

Performance Investigation of Stand-alone Photovoltaic System with Three Phase Developed H-Bridge Multilevel Inverter

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Abstract: In this paper a three-phase developed H-bridge multilevel inverter (MLI) based stand-alone solar photovoltaic system is presented. The proposed topology can generate 7-levels of phase voltages and 13-levels of line voltages. The proposed MLI consists of six switches, two asymmetric dc sources to generate seven positive voltage states in each phase, as a result, a higher number of voltage levels are obtained with a minimum number of switches. This in turn, make the proposed topology less complex in-terms of architecture and control. Furthermore, Phase disposition pulse width modulation (PD-PWM) technique is opted as a control scheme for controlling MLI switching. After this, Solar photovoltaic system with three-phase developed H-bridge MLI is modelled and simulated on the MATLAB platform. When this thirteen-level MLI is connected with PV panels, will reduce the harmonics with smaller number of components. The obtained total harmonic distortion is less. Finally, the performance of the proposed MLI is validated by simulation.

Index Terms—Photovoltaic cell, Phase disposition (PD-PWM), Multilevel inverter (MLI), Total Harmonic Distortion (THD).

I. INTRODUCTION

NOW a days, demand of electricity all over the world is rapidly increasing which results in the depletion of conventional energy resources such as oil, natural, coal, gas, etc. Using sustainable and dependable energy sources, such as non-conventional or renewable energy resources, will help the globe fulfill its future electricity needs. So, researchers are primarily concentrating their attention on the power generation method based on unconventional energy sources.[1] In this regard, one of the most gifted renewable energy sources is PV. PV is frequently chosen to address future energy needs because it is pollution and noise-free.[2] 2020 will see 142 GW added to the world's yearly solar installations, an increase of 14% over 2019. However, some of the dc loads are powered by photovoltaic (PV) system's directly generated dc power, but the majority of the remaining loads need ac power. This conversion is carried out using an inverter. [3] Traditionally, the two-level inverter may provide an AC output that has the same peak value throughout both positive and negative cycles. A substantial amount of EMI, voltage stress on power components, losses, total harmonic distortion (THD), and the requirement for extensive filtering are some of the disadvantages of the two-level inverter. Due to the numerous shortcomings of two-level inverters, multilevel inverters (MLI) are becoming more and more common in high voltage and high efficiency applications.

These benefits include improved electromagnetic interference (EMI), reduced total harmonic distortion (THD), reduced dv/dt stress on switches, and multistep voltage waveforms. Neutral

point clamp (NPC) MLI, Cascaded H-bridge (CHB) inverter, and Flying Capacitor FC-MLI are the three basic MLI topologies. In NPC and FC-MLI, the quantity of diodes, capacitors, and switches grows as the voltage level rises. Moreover, voltage balancing issues cause both NPC and FC-MLI to produce more steps. [4] H-bridge topologies are becoming more popular among the many multilevel topologies due to their increased dependability and modular design [5]. In this paper, A three-phase H bridge MLI is proposed which mitigates all the demerits associated with conventional and two level MLI topologies. To control the proposed MLI, level shifted PWM technique is used.

II. METHODOLOGY

The entire proposed research work is modelled on MATLAB/ Simulink software. The methodology of proposed three-phase developed H-bridge MLI with standalone PV system is shown in Figure-1 step by step with the help of flow chart.

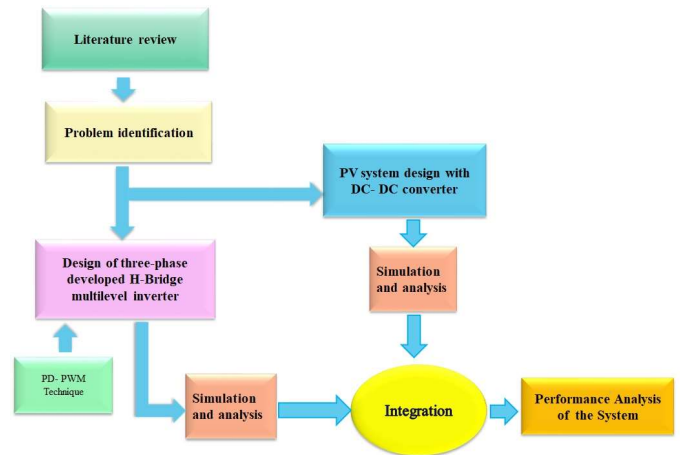


Figure 1: Methodology of proposed research work

III. PROPOSED SYSTEM

Figure-2 shows the block diagram of proposed three-phase MLI with stand-alone solar energy system. The PV panel is connected with proposed MLI through Boost converter by using suitable MPPT technique. After this, Multicarrier PWM

technique is also used to reduce the harmonics of MLI. This as a result makes the proposed MLI suitable for PV system. Finally, the three-phase load is connected with proposed MLI.

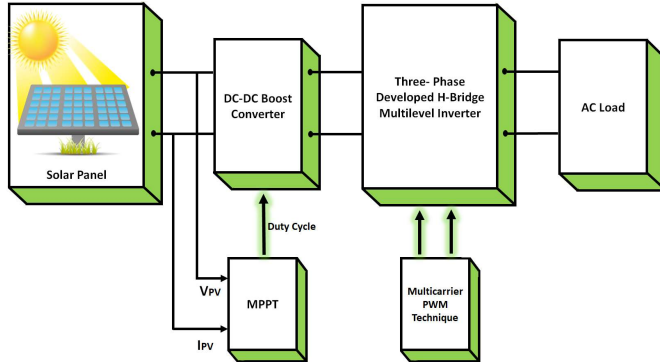


Figure 2: shows the block diagram of proposed three-phase MLI with standalone solar energy system.

A. PV panels:

PV system is selected for the application. The various ratings of PV Panels used in this research work are tabulated in Table 1. The inputs of the solar PV module are temperature and irradiation. Four PV panels have been used, each of rating is 50W.

Figure-3 shows an equivalent circuit of solar cell circuit. The simplified circuit consists of series and parallel resistors, a single current source and a P-N junction diode. The diode is used to produce a stream of charges by absorbing solar irradiance. The equations of output current, PV current and thermal voltage are given as follows:

The output current of PV is given in equation 1.

$$I = I_{PV} - I_0 \left[\exp\left(\frac{V+IR_s}{V_t\alpha}\right) - 1 \right] \left(\frac{V+R_s I}{R_s}\right) \quad (1)$$

where V_t is the thermal voltage, I_0 is the reverse saturated current, R_s is the series resistance, V is the output voltage of PV, α is the ideality factor, I is the output current, and I_{PV} is the PV current. The PV current can be found by using Equation 2.

$$I_{pv} = (I_{sc} + k_i(T - T_n)) \times \frac{G}{G_n} \quad (2)$$

Here, k_i is the temperature coefficient of current, G is the irradiance, T_n is the standard temperature, G_n is standard irradiance, I_{sc} is the short circuit current, and temperature of the module is represented by T in degree Kelvin. The reverse saturated current can be found by using equation 3.

$$I_0 = I_{ph} / \left[\exp\left(\frac{V_{ocn} + k_v(T - T_n)}{\alpha V_t}\right) - 1 \right] \quad (3)$$

Here, I_{ph} is the photon current, V_{ocn} is the open circuit voltage, k_v is temperature coefficient voltage, and α is ideality factor of the diode.

Accordingly, Equation (1) is rewritten as Equation (4):

$$I = N_p I_{ph} - N_p I_D \left(\exp\left(\frac{q(V + R_s I)}{N_s \alpha V_t k T}\right) - 1 \right) - N_p \frac{V + R_s I}{N_s R_{sh}} \quad (4)$$

Where, N_p are Parallel PV cells, I_D is diode current, N_s are Series PV cells and R_{sh} is shunt resistance.

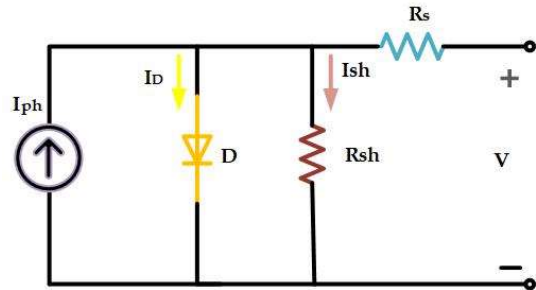


Figure 3: Equivalent circuit of PV

B. DC-DC Boost Converter:

In this study, boost DC-DC converters are utilized to control PV panel output and generate the required DC voltages for the proposed MLI's inputs. In this research work, Perturb and Observe (P&O) MPPT technique is chosen. The load at the output of converter is resistor. P&O MPPT technique uses small step size to obtain the maximum power point. This technique is very simple and easy to implement. Figure-4 shows boost converter with PV system.

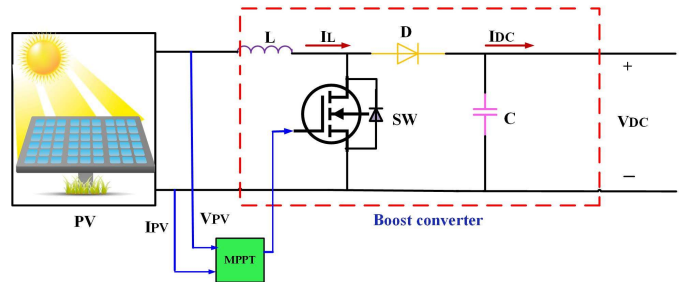


Figure 4: shows the Boost converter with PV system.

Output voltage, duty ratio, inductance and capacitance of the boost converter are given as follows:

$$V_{out} = \frac{V_{in}}{1-D} \quad (5)$$

Where, V_{out} is the output voltage and V_{in} is the input voltage and D is the duty ratio.

$$Duty\ ratio = \frac{T_{on}}{T_s} \quad (6)$$

In (6), T_{on} is the turn on time and T_s is the switching time of semiconductor Switch.

$$L = \frac{V_{in} \times D}{f_s \times \Delta I_L} \quad (7)$$

Where, L is the inductance, f_s is the switching frequency and ΔI_L is the change in the current i-e (20 to 40% of I_L).

$$C = \frac{I_o \times D}{f_s \times \Delta V_c} \quad (8)$$

C is the capacitance, I_o is the output current, and ΔV_c is change in voltage i-e (1 to 5% of V_o)

C. Inverter:

Inverter is the type of dc to ac converter. It converts dc voltage into ac voltage. The input of inverter may be from battery, PV, fuel cells etc. the output waveform of inverter is not purely sinusoidal. The general waveforms of inverter are quasi-square, triangular, square etc. Inverter are classified as voltage and current source inverters. When voltage(V) remains constant but the current changes its direction, it is called current source inverter. When voltages change its polarity but current remains constant, it is called constant voltage source inverter.

IV. PROPOSED MLI TOPOLOGY

The schematic diagram of proposed MLI topology is shown in Figure-5. In this topology of MLI eighteen switches are required to develop thirteen level MLI. The proposed topology requires four DC sources and eighteen gate driver circuits to generate 13 levels output.

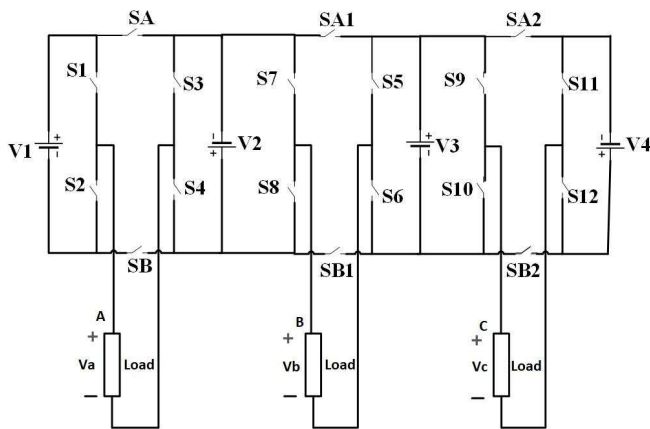


Figure 5: schematic diagram of proposed three-phase MLI

The switches used in this proposed topology are labeled with subscripts that indicate the phase to which they belong. S1, S2, S3, S4, SA and SB correspond to switches in phase A, S7, S8, S5, S6, SA1 and SB1 correspond to switches in phase B, and S9, S10, S11, S12, SA2 and SB2 correspond to switches in phase C. To achieve the desired 7 levels of output voltage in each phase, the magnitudes of the input dc voltages should vary. Specifically, V_1 should not be equal to V_2 , and V_2 should not be equal to V_3 , and so on. The asymmetric nature of the dc sources ensures the availability of higher levels of output voltage. Additionally, when considering the polarity, connections of the dc sources from both sides of the converter for each phase should be antiparallel or have a series connection. This symmetric characteristic of the input voltages

provides equal conditions for all phases of the converter.

The dc voltage equation can be expressed as follows:

$$V_2 = V_4 = V_{DC} \quad (9)$$

$$V_1 = V_3 = 2V_{DC} \quad (10)$$

Equations for the proposed MLI are given as follows:

$$N_{Level} = 13 \quad (11)$$

$$N_{Switches} = 18 \quad (12)$$

$$N_{Driver} = 18 \quad (13)$$

$$N_{DC-source} = 14 \quad (14)$$

V. RESULTS AND DISCUSSION

A. Modeling and simulation:

The overall simulation model of the proposed system is shown in Figure-6(a) in which four PV panels are used. These PV panels act as an isolated dc sources. All the ratings are mentioned in Table 1. DC-DC boost converter with Perturb & Observation (P&O) is used to implement MPPT at each solar PV panel followed by the thirteen level MMLI. In addition to this, Level Shifted PWM technique is implemented to derive each switch individually. The control scheme is shown Figure - 6(b)

Table 1: Performance Parameters

Parameters	Values
PV voltage (V_{PV}), PV current (I_{PV})	17.5.V, 2.86A
DC Voltages ($V_1 = V_2 = V_{DC}$)	20V
DC Voltages ($V_3 = V_4 = 2V_{DC}$)	40V
Peak Output Voltage (V_{max})	60V
Sinusoidal frequency	50Hz
Switching frequency (f_s)	1 kHz
Resistive load	10 Ω

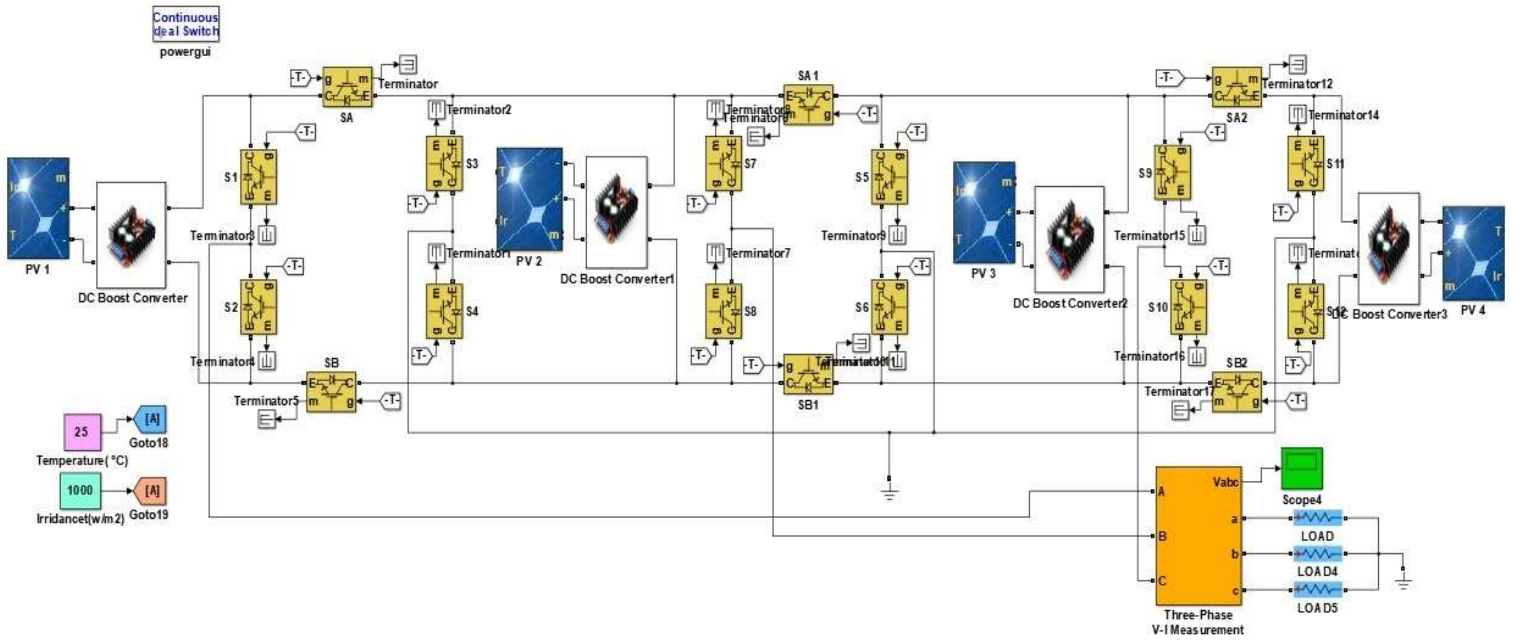


Figure 6(a): simulation model of three-phase developed H-Bridge MLI with PV system

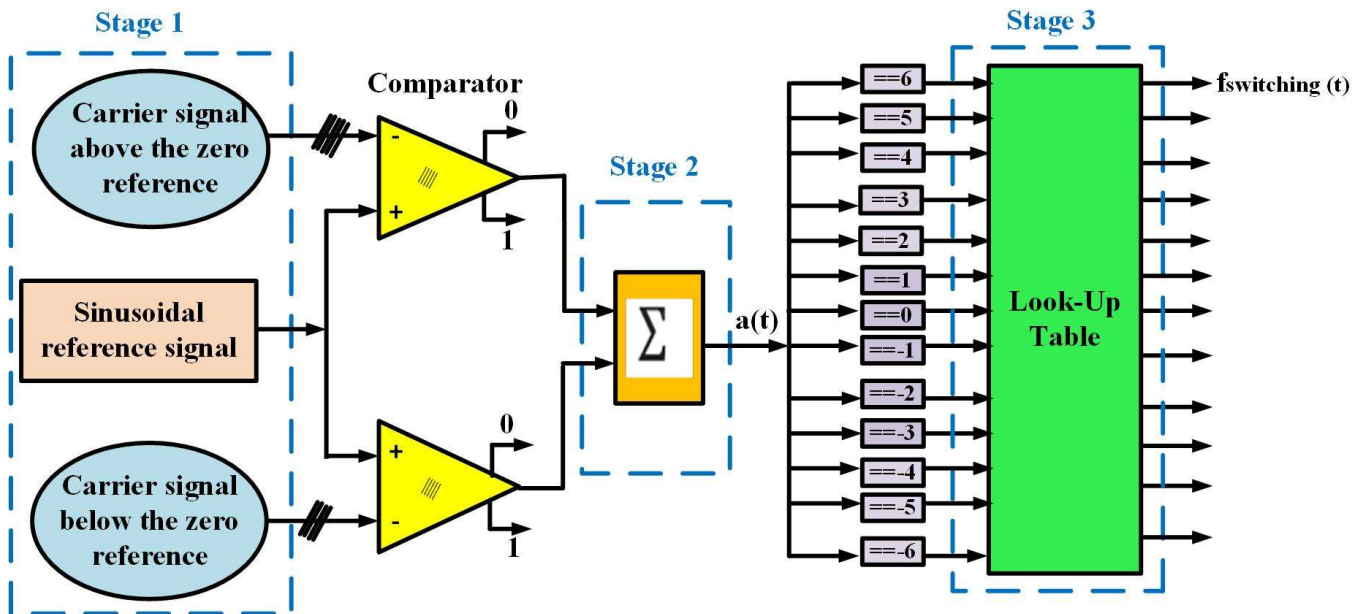


Figure 6(b): Phase disposition (PD) control scheme for proposed MLI topology

B. Simulation Results

MATLAB/SIMULINK model of proposed 13-levels. three-phase developed H-Bridge MLI with PV system is simulated. Figure-7 shows the simulation results of PV with boost converter. Figure-7(a) shows the PV irradiance, Figure-7(b) shows the PV voltage, Figure-7(c) shows the PV current and Figure-7(d) and Figure-7(e) show the boost voltages. The phase voltages are illustrated by Figure-8, with an input voltage of 20 V and 40 V. As shown in Figure-8, V_a corresponds to phase A

voltage, V_b corresponds to phase B voltage and V_c correspond to phase C voltage. The generated phase-to-phase voltage, which consists of seven levels (7 levels) and has a peak-to-peak magnitude of approximately 60 V. Figure-10 shows the THD obtained with PD-PWM technique.

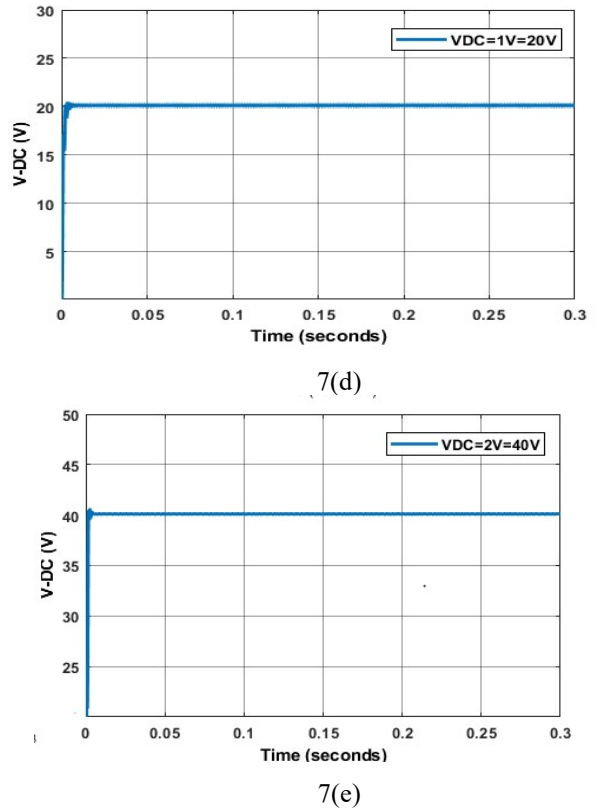
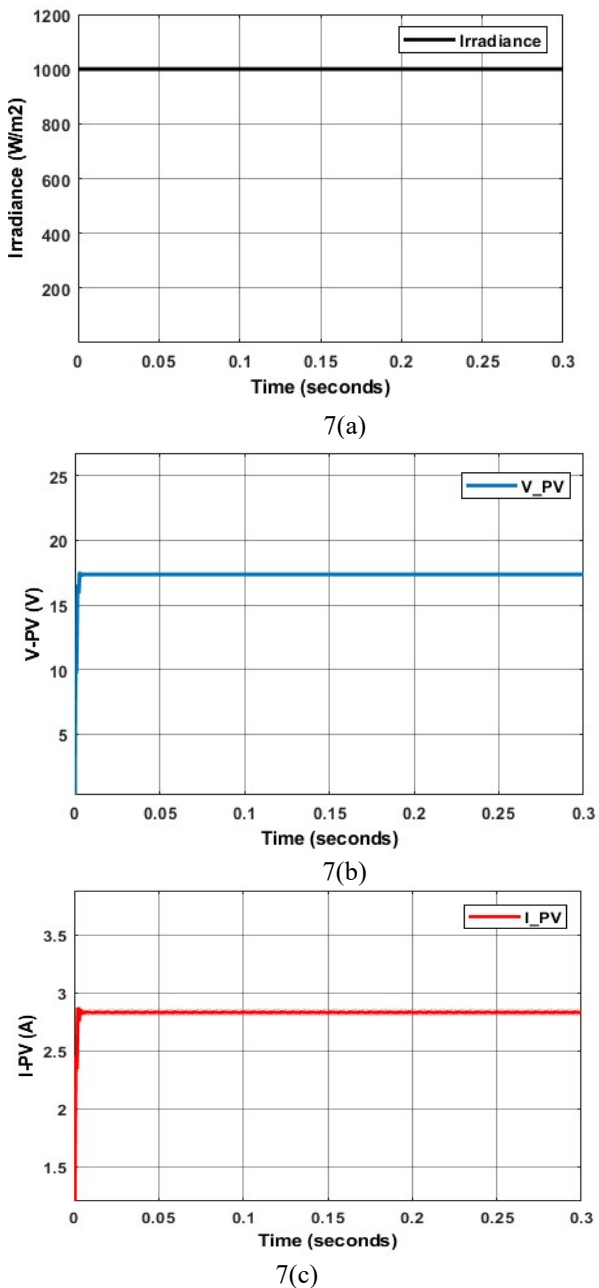


Figure 7: Simulation of start-up waveforms (a) Irradiance (b) PV voltage at constant irradiance (c) PV current at constant irradiance (d) and (e) Boost voltages at constant irradiance

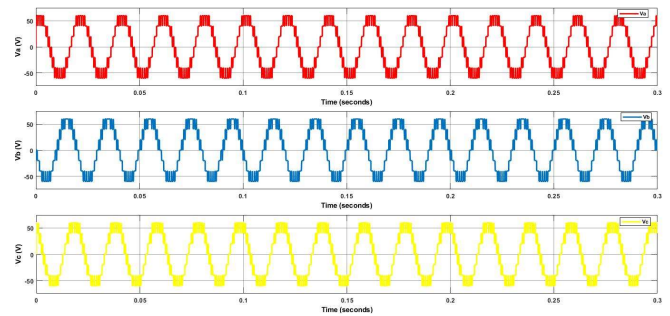


Figure 8: Output voltage waveforms of proposed MLI (a)R phase (b) Y phase and (c) B phase for R load.

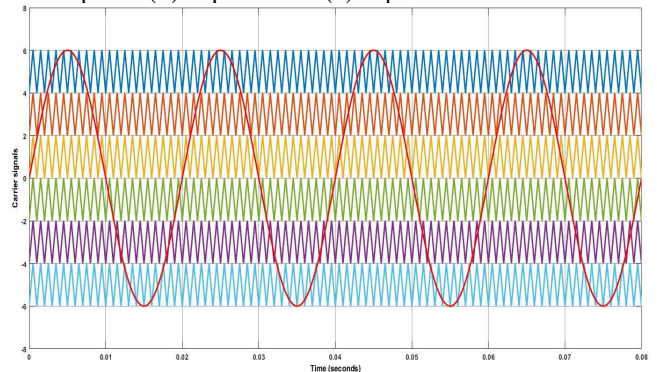


Figure 9: Carrier signals of Phase disposition (PD)

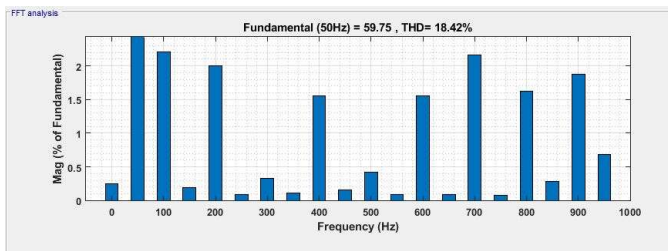


Figure 10: THD of MLI

VI. CONCLUSION

In this research work, a three-phase developed H-bridge MLI with stand-alone PV system is designed. This topology of MLI requires less number of components to generate thirteen levels of output. The proposed topology uses eighteen switches and four dc sources. PV panels are used as an isolated dc sources. The proposed topology is simulated in MATLAB/Simulink environment. Furthermore, the Phase Disposition (PD-PWM) control scheme with six carrier signals and one modulated signal is used as a control scheme to reduce the THD in the output voltage. The THD of the output voltage of the proposed MLI is 18.42%.

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REFERENCES

- [1] Kim, Y. K., Lee, G. S., Yoon, J. S., & Moon, S. I. (2022). Evaluation for maximum allowable capacity of energy source considering ac system strength measures. *IEEE Transactions on Sustainable Energy*, 13(2), 1123-1134.
- [2] Tummuru, N. R. (2021). A Grid-connected Converter Configuration for the Synergy of Battery-supercapacitor Hybrid Storage and Renewable Energy Resources. *IEEE Journal of Emerging and Selected Topics in Industrial Electronics*.
- [3] Solangi, M. H., Mahar, M. A., Larik, A. S., & Mahessar, M. R. (2020). Design a Perturb & Observe MPPT Algorithm for PV System Based Asymmetric Cascaded Half-Bridge Multilevel Inverter. *Indian Journal of Science and Technology*, 13(04), 439-452.
- [4] Chamarthi, P. K., Al-Durra, A., EL-Fouly, T. H., & Al Jaafari, K. (2021). A novel three-phase transformerless cascaded multilevel inverter topology for grid-connected solar PV applications. *IEEE Transactions on Industry Applications*, 57(3), 2285-2297.
- [5] Mondol, M. H., Biswas, S. P., Rahman, M. A., Islam, M. R., Mahfuz-Ur-Rahman, A. M., & Muttaqi, K. M. (2022). A new hybrid multilevel inverter topology with level shifted multicarrier PWM technique for harvesting renewable energy. *IEEE Transactions on Industry Applications*, 58(2), 2574-2585.
- [6] Shahabadini, M., Moeini, N., Bahrami-Fard, M., & Iman-Eini, H. (2022). HERIC-Based Cascaded H-Bridge Inverter for Leakage Current Suppression in PV Systems. *IEEE Transactions on Power Electronics*, 38(3), 4005-4014.
- [7] Soomro, F., Mahar, M. A., & Larik, A. S. (2021). Design a Switched DC Sources based Multilevel Inverter for PV System. *International Journal of Computer Applications*, 183(1).
- [8] Yadav, A. K., Gopakumar, K., Umanand, L., Bhattacharya, S., & Jarzyna, W. (2019). A hybrid 7-level inverter using low-voltage devices and operation with single DC-link. *IEEE Transactions on Power Electronics*, 34(10), 9844-9853.
- [9] Qaimkhani, T. M., Mahar, M. A., & Larik, A. S. Performance Investigation of a Single-phase Reduced Switched Count Multilevel Inverter with Switched DC Sources. *International Journal of Computer Applications*, 975, 8887.
- [10] Siwakoti, Y. P., Mahajan, A., Rogers, D. J., & Blaabjerg, F. (2019). A novel seven-level active neutral-point-clamped converter with reduced active switching devices and DC-link voltage. *IEEE Transactions on Power Electronics*, 34(11), 10492-10508.
- [11] Korai, J. J., Mahar, M. A., Larik, A. S., Soomro, F. U. R., Ali, I., & Awan, M. S. (2020). Design Level Shifted Multicarrier Techniques for Cascaded H-Bridge Sub-Multilevel Inverter. *Journal of ICT, Design, Engineering and Technological Science*, 23-28.
- [12] Siddique, M. D., Mekhilef, S., Shah, N. M., Ali, J. S. M., & Blaabjerg, F. (2019). A new switched capacitor 7L inverter with triple voltage gain and low voltage stress. *IEEE Transactions on Circuits and Systems II: Express Briefs*, 67(7), 1294-1298.
- [13] Sandeep, N. (2020). A 13-level switched-capacitor-based boosting inverter. *IEEE Transactions on Circuits and Systems II: Express Briefs*, 68(3), 998-1002.
- [14] Tackie, S. N., & Babaei, E. (2020). Modified topology for three-phase multilevel inverters based on a developed H-bridge inverter. *Electronics*, 9(11), 1848.
- [15] Chamarthi, P. K., Al-Durra, A., EL-Fouly, T. H., & Al Jaafari, K. (2021). A novel three-phase transformerless cascaded multilevel inverter topology for grid-connected solar PV applications. *IEEE Transactions on Industry Applications*, 57(3), 2285-2297.
- [16] Roy, T., Tesfay, M. W., Nayak, B., & Panigrahi, C. K. (2021). A 7-level switched capacitor multilevel inverter with reduced switches and voltage stresses. *IEEE Transactions on Circuits and Systems II: Express Briefs*, 68(12), 3587-3591.
- [17] Pal, P. K., Jana, K. C., Siwakoti, Y. P., Majumdar, S., & Blaabjerg, F. (2022). An active-neutral-point-clamped switched-capacitor multilevel inverter with quasi-

resonant capacitor charging. IEEE Transactions on Power Electronics, 37(12), 14888-14901.

- [18] Elias, M. F. M., Abd Rahim, N., & Rosli, N. F. (2022). A Three-Phase Hybrid Multilevel Inverter with Enhanced Pulse-Width Modulation Strategy. IEEE Transactions on Power Electronics.
- [19] Liu, J., & Dong, D. (2022). A Flying Capacitor Hybrid Modular Multilevel Converter with Reduced Number of Submodules and Power Losses. IEEE Transactions on Industrial Electronics, 70(4), 3293-3302.
- [20] Barzegarkhoo, R., Forouzes, M., Lee, S. S., Blaabjerg, F., & Siwakoti, Y. (2022). Switched-capacitor multilevel inverters: a comprehensive review. IEEE Transactions on Power Electronics.