A Novel Integrated AC/DC/AC Converter For Direct Drive Permanent Magnet Wind Power Generation System

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Abstract **–This paper proposes to reduce the switching loss and minimize the circulatingcurrent present in the power converters used in wind power generation system. In the paper the power factor is improved and by minimizing circulating current and switching loss the overall performance is improved. The experimental result shows the high performance of the system.**

Keywords **– Switching loss, circulating current, power converters, and wind power.**

I. INTRODUCTION

The wind turbine has become a significant part of our electrical generation capacity, it is increasingly important that the performance of wind turbine is similar to the performance of our conventional generator.Power systems with power converters, combined with permanent magnet synchronous generators (PMSG) represent the newest technology in wind power market. Using power converters has many advantages compared to older technologies.The different switching characteristics of the power converter results in circulating current. The circulating current circulates among the power switching devices that increase the current flow through the power switching devices, increase the loss of converters, and perhaps damage the converters.In this paper to minimize the switching loss and circulating current for rectification a three switch Vienna rectifier and for inversion a nine switch Ultra sparse matrix converter (USMC) is used. The purpose of converting AC to DC is to convert an unstable AC to a stable DC voltage and the stable DC voltage is converted to a stable AC voltage.

II. METHODOLOGY

The wind turbines with PMSG along with Vienna rectifier deals with the reduction of harmonics on the source side and reduce switching losses.In the paper, closed loop PWM with PI controller technique is used, and hence the DC output voltage of Vienna rectifier stabilizes faster. As the pulse number increases, the harmonics present in the input decreases and the total harmonic distortion reduces. The output of the wind turbine varies according to the wind but while connecting to load we have to maintain constant voltage so to step up & step down the voltages in rectifier section a three switch Vienna rectifier and in inverter section a nine switch Ultra sparse matrix converter is implemented. The wind turbine converts the kinetic energy present in the wind into mechanical energy. The output of the wind turbine is connected to Permanent magnet Synchronous generator. The PMSG converts the mechanical energy into electrical energy. The output of the PMSG is connected to Vienna rectifier; it converts the unstable AC voltage into stable DC voltage. The Vienna rectifier is used to make power factor correction and only three IGBT switches are used so switching loss is reduced. The output of the Vienna rectifier is given to Ultra sparse matrix converter, the USMC converts the DC voltage into AC voltage and it minimizes the circulating current and finally the output of the Ultra sparse matrix converter is given to the load.

III. CONTROL OF PMSG

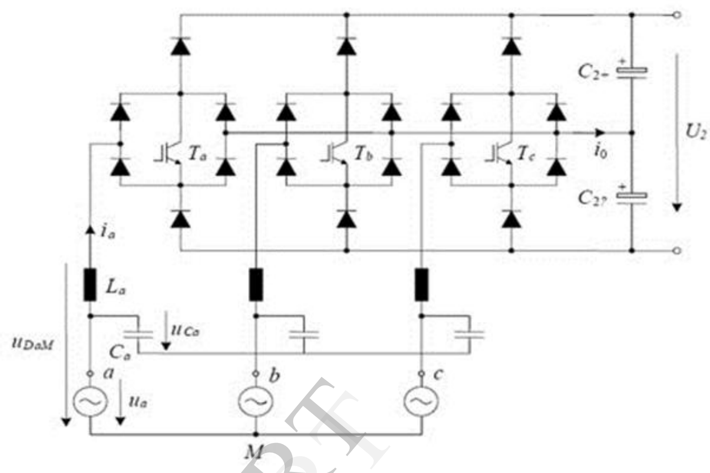
The PMSG converts the mechanical energy into kinetic energy & in synchronous generator instead of electromagnet, permanent magnets are used, so no DC current is used to produce magnetic field. The magnetic fields are produced by the permanent magnets and without gearbox the rotor shaft of the wind turbine is directly coupled with PMSG and so it is called Direct drive PMSG.In the absence of gear box, to maintain the synchronous speed a PWM technique is used.

IV. MINIMIZATION OF SWITCHING LOSS AND CIRCULATING CURRENT

A. Rectification using Vienna rectifier

The Vienna rectifier consists of three switches IGBT, it converts the unstable AC voltage into a controlled DC voltage. It can also provide sinusoidal input currents and controlled DC-voltage.

Fig.1. Three switch Vienna rectifier



The AC voltage from the PMSG is given to the Vienna rectifier. The current flows through the three IGBTs and the capacitors in the capacitor bank begins to charge and when the capacitors are fully charged it compensates the reactive power and hence the power factor is improved.The topology of the three-phase/three-switch/three-level PWM ("Vienna") rectifier is depicted in circuit diagram. Herein, we consider the electromechanical system until the dc bus, which is assumed to maintain a constant dc voltage. The switches are placed and the switching is made in such a way that the numbers of solid state switches are reduced. The PWM block is made to generate the gating signals for IGBT. In Vienna Rectifier the output capacitor is split in two parts as two equal value capacitors, C1 and C2, connected in series. Across the output capacitors the –Vdc and +Vdc are developed as 3-Phase peak detected outputs. A switch for each phase is connected, such that when "ON", it connects the line phase to the center node of C1 and C2 through a series inductance. For a short switching period, (assuming 10 microseconds), the capacitors charge linearly. This offsets -Vdc and +Vdc. The offset depends on the corresponding phase voltage and the switch "ON" time duration. The common node of C1 and C2 will have Voltage with triangular wave shape, having three times the mains frequency and its amplitude will be one quarter of the phase voltage.The Vienna rectifier allows the input current I to lead or lag the input voltage (V) by no more than 30◦.The phase shift between ˜ V and ˜I is denoted by β (β>0when current is lagging) the Vienna rectifier cannot supply enough reactive power to the machine. One possible way to provide reactive power is by connecting a capacitor bank across the machine terminals, as shown in Fig.1

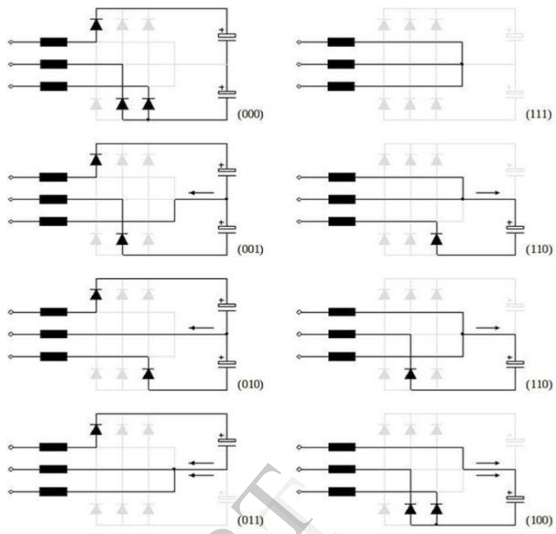


Fig.2. Switching sequences

Conduction states of the Vienna Rectifier, for ia>0, ib,ic<0, valid in a sector of the period T1 sa,sb, and sc characterize the switching state of the system. The arrows represent the physical direction and value of the current midpoint i0.

B. Inversion using USMC

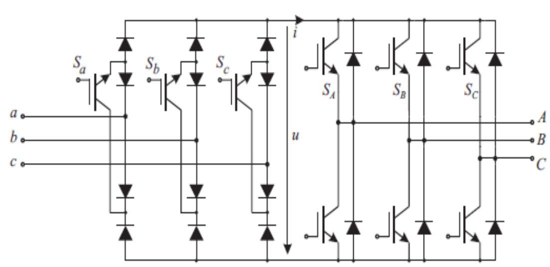


Fig.3.1 Ultra sparse matrix converter(USMC)

Further reduction of the switches of the Sparse Matrix Converter (SMC) topology to 9 switches is possible. The reduced topology is termed as the Ultra Sparse Matrix Converter (USMC) topology as shown in Figure 3. The Ultra Sparse Matrix Converter (USMC) is the simplest form of the IMC, comprising only 9 individual switches and 18 diodes 7 isolated driver potentials. The USMC itself is a variant of the Sparse Matrix Converter (SMC).Ultra Sparse Matrix Converter does show very low realization effort; in case unidirectional power flow can be accepted (admissible displacement of 90° the input current fundamental and input voltage, as well as for the output voltage fundamental and output current) accordingly a possible application area would be variable speed motor drives of high dynamics. The modulation technique which is used in Sparse Matrix Converter (SMC) can be extended to control the Ultra Sparse Matrix Converter (USMC) topology.

Figure 3.1 illustrated the Ultra Sparse Matrix Converter (USMC) topology presented in this dissertation. On the load side, the arrangement has the same conventional inverter as for the AC-DC-AC converter. As a consequence, traditional PWM methods may be used to generate the output voltage waveform. However, in order to ensure proper operation of this converter, the DC side voltage should always be positive. On the line side, the converter has a rectifier which is similar to traditional one except that the switches are all bidirectional. Thismodification also provides the distinguishing feature whichdiffers this converter from circuits of previous researchers. The main objective of this rectifier is to maintainpure sinusoidal input current waveforms as well as maintainpositive voltage on the DC side. In contrast to the AC-DC-AC converter, the DC capacitors can now bereplaced by a small filter on the line side. In a conventional matrix converter, a complex multi-step commutation strategy is employed to prevent short-circuits between the input phases and open circuits in the output phases. However, with the Ultra Spare Matrix Converter (USMC) a simpler zero DC-link current commutation schemes can be used since the converter is separated into input and output stages. To commutate the input stage, the output inverter stage is set into freewheeling mode, allowing the input stage to commutate under zero current. Consequently the input stage does not incur switching losses.The three phase Ultra Sparse Matrix Converter (USMC) shown in Figure 3.1. In this Figure diode bridge bidirectional switch topology is used. In Figure 3.2 a simple diode bridge bi-directional switch configuration is presented. It implements only one switching device and a diode bridge bi-directional configuration.

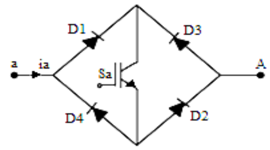


Figure 3.2 Diode Bridge Bi-Directional Switch Configurations

The collector of the IGBT is connected to the anodes of the bridge and the emitter is connected to the cathodes. Only one active switching element makes this a very attractive solution from point of view of costs and complexity of gate drive circuits. For purposes of analysis, one can assume that theswitching frequency is far greater than fundamentalfrequencies of both the input voltage source and outputcurrent source. Thus during each switching cycle, both theinput voltage and output current can be assumed as constant.Assuming a stiff voltage source on the line side and stiffcurrent sink on the output side, the DC side voltage isessentially decided by the switching functions of the rectifierand the input voltage, the DC side current is determined bythe combination of output switching functions and outputcurrent. It is assumed that, on the input side.

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C. *Switching Strategies*

State 1:

In state 1 input phase *a*is at its peak positive value and is clamped to the positive DC link rail by input switch S_a. Switch $S_c$is also turned on to conduct the return current.

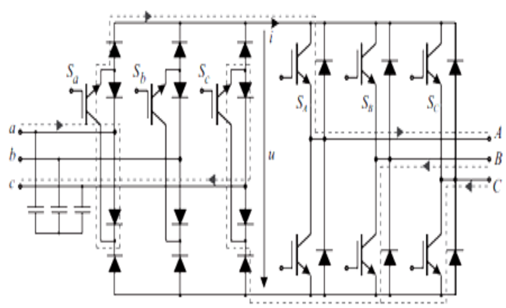

Figure 3.3 Switching operation of State 1: $u = u_{ac}$,$i = i_A$

During this interval output leg $S_A$has its high side switch active while the other output switches have their low side switches active.

State 2:

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In state 2, the input stage remains unchanged while the output leg $S_B$switches from low side to high side operation.

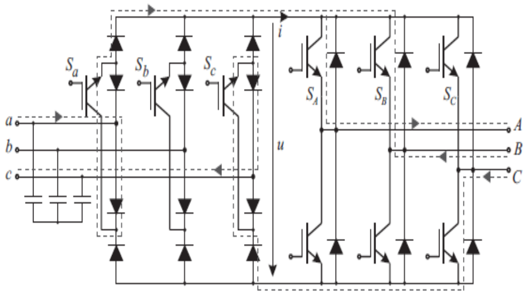


Figure 3.4 Switching operation of State 2: $u = u_{ac}$,$i = -i_C$

State 3, 4:

In states 3 and 4, the zero current switching of the input stage occurs. Firstly output leg $S_C$is switch to high-side operation to create a freewheeling state at the output. The input stage then commutates from $S_c$to $S_b$under zero current.

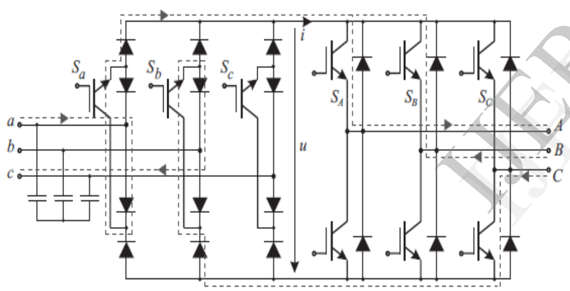
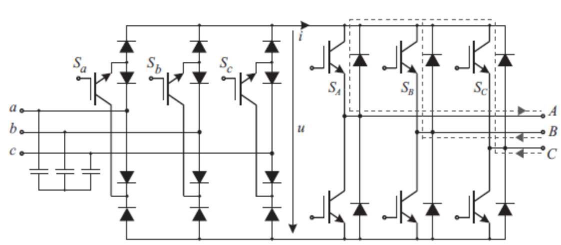


Figure 3.5 Switching operation of State 3, 4: u switched from u_{ac} to u_{ab},$i = 0$

State 5:

The converter then switches into state 5, which is similar to state 2 except the DC link voltage is now $u_{ab}$and input switch $S_b$conducts the return current. In the final state output leg B switches from high to low side operation such that the output stage is the same as shown in state 1.

Figure 3.6 Switching operation of State 5: $u = u_{ab,}$ $i = -i_C$



V. EXPERIMENTAL RESULTS

An experimental platform has been set up to test the performance

TABLE I

PMSG Parameters

Stator resistance	0.016 pu
Inductance	0.06 pu
Nominal power	$275e^{3}$VA
Line-Line voltage	480V
Frequency	60Hz
Pole pair	2
Speed	1500rpm

TABLE II

IGBT Parameters

Resistance	.01 ohms
Forward voltage	1V
Current 10% fall time	$1e^{-6}$
Current Tail time	$2e^{-6}$
Snubber resistance	$1e^{5}$ohms
Capacitor	$1000e^{-3}$F

TABLE III

PI Parameters

Proportional	0.013
Integral	16.61
Min & Max O/P	-500,500

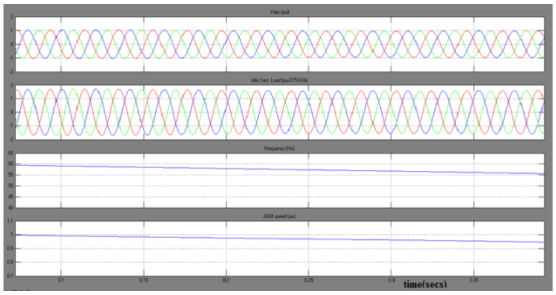


Fig 4.1.Input waveforms of PMSG

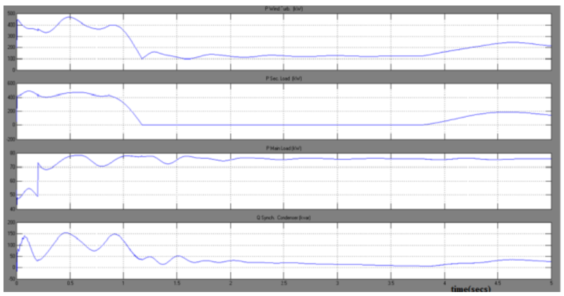


Fig 4.2. Input waveform of Vienna rectifier

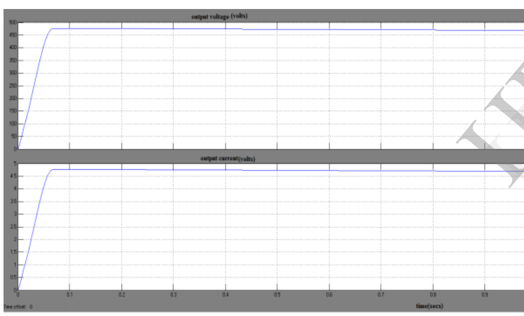


Fig 4.3. Output waveform of Vienna rectifier

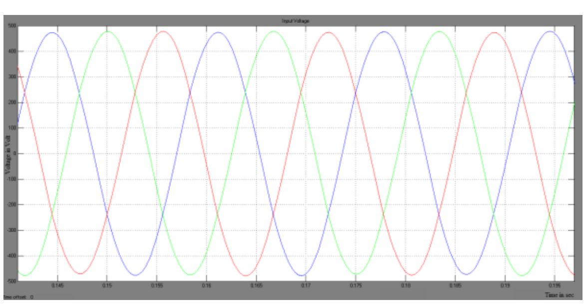


Fig 4.4 Input voltage of USMC

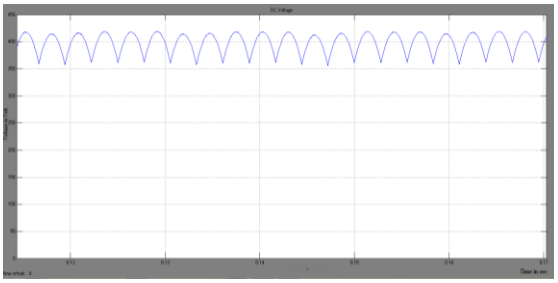


Fig 4.5 Waveform for DC link voltage

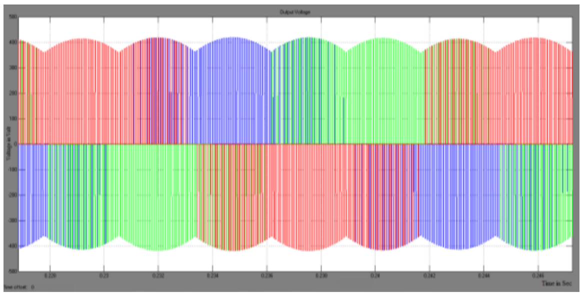


Fig 4.6 Waveform for load voltage

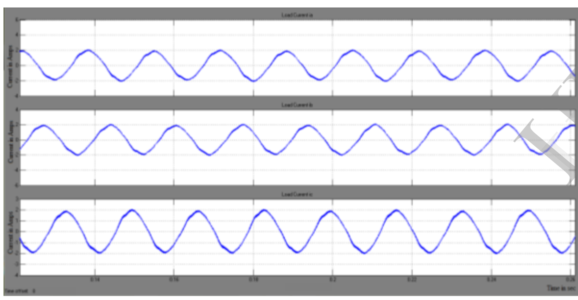


Fig 4.7 Waveform for load current

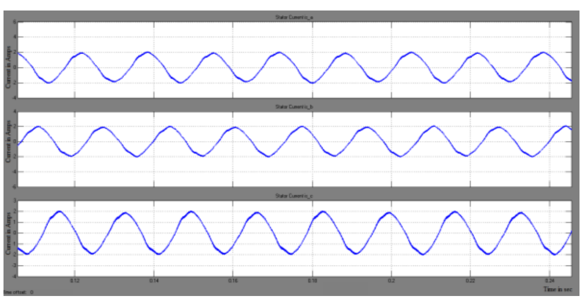


Fig 4.8 Waveform for stator current

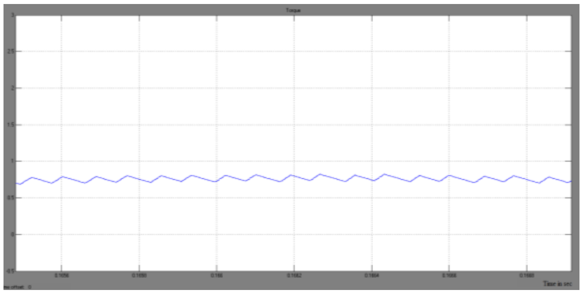


Fig 4.9 Waveform for electromagnetic torque

VI. CONCLUSION

This paper has comprehensively addressed the mimization of circulating current and switching losses. In this method the unstable AC voltage is converted to a stable AC voltage with power factor correction. Experimental verification of the power converters confirms the good performance and promising features of the proposed directly driven permanent magnet wind power generation system.

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