Cascaded Hybrid Device Multilevel Converters for Wind Mill Applications

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Abstract. In recent years Multilevel Converter (MLC) plays a vital role in wind power genration. In this paper, Shifted Carrier - Pulse Width Modulation (SC-PWM) based hybrid device multilevel converter configuration for 5 MW wind mill are proposed. A five level cascaded hybrid device MLC is developed and the simulations are performed using MATLAB/Simulink. The simulation results are offered and their performances are analyzed by implementing FPGA SPARTAN-3 processor. The proposed MLC reduces the THD and increases the output voltage.

Keywords: Wind mill · Shifted carrier-pulse width modulation · Hybrid device multilevel inverter

1 Introduction

The power generation through wind mill has been introduced in Ethiopia in the year 2010. The generated power from wind mill need to be integrated with the existing power system and it becomes a challenging one for system engineers. The integration of wind power with the existing system needs the power electronic converters, which affect the quality of power supplied to the consumer. Since the introduction of power electronic converters for integration of wind power to the existing system may generate Total Harmonic Distortion (THD), which affects the power quality. Hence system operator to be ensured for supplying the quality power to the consumer [1]. A review has been made for the application of power electronic devices for wind power generation and their integration to the existing power system for supplying quality power to the consumer [2].

The cost of power semiconductor devices used for medium voltage MLC for industrial application has been compared [3]. In order to overcome the loss occurs in semiconductor devices of inverter, a NPC inverter has been applied in multi level inverter and their operation also discussed [4, 5]. A three phase MLI with novel switching strategy has been proposed for grid integration, which reduces the switching count and improves the higher levels in output voltage [6]. SHE-PWM technique has been proposed for cascaded H-bridge inverter containing single DC source [7]. A hybrid MLC has been developed for interfacing wind energy system with the grid. The

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developed system reduces the capacitor ripple voltage which helps to choose the reduced capacitor value [8]. A different PWM technique has been applied for MLI in order to reduce THD and enhance the output voltage [9, 10]. A Fuzzy and PI technique has been applied for cascaded H-bridge MLI for reducing THD [11].

In this paper, SC-PWM based hybrid device MLC configuration for wind mill applications are proposed and designed. SC-PWM technique is applied to hybrid device MLC for analyzing performance of proposed MLC. The SC-PWM technique is able to reduce THD and improve the output voltage. The simulations results are compared with the experimental results.

2 Hybrid Multilevel Converters (MLC) for Wind Turbine

Wind power converter system plays a vital role for interfacing the wind mill generator and an electric grid as shown in Fig. 1. Hybrid MLC is the main component of wind power converter system. The MLC has to fulfill the requirement of generator and electric grid to provide the quality power to the consumer.

The MLC has to get greatest possible real power from the wind mill generator. Also it should be able to control the generator frequency and voltage magnitude. Similarly the MLC should have the ability to absorb/inject the reactive power in electric grid side. Also MLC helps to maintain voltage magnitude and frequency in the electric grid constant. In order to fulfill the need of generator and grid side wind power converter system containing a five level MLC is proposed for 5 MW wind mill.

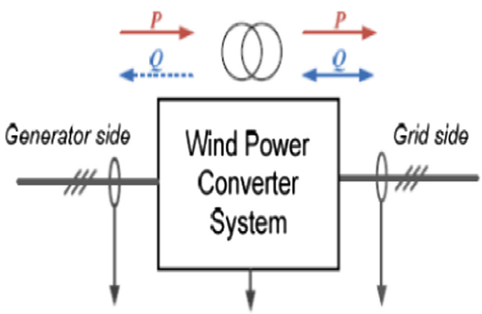

Fig. 1. Wind power converter system.

The proposed 5 MW wind mill system is shown in Fig. 2. In the proposed system 5 MW at 8.2 m/s is generated with the output voltage of 24 V and speed of 300 RPM. The battery is used to store the generated electric power and constant 400 V DC is supplied to the inverter from the step up chopper (24/400).

A three phase 180° conduction mode of five-level inverter is designed and implemented to deliver 400 V AC power to the grid. A feedback is introduced with a pulse generator between grid and inverter for controlling action.

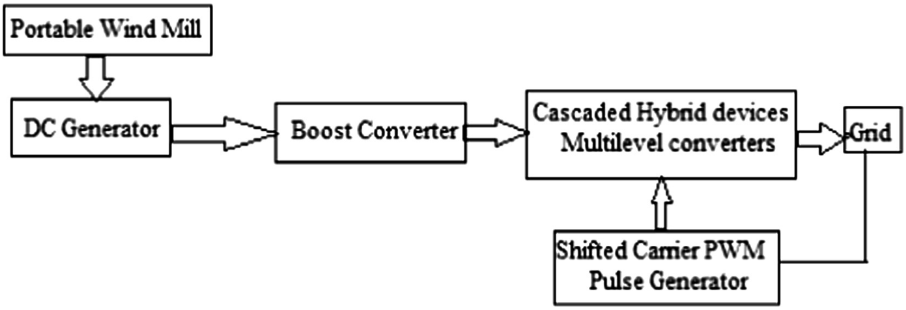

Fig. 2. Block diagram of cascaded hybrid device multilevel converters.

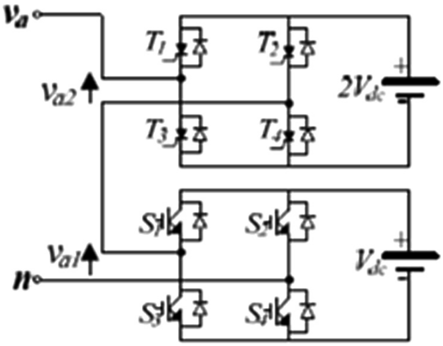

Fig. 3. Cascaded hybrid device MLC circuit diagram

The proposed cascade MLC circuit diagram is presented in Fig. 3. The proposed inverter contains one IGBT and one IGCT H-bridge inverter. The IGCT are used to operate at high voltage and current ratings. The IGBT inverter is used to operate at higher switching frequency. Since the proposed system contains one IGCT and one IGBT H-bridge inverter it is termed as hybrid inverter and can be operated at high volt-Amp rating than a conventional inverter.

3 Design Criteria

In order to conduct evaluation of each converter candidate, the parameters of generator and basic design for converters are needed.

The parameters considered for the proposed system is given in Table 1. The voltage rating for IGBT is chosen as 3.3 kV. Three 20 kV and 50 Hz AC voltage sources are considered for analysis. The resistance of the conductor is not considered and transformer is considered as ideal.

Table 1. Design parameter for 5 MW wind turbine.

WT parameter	Value
Wind power capacity	5 MW
Generator voltage	2200 V
Generator current	852 A
Multilevel inverter rating	2 MVA
Input voltage	3110 V (DC)
Input current	1204 A (DC)
Fundamental frequency	50 Hz
Switching frequency	5000 Hz
IGBT voltage rating	3.3 kV
IGBT current rating	1.5 KA

3.1 Design of Converter for Grid Side

The parameters chosen for the converter of grid side is presented in Table 2. The output voltage of DC bus and each configuration can be obtained based on commutated voltage of power electronic devices. In order to achieve the acceptable switching losses of power electronic devices, the switching frequency is chosen as 5000 Hz. The filter capacitance is not considered and the output filter inductance value is chosen to bound the ripple of current to 25% of the rated current.

Table 2. Parameters of grid side converter at different wind speeds.

Wind speed VW (m/s)	5	8	11	14
Generator power PG (MW)	2	3	4	5
Primary side voltage (Vrms)	2200 V			
Fundamental frequency (Fg)	50 Hz			
Switching frequency (Fs)	5000 Hz			

3.2 Design of Converter for Generator Side

The parameters chosen for the generator side converter is presented in Table 3. Switching frequency is chosen as 10 times of generator fundamental frequency. i.e. 800 Hz. The filters are not considered in order to avoid complexity. The wind speed is greater than 14 m/s the stator voltage control are used, if the wind speed is less than 14 m/s, the maximum torque control is used.

Table 3. Parameters of generator side converter at different wind speeds.

Wind speed VW (m/s)	5	8	11	14
Generator power PG (MW)	1.5	2.3	3.4	4.5
Primary side voltage (V_{rms})	1800 V			
Fundamental frequency (F_g)	50 Hz			
Switching frequency (F_s)	800 Hz			

4 Modulation Technique

In this work, SC-PWM technique is considered. The wave form of SC-PWM is presented in Fig. 4. The sinusoidal and bipolar pulse width modulation is considered for modulating each cell separately. The each cell of shifted carrier signal is continuously compared with the reference voltage signal. A phase shift of 180° for each full bridge inverter in a multilevel phase leg is introduced.

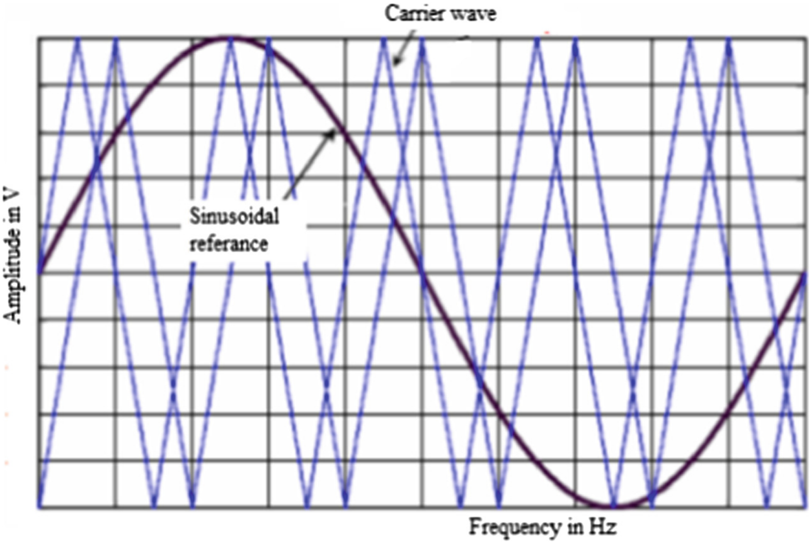

Fig. 4. SC-PWM.

The waveform of SC-PWM signal is presented in Fig. 5. The n − 1 phase shifted carrier signal is generated for a n- level inverter.

A five level inverter is designed and simulations are performed. PS-PWM technique is considered and their operating procedure is as follows.

- n = level of the inverter.
- n − 1. i.e. four carrier waveforms are arranged. The phase shift of 90° is chosen for carriers among the full bridge inverter.
- If the reference is more than all the carrier wave form than the converter switches to + $V_{dc.}$
- If the reference is lower than the upper most carrier waveform and more than all other carriers than the converter switches to $V_{dc}/2$.
- If the reference is lower than the two upper most carrier waveform and more than two lower most carriers than the converter switches to 0.
- If the reference is more than lower most carrier and lesser than all other carriers, than the converter switches to - $V_{dc}/2$.
- If the reference is lower than all carriers, than the converter switches to - $V_{dc.}$

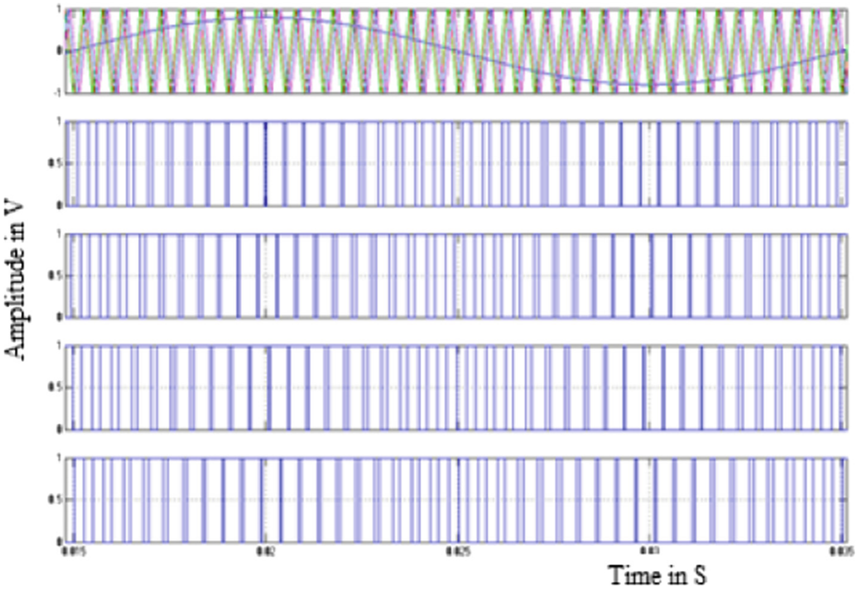

Fig. 5. SC-PWM signal generation

The carrier phase shifting is as follows,

$$Pcr = \frac{(S-1)\prod}{n} \quad (1)$$

Where, S = S^{th} bridge.
n = Number inverter.

$$\mathrm{n} = (\mathrm{P}-1)/2 \quad (2)$$

Where, P = Number of switched DC levels, which can be attained in each phase Leg.

The output voltage of power cell ‘i’ is given by

$$V_{oi} = 1/T_{cr}.\int V_{oi}(t)\,dt \quad (3)$$

$$V_{oi} = T_{on}/T_{cr}.V_{dc} \quad (4)$$

$$V_{oi} = V \quad (5)$$

Where, V_{oi} = Output voltage of cell i,

The three phase sinusoidal modulating signals are generated by using phase shift oscillator. The generated signal is compared with (n−1) phase shifted carrier waves and PWM pulses are generated. These PWM pulses are applied to 3 phase 5 level inverter.

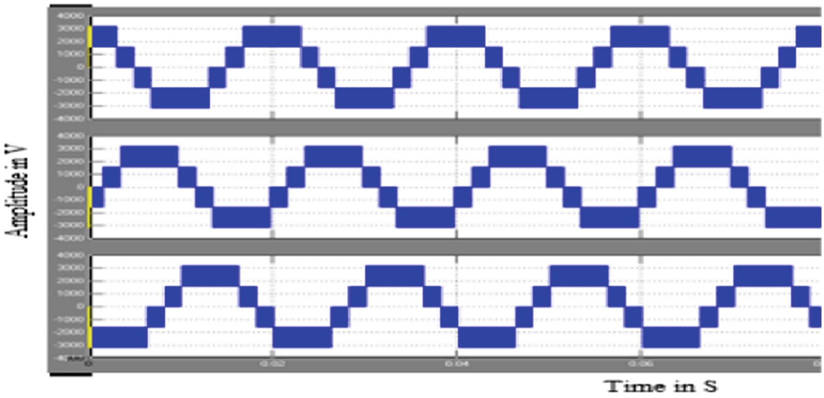

Fig. 6. Simulation results of five level output voltage

The simulation and experimental results of five level output voltage is presented in Figs. 6 and 7 respectively. The output voltage is 3212 V. But input voltage is only 3110 V. Here output voltage is enhanced for nearly 5%. So, PS-PWM is used to enhance output voltage. This technique used to wind power converter systems. The hardware output voltage shown in Fig. 7. The hardware and simulation output voltage more or less same output level. The SC-PWM frequency spectrum is presented in Fig. 8.

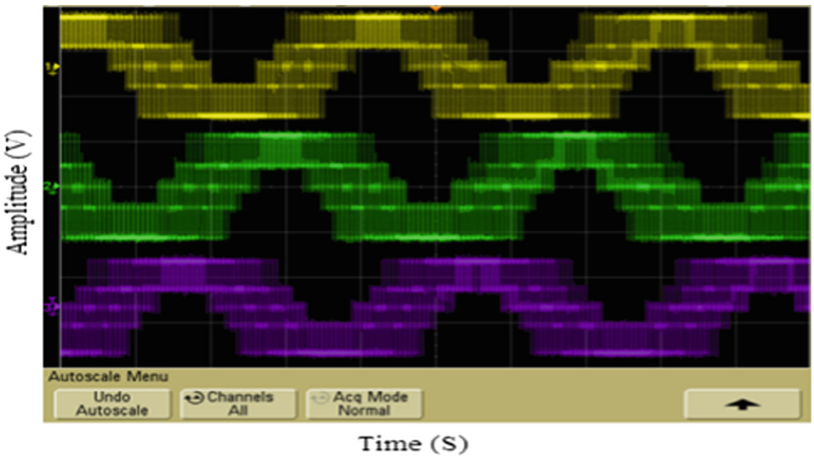

Fig. 7. Experimental output voltage of five level inverter.

Switching frequency of 5 kHz and fundamental frequency 50 Hz is considered in switching spectrum. The output voltage obtained by SC-PWM is about 3212 V for input voltage of 1550 V from each source. As switching frequency is 5 kHz and fundamental frequency is 50 Hz, so harmonic order is about 100 which is shown in Fig. 9. The THD value is about 3.84%.

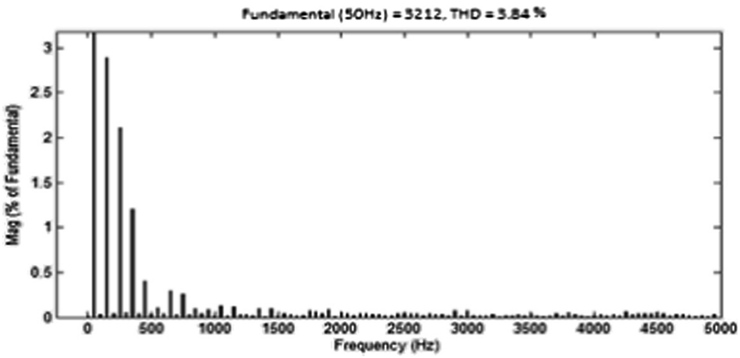

Fig. 8. SC-PWM based five level converter frequency spectrum.

It is observed that the SC-PWM gives better result compared to the other methods. Here, the SC-PWM technique lowers the THD and improves the output voltage. The output voltage V_{ac} is maintained at 3212 V. The THD value is 3.84%.

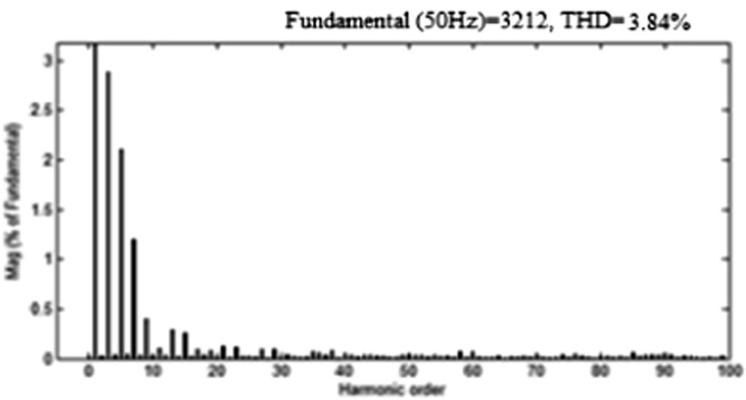

Fig. 9. SC-PWM based five level converter harmonic spectrum.

5 Conclusion

A five level inverter is designed for 5 MW wind mill. The shifted carrier PWM technique is considered and it gives superior performance in terms of enhanced output voltage and reduced THD when compared to other techniques. The results are analyzed by simulation using MATLAB/Simulink and validated by implementing FPGA, SPARTAN-3 processor. The results are obtained from experimental work which is almost similar to the simulation work.

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