Circuit Analysis of Multilevel Inverter in the Conversion System of Wind Energy

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Abstract:- This paper provides the circuit analysis of single-phase 9-level multilevel inverter. It is used in wind energy conversion system at the grid side. The 9-level multilevel inverter provides a good steady state voltage regulation and low total harmonic distortion. The multilevel inverter is integrated with a low voltage wind energy conversion system. The simulation results of multilevel inverter for different modulation index are provided in this work.

Keywords:- *Multilevel Inverter, Wind Energy Conversion System.*

I. INTRODUCTION

The microgrid is one of the most widely used techniques that can handle climate change effectively. In the microgrid, the renewable energy sources (RES) is installed near to the local community and the energy needs of the local community is met through the microgrid. The microgrid operates either in islanded mode or in grid connected mode. There are different types of RES and among them wind energy is one of the promising RES. To convert the wind energy to electrical energy through electrical generators, the wind energy conversion system (WECS) uses wind turbine (WT). Among different electrical generators, permanent magnet synchronous generator (PMSG) is widely used because of different attractive features. The WECS comprises of power electronic interface (PEI) to convert the voltage generated by WT to utility voltage. The PEI comprises of two types of converters i.e. Grid Side Converter (GSC) and Machine Side Converter (MSC). The MSC or AC to DC converter provides a stable DC voltage where as the GSC provides utility AC to the grid. The GSC comprises of DC-AC VSI but the VSI has different limitations such as higher THD, higher TDD and lower switch utilization ratio [1,2]. Fig. 1 shows the power circuit for MLI based WECS.

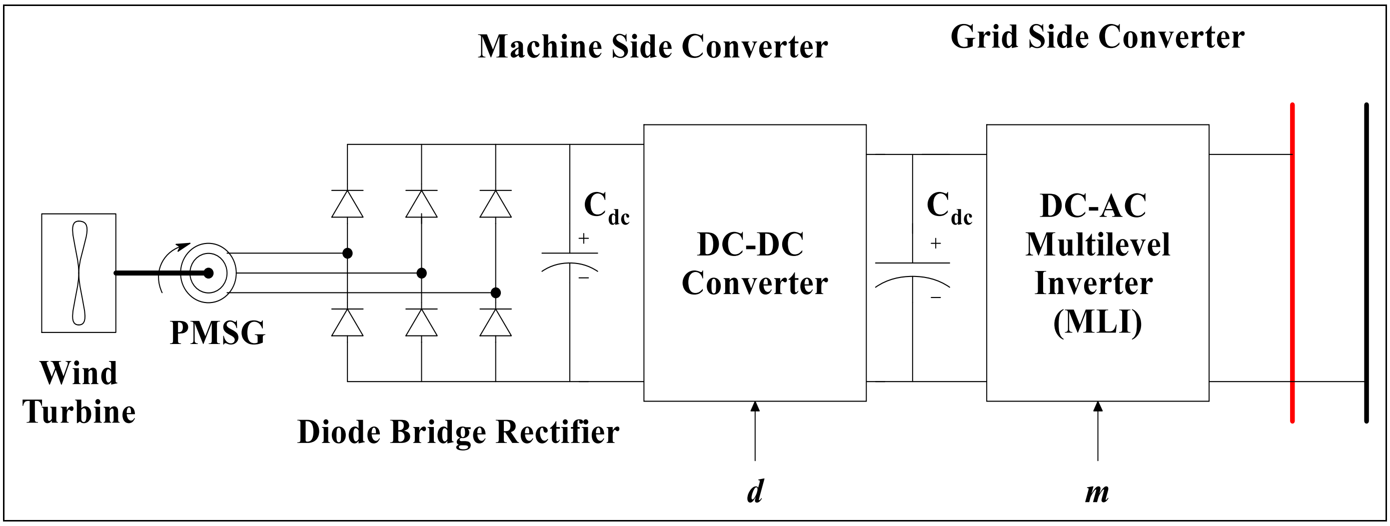

Fig. 1: Power Circuit of PMSG based WECS Comprising of MSC and GSC

In power electronics literature, there are many work that has studied the concept of MLI based WECS. A robust control approach for integration of DC grid has been presented in [3], which is based on WECS. In this work the authors employed 17-level hybrid cascade MLI. A model predictive control scheme have been proposed in [4] that is for MLI used in WECS. In [5], a 5-level MLI is proposed for parallel operated PMSG based standalone WECS. The two back-to-back converter comprising of diode clamped multilevel inverter (DCMLI) is used for WECS in [6]. The DCMLI is used as MSC and GSC and relevant control schemes are used to control the WECS.

This paper provides the circuit analysis of single-phase 9-level MLI used in GSC of the WECS. The detailed circuit analysis and modulation scheme of the 9-level MLI has been discussed along with simulation results.

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II. MULTI-LEVEL INVERTER AS GRID SIDE CONVERTER

The proposed single-phase nine-level inverter working as GSC used in WECS is shown in Fig. 2. The proposed MLI uses different switching devices, clamping diodes, and dc-link capacitors with a single independent dc source. All the switching devices are bidirectional conducting with unidirectional voltage sustaining ability. This topology requires a switch of bi-directional voltage blocking property. It is achieved by using two unidirectional voltage blocking switches connected in anti-series. Fig.2 shows the anti-series connection of switches S8 and S9.

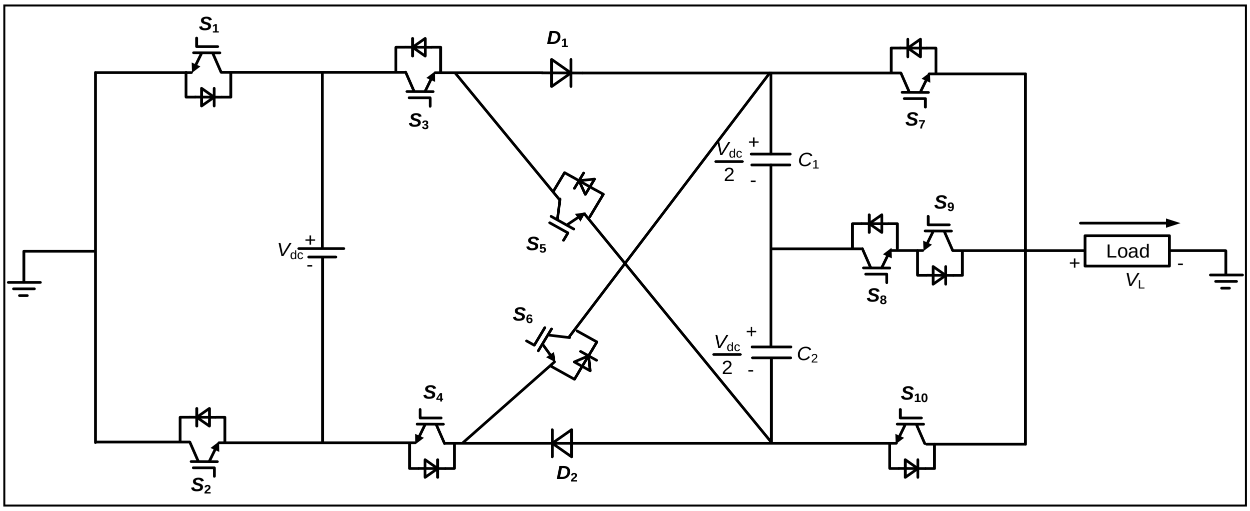
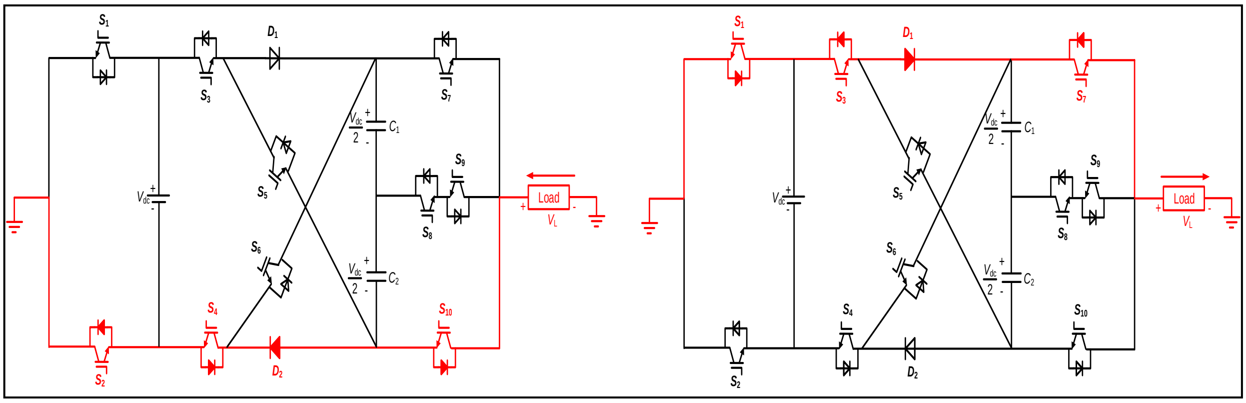
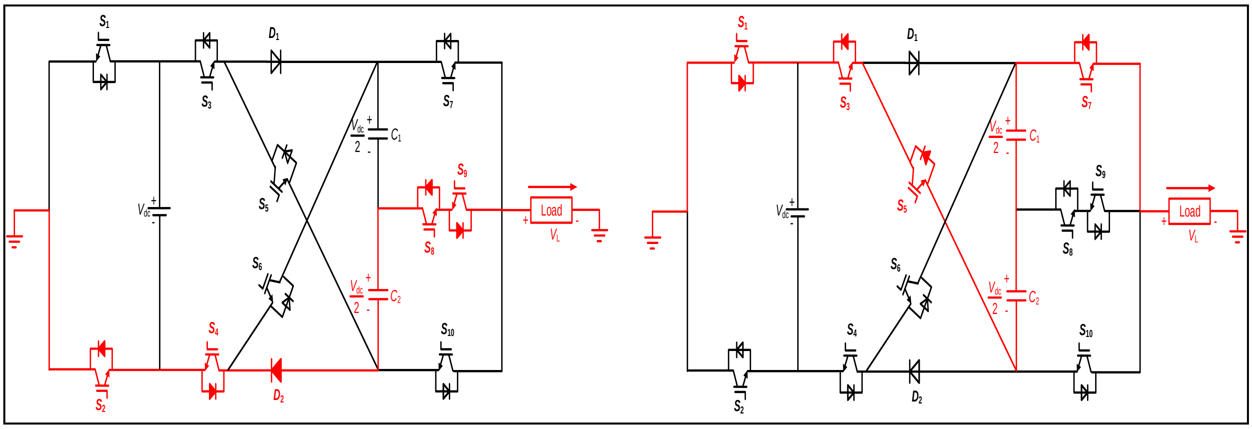


Fig. 2. Circuit Diagram of the 5-level MLI.



(a) (b)

Fig. 3. Zero Switching States: (a) V_L = 0+ (b) V_L = 0-.



(a) (b)

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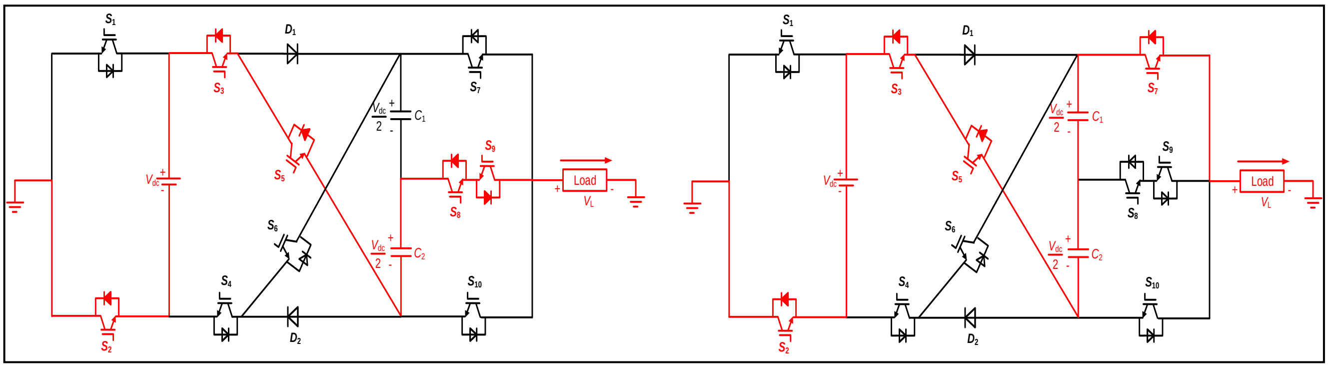
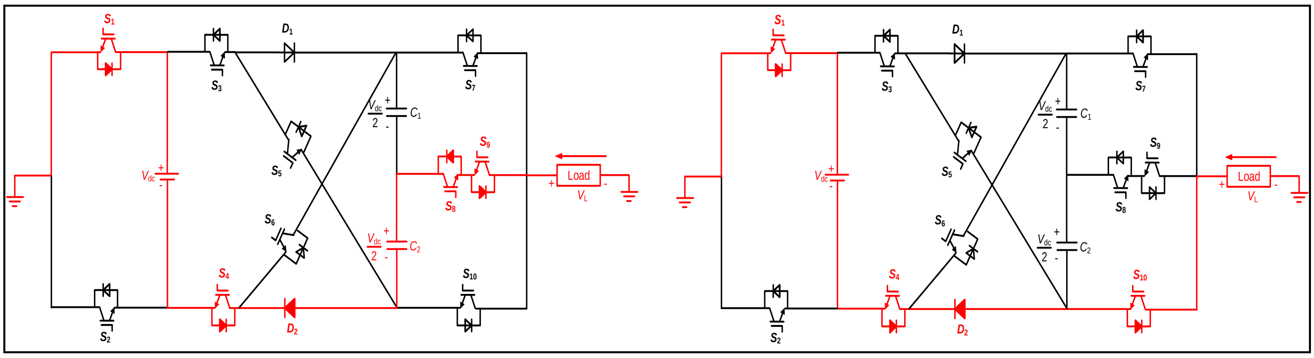
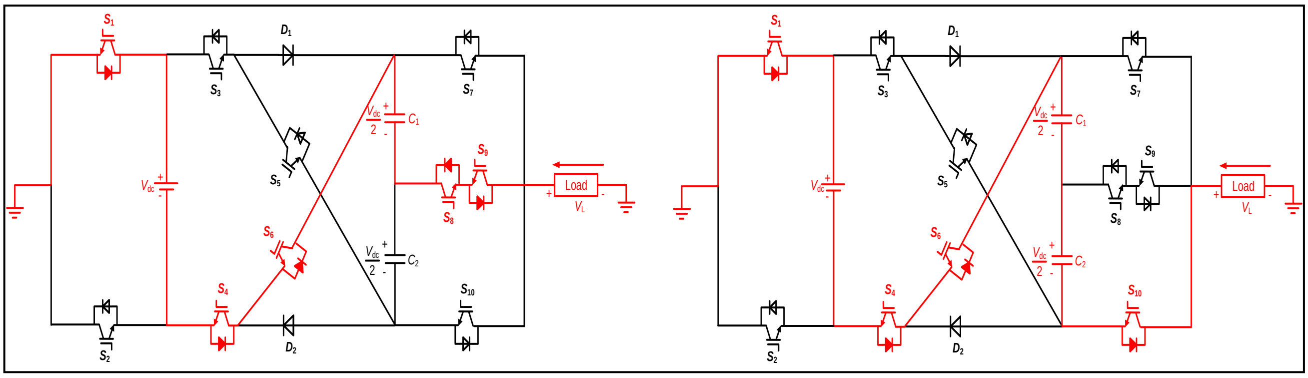


(c) (d)

Fig. 4. Positive Switching States: (a) V_L = Vdc/2, (b) V_L = Vdc, (c) V_L = 3Vdc/2, and (d) V_L = 2Vdc.



(a) (b)



(c) (d)

Fig. 5. Negative Switching States: (a) $V_L = -V_{dc}/2$, (b) $V_L = -V_{dc}$, (c) $V_L = -3V_{dc}/2$, and (d) $V_L = -2V_{dc}$.

Table 1: Switching States of the Inverter

Output Voltage (V_O)	***Conducting Devices***
$2V_{dc}$	S_2, S_3, S_5 and S_7
$3V_{dc}/2$	S_2, S_3, S_4, S_8 and S_9
V_{dc}	S_1, S_3, S_5 and S_7
$V_{dc}/2$	S_2, S_4, D_2, S_8 and S_9
0^+	S_2, S_4, D_2 and S_{10}
0^-	S_1, S_3, D_1 and S_7
$-V_{dc}/2$	S_1, S_4, D_2, S_8 and S_9
$-V_{dc}$	S_1, S_4, D_2 and S_{10}
$-3V_{dc}/2$	S_1, S_4, S_6, S_8 and S_9
$-2V_{dc}$	S_1, S_4, S_6 and S_{10}

The proposed converter has various switching states which has been listed in Table 1 operating in 9-level mode. The numbers 0 and 1 is the representation of switch-off and switch-on respectively. The switches S_1 and S_2 are operated at lower switching frequencies. This results in lower switching losses of the inverter.

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From the above discussion, it can be concluded that the switches S_5 and S_6 conduct during positive and negative level operating modes respectively. These switches operate at the fundamental switching frequency and hence, the losses in these switches are minimum.

The modulation method to generate the gate pulses are represented in Fig. 6 which is provided to the switches. A modulating sinusoidal signal is cross-compared with eight level-shifted triangular waves. This results in the nine-level PWM as output voltage. The Modulation Index (MI) is defined as follows,

$$M.I.= V_{OPeak}/3*V_{dc} \quad (1)$$

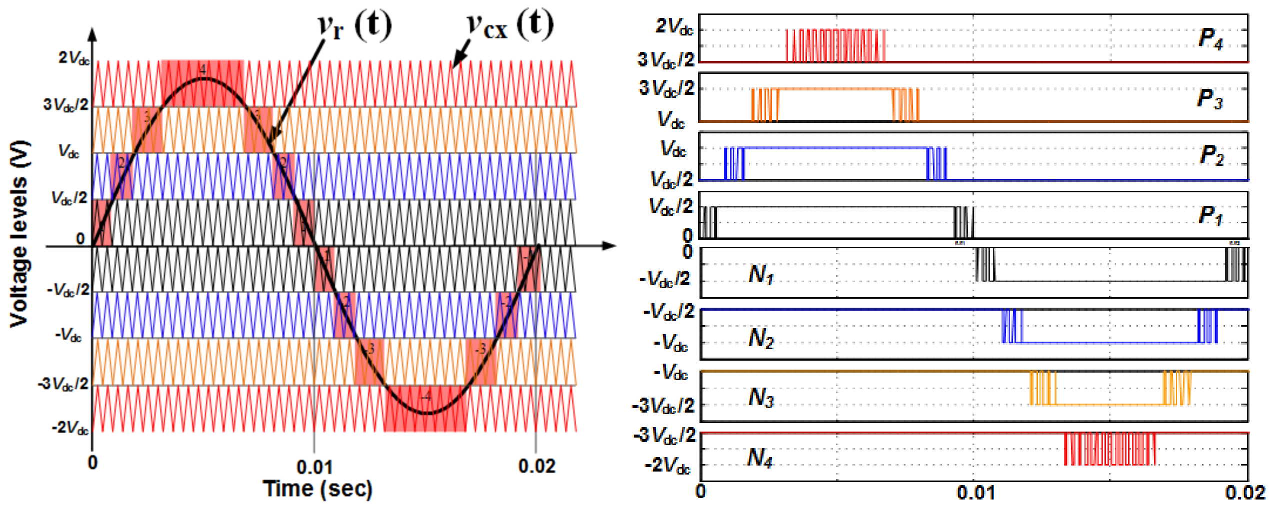


Fig. 6. Sine-Triangle Comparison PWM Scheme.

III. SIMULATION RESULTS

For the simulation purpose, a low voltgae WECS is considered. The simulation is done for 9-level MLI working as GSC. Table 2 shows the paramaters of MLI in WECS.

Table 2: Simulation parameters of MLI in WECS

Parameters	Values	
	M.I.= 0.9	M.I.= 0.7
V_{dc}	200 V	200 V
P_{output}	1070 W	650 W
$V_{01(peak)}$	260 V	203 V
$I_{01(peak)}$	4.5 A	3.5 A
Fundamental frequency (f_m)	50 Hz	50 Hz
Switching frequency (f_{sw})	4 KHz	4 KHz

The MLI volatge output for different M.I. is shown in Fig. 6(a) and Fig. 7(a) respectively. Fig. 6(b) and 7(b) illustrate the waveforms of the capacitor voltages (V_{C1} and V_{C2}). The capacitor voltages are balanced naturally, due to the equal utilization during positive and negative half-cycles. It can be understood that the voltage variation is less in the capacitor voltages are of approximately 5% each.

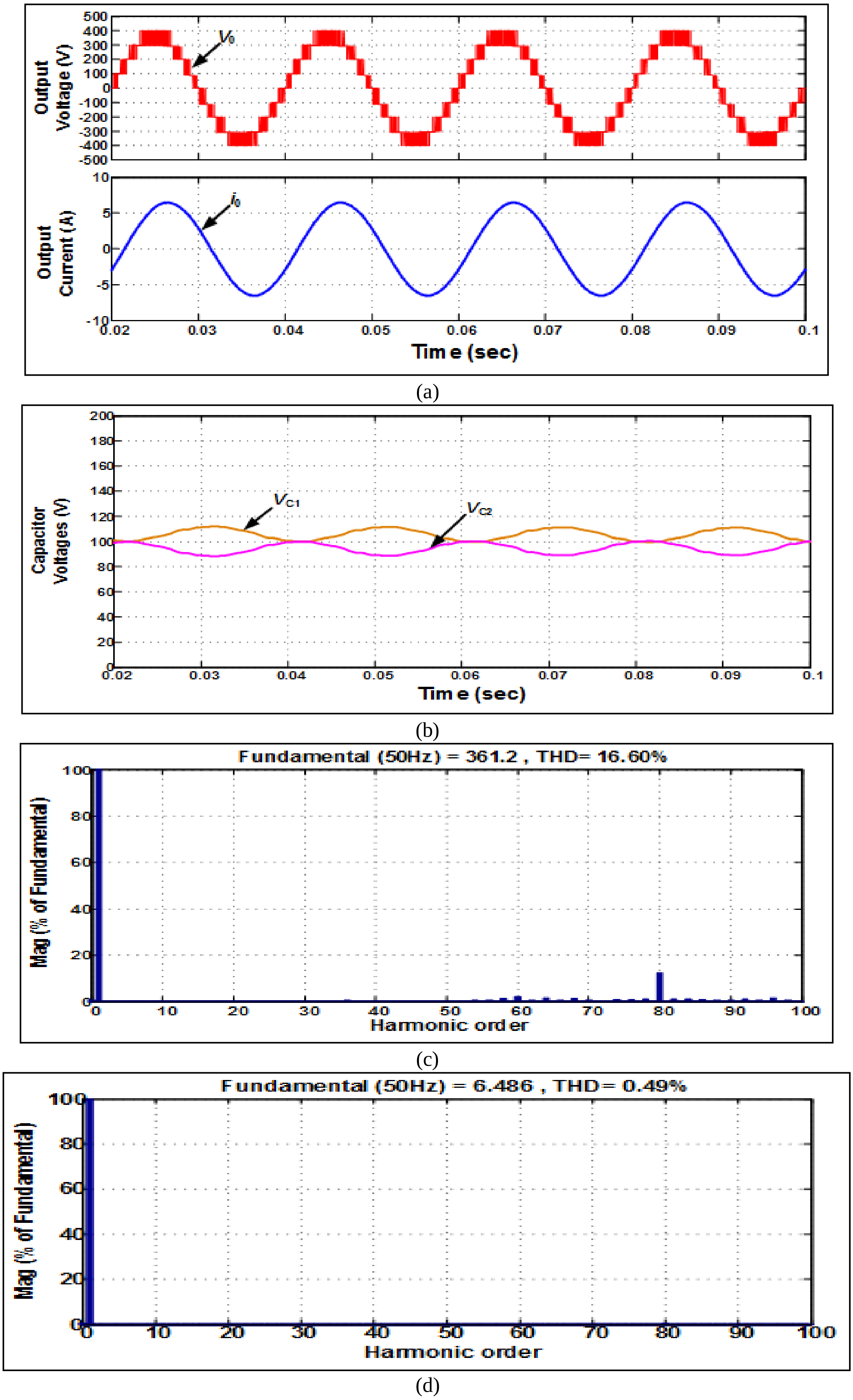
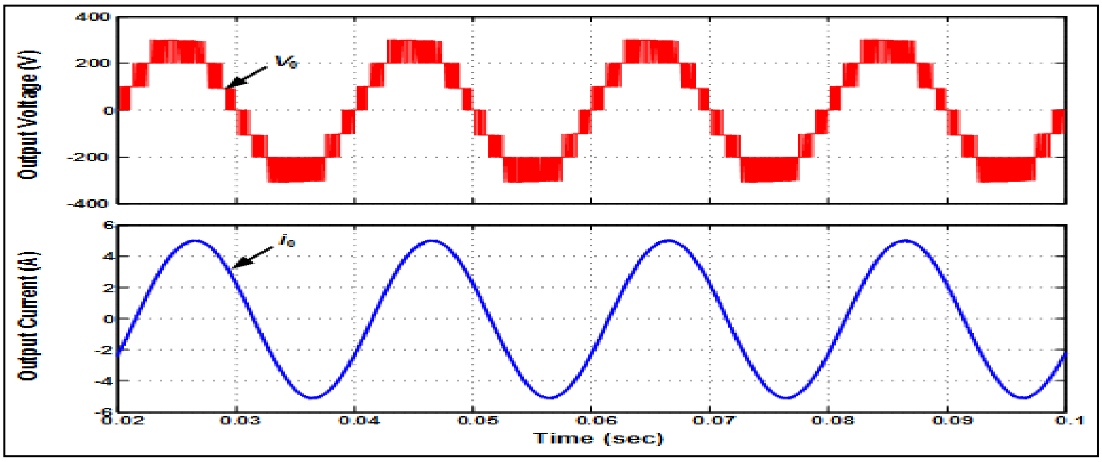
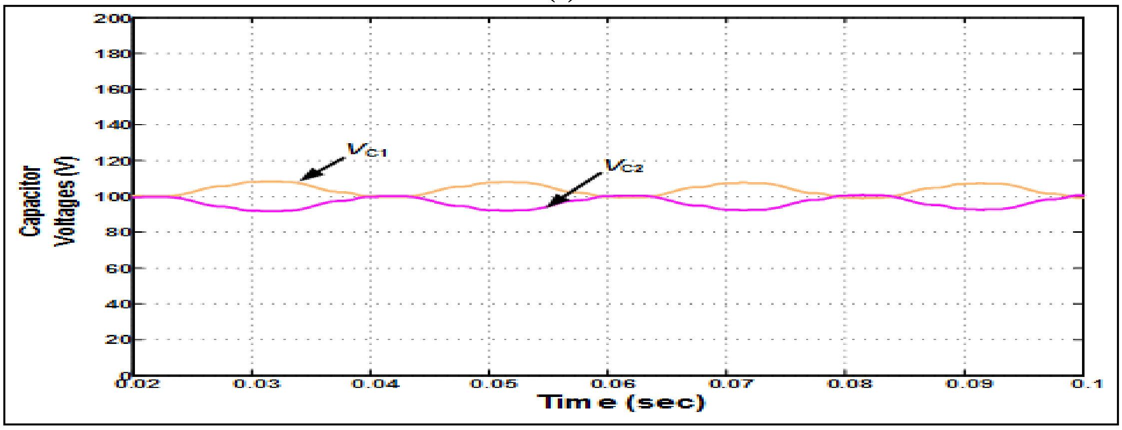


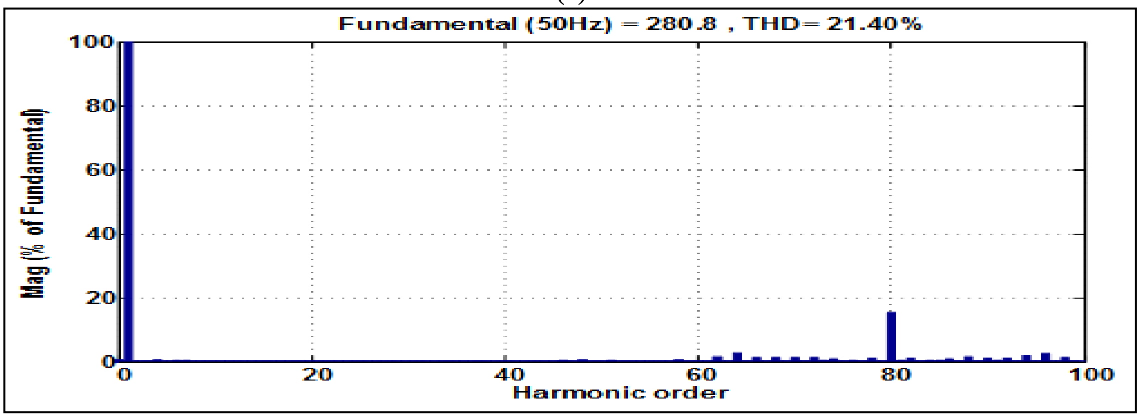
Fig. 6. Simulation Results at MI=0.9 (a) Voltage and Current Waveforms (b) Capacitor Voltages (c) Voltage THD (d) Current THD



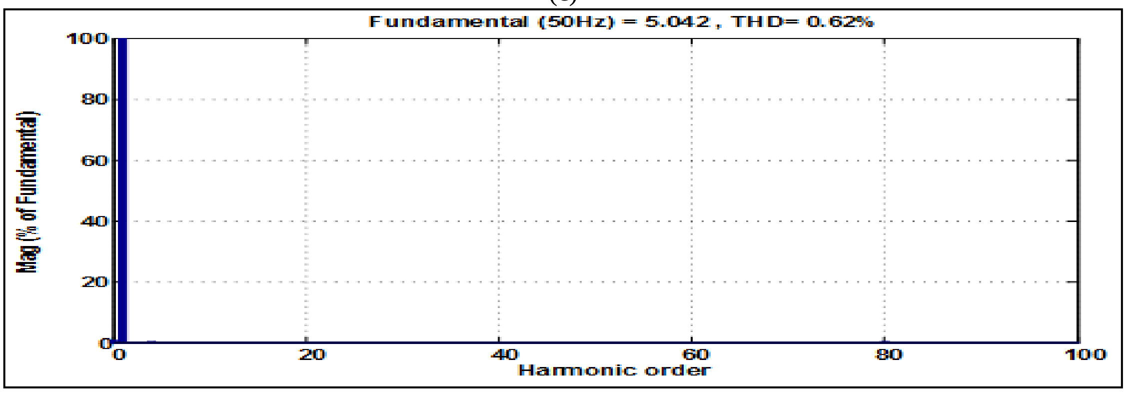
(a)



(b)



(c)



(d)

Fig. 7. Simulation Results at MI= 0.7 (a) Voltage and Current Waveforms (b) Capacitor Voltages (c) Voltage THD (d) Current THD.

IV. CONCLUSION

This paper provides the circuit analysis of 9-level MLI used as GSC in WECS. The circuit analysis and modulation techniques analysis of MLI is shown in this work. The 9-level MLI provides a waveform that resembles sinusoidal function and has very low THD in accordance with IEEE-1547-519. The MLI is used alongside a low voltage WECS.

REFERENCES

[1]. S. Kouro, M. Malinowski, K. Gopakumar, J. Pou, L. G. Franquelo, B. Wu, J. Rodriguez, M. A. Perez, J. I. Leon, “Recent Advances and Industrial Applications of Multilevel Converters,” IEEE Trans. Ind. Electron, vol. 57, pp. 2553–2580, 2010.

[2]. J. Rodriguez, J. Lai, F. Z. Peng, “Multilevel Inverters: A Survey of Topologies, Controls, and Applications,” IEEE Trans. Ind. Electron, vol. 49, pp. 724-738, 2002.

[3]. B. Sahoo, S.K. Routray, P.K. Rout, “Robust control approach for the integration of DC-grid based wind energy conversion system,” IET Energy Systems Integration, 2020.

[4]. M. Annoukoubi, A. Essadki, Y. Akarne, “Model predictive control of multilevel inverter used in a wind energy conversion system application,” e-prime-Advances in Electrical Engineering, Electronics and Energy, vol. 9, Sep. 2024.

[5]. A Palani, V Mahendran, K Vengadakrishnan, S Muthusamy, O P Mishra, P Ramamoorthi, M R Maurya, K K Sadasivuni, “A novel design and development of multilevel inverters for parallel operated PMSG based standalone wind energy conversion system,” Iranian Journal of Science and Technology. Transactions on Electrical Engineering, 48, 2024, pp. 277-287.

[6]. S. A Verne, M I Valla, “Direct connection of WECS system to the MV grid with multilevel converter,” Renewable Energy, vol. 41, 2012, pp. 336-344.

[7]. M. Diaz, R. Cardenas, M. Espinoza, F. Rojas, A. Mora, J.C. Clare, P. Wheeler, “Control of wind energy conversion systems based on the modular multilevel matrix converter,” IEEE Transactions on Industrial Electronics, vol. 64, no. 11, 2017, pp. 8799-8810.

[8]. M P Selvam, S K Palraj, G S Madasamy, “Adaptive control of a single source reduced switch MLI-based DSTATCOM for wind energy conversion system,” Electrical Engineering, 2024.