4. CURRENT PATH AND OUTPUT VOLTAGES OF THE RECTIFIER

The phase voltages changes six times per fundamental cycle, so the whole period is divided into six sections as shown in Fig 2. Let us consider the section-1 to understand the current paths. In section-1, the maximum and minimum input phase voltages for the upper supply are v_{an} and v_{bn} and for the lower supply are v_{yn} and v_{xn} respectively. When the T2 is OFF the two diode bridges are connected in parallel, have separate current paths as shown in Fig 3(a). The rectifier's output is equal to the line-to-line input voltage. In the upper diode bridge rectifier, D_1 and D_5 are ON and the output voltage equals to v_{ab}. In the lower diode bridge rectifier, D_8 and D_{10} are ON and the output voltage equals to v_{yx}. The output voltages of the two diode bridges v_d are connected in parallel, so the output voltage at the load equals to v_{ab}. When thyristor T2 is triggered on in section-1, connects to the minimum voltage phase in the upper supply (phase b) and the maximum voltage phase in the lower supply (phase y) as shown in Fig 3(b). Then the two bridge rectifiers are cascaded in series, the output voltage v_d is equal to the sum of the individual bridge outputs v_{ab} and v_{yx} , which is equals to $2v_{ab}$.

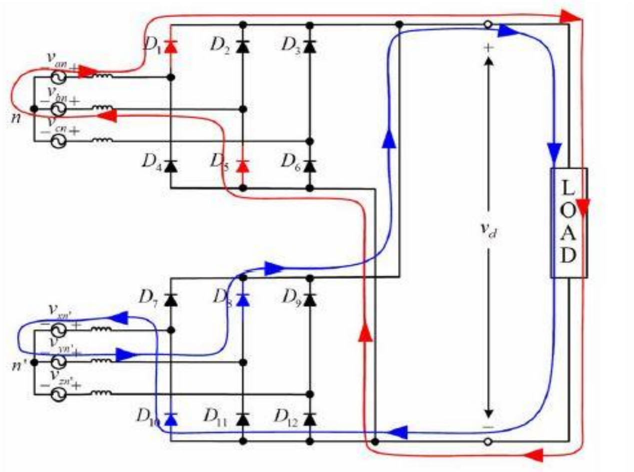


Fig -3(a): Current flowing path for section-1 when Thyristor is OFF

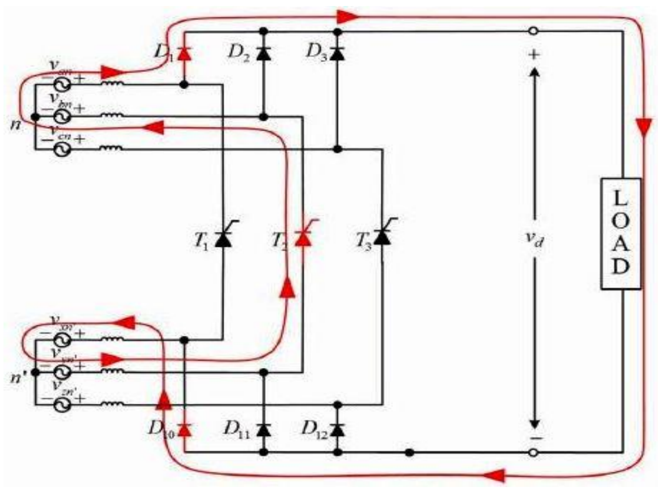


Fig -3(b): Current flowing path for section-1 when Thyristor is ON

The output voltage can be adjusted by properly controlling the thyristors at the right instants of time. Firing angle for the thyristor controlling range can be explained by using sections 2 and 3 in Fig 2. In sections 2 and 3 ($\frac{\pi}{2}$ to $\frac{7\pi}{6}$) , in the upper supply phase c has the minimum voltage and in the lower supply phase z. T3 will conduct during this period at any instant till $4\pi/3$ when no other thyristors are triggered on. At $4\pi/3$ the magnitude of v_{ba} becomes greater than $2v_{bc}$ and provides reverse voltage across T3 and turns it OFF. So, the range of firing angle α is 0-150˚. The three thyristors conducts alternately and each thyristor will conduct for 120˚ and then turned Off by turning on the next thyristor. The two extreme cases of the output voltage v_d is obtained when α=0˚ and α=150˚. When α=0˚, the two diode bridges are connected in series gives the double the maximum dc output voltage of the single three-phase diode bridge. When α=150˚, the two diode bridges are connected in parallel gives the maximum dc output voltage of the single three-phase diode bridge.

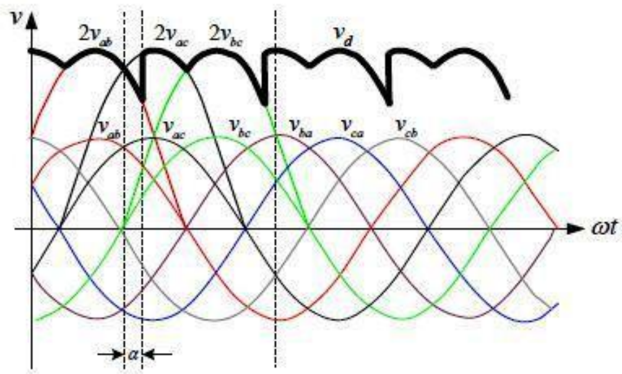


Fig -4(a): Rectifier output for $0^\circ \leq \alpha \leq 30^\circ$

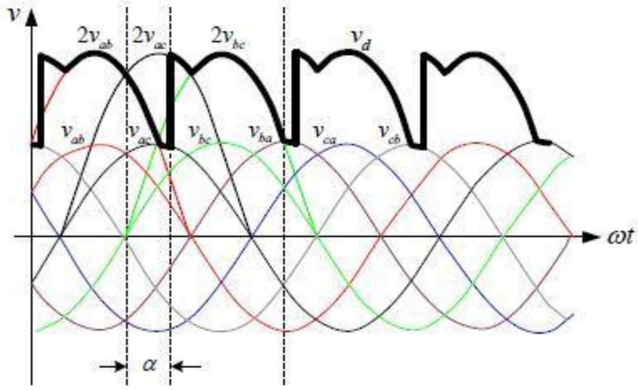


Fig -4(b): Rectifier output for $30^\circ \leq \alpha \leq 120^\circ$

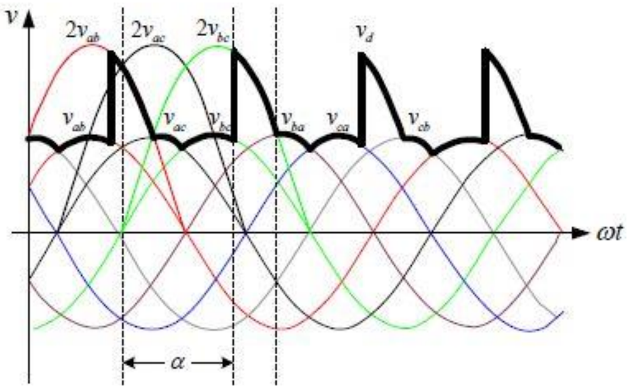
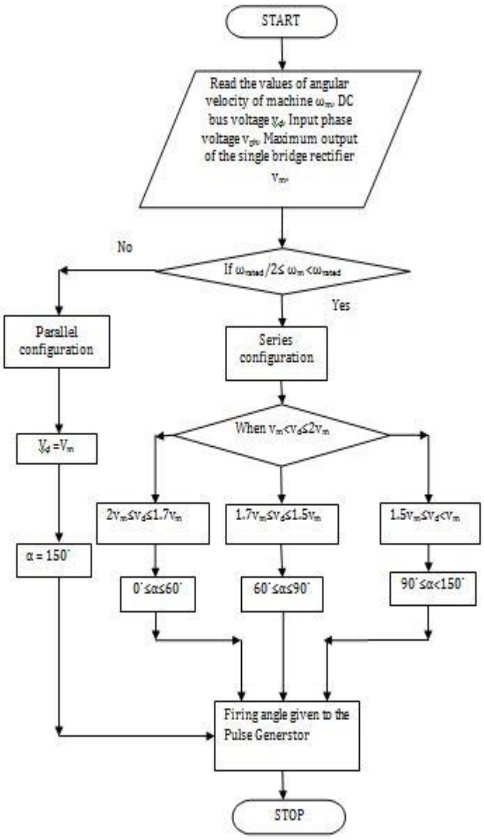


Fig -4(c): Rectifier output for $120^\circ \leq \alpha \leq 150^\circ$

5. FLOW-CHART

The flow chart for the firing pulses to the pulse generator of the rectifier to trigger thyristors is shown below.



6. SIMULATION AND RESULTS:

The Matlab/Simulink model of the dual bridge rectifier is shown in Fig 5.

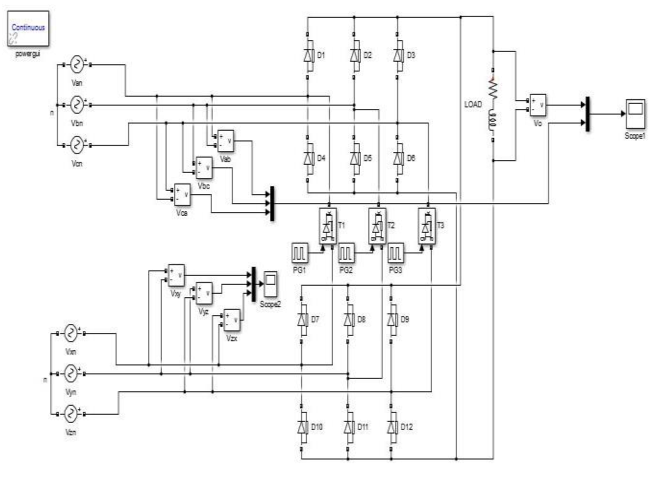
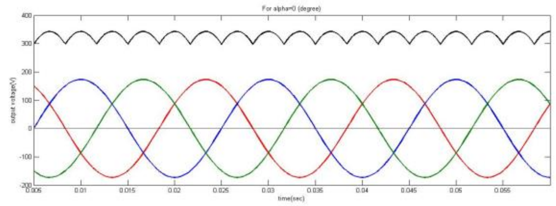
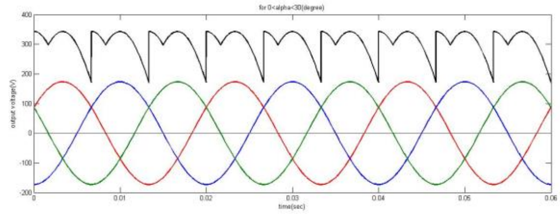


Fig-5:. Matlab/ Simulink model of the Rectifier

The simulated output waveforms for the input voltage 100v is shown in below Fig 6.



(a)



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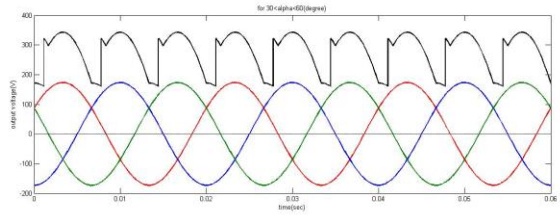

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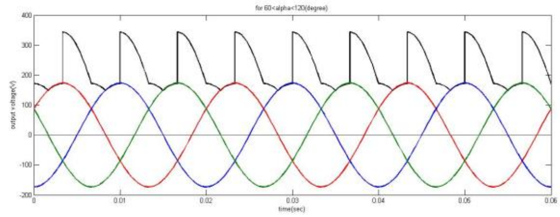
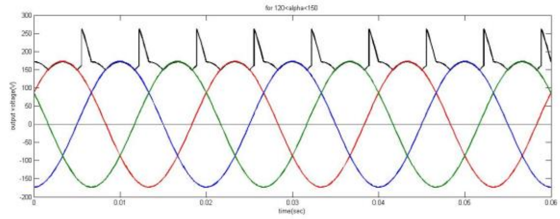
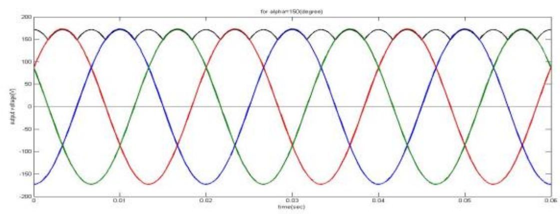


(d)



(e)



(f)

Fig -6: Simulated output waveforms

7. CONCLUSIONS

In this paper, a dual bridge rectifier topology for a variable speed Wind Energy Conversion Systems (WECS) is presented. The dual bridge rectifier topology is simulated by using MATLAB/SIMULINK. The diodes and thyristors used in the rectifier reduces the cost, the complexity of switching control, reduces switching losses and highly reliable. This rectifier is suitable for variable wind speeds. The speed range of wind turbine is 2:1.

REFERENCES

[1] Anagha R. Tiwari,Anuradha J. Shewala, Anuja R. Gagangras, Netra M. Lokhande, "Comparison of various Wind Turbine Generators" Multidisciplinary Journal of Research in Engineering and Technology, Volume-1, Issue 2, Pg.129-135.

[2] S. Muller, M. Deicke and R.W. De Doncker, " Doubly Fed Induction Generator systems for Wind Turbines", IEEE ind. Appl. MAg., Vol. 8, no.3, pp. 26-33, May/June. 2002.

[3] Z.Chen, J. M. Guerrero and F.blabbjerg, "A Review of the state of the art of power electronics for wind turbines" IEEE Trans. Power Electron., vol. 24, no.8, pp. 1859-1875, Aug. 2009.

[4] J. A. Baroudi, V. Dinavahi and A.M.Knight, " A Review of Power Converter Topologies for Wind Generators", Renewable Energy, Vol.32, no. 14,pp. 2369-2385,2007.

[5] A. Yazdani and R. Iravani, " A neutral-point clamped converter system for direct-drive variable-speed wind power unit", IEEE Trans. Energy Conv., Vol. 21, no.2, pp.596-607, June 2006.

[6] S. Alepuz, S. Busquets-Monge, J. Bordonau, J. A. Martinez-Velasco, C. A. Silva, J. Pontt and J. Rodriguez, " Control Strategies based on symmetrical components for grid-connected converters under voltage dips", IEEE Trans. Ind. Electron., vol. 56, no.6, pp. 2162-2173, Jun. 2009.

[7] C. H. Ng, M. A. Parker, L. Ran, P. J. Tanver, J.R, Bumby and E. Spooner, " A Multi-level modular converter for a large, light weight wind turbine generator", IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1062-1074, May-2008.

[8] Dewei Xu, Zhenhan Luo, " A Novel AC-DC Converter for PMSG Variable Speed Wind Energy Conversion Systems" Power Electronics Motion Control Conference,2009. IPEMC'09.

[9] Jiacheng Wang, Student Member, IEEE, Dewei (David) Xu, Member, IEEE, Bin Wu, Fellow, IEEE and Zhenhan Luo " A Low-Cost Rectifier Topology for Variable-Speed High-Power PMSG Wind Turbines" IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 26, NO. 8, AUGUST 2011, pp. 2192-2200.

[10] Midhun Raju and Lydia M, " Simulation of a Novel Rectifier Topology for Variable-Speed High-Power PMSG Wind Turbines using MATLAB/SIMULINK" INTERNATIONAL CONFERENCE ON RENEWABLE AND SUSTAINABLE ENERGY (ICRSE-13), Vol 2, special Issue, pp. 7-11,2014.