Modified Multi-Level Boost Inverter For Hybrid Energy Systems

Titus Sigamani, Ram Prakash Ponraj

Abstract: Applications of Renewable Energy Sources increased rapidly on the limited availability of fossil fuels and the environmental awareness over the decades. Hybrid System uses two or more input sources for the single output and this is normally used over the limited availability of renewable energy sources. Wind Energy and solar Energy are normally used as sources in hybrid energy system whereas fuel cells are also used in some limited applications. This paper proposes a multilevel Inverter system for hybrid energy sources with unequal voltage values. The proposed converter is explained with and without Boost operation. This paper also proposes a suitable PWM technique to control the voltage and frequency of the system and also to make the system ready for grid connection. The MATLAB/ Simulink simulation with the results are presented to validate the performance of proposed multilevel inverter system.

Index Terms: Boost Converter, Inverter, Pulse Width Modulation, Hybrid Systems, Photovoltaic, Wind Energy Conversion, Multi-level.

1. INTRODUCTION

THE invention of Multi-level inverters is the significant achievement in the modern power electronics, since they have numerous advantages over conventional inverters in the fields of Electrical Engineering. Diode Clamped MLI (DCMLI), Flying Capacitor MLI (FCMLI) and Cascaded H Bridge MLI (CHMLI) are the commonly used conventional multi-level inverters [1-2]. DCMLI and FCMLI use single source for power conversion while the CHMLI uses multiple number of sources which decides the number of output voltage levels and the requirement of filters [3-4]. The voltage sources used in the CHMLI have the same value or the multiple of fundamental value based on the application, complexity of the control circuit and the filter design considerations [5-6]. The modern MLI structures use reduced number of power electronic switches compared to the conventional structures [7-10]. To reduce the number of input sources, series connected capacitors are used as a potential dividers. To achieve balanced voltage across all DC-link capacitors, a separate feedback circuit is used [11-12] which increases the complexity of the circuit. In the case of renewable energy source input, the voltage is normally DC and variable in nature. The variable voltage has to be converted into constant voltage by controlling the pulse width of the chopper circuit used [13]. If more than one source is used, traditionally separate dc/dc converter was used for each source. The cost, complexity, switching losses etc., will be more in this method. In order to reduce this problem of separate chopper circuit, a double input dc/dc converter which can transmit power individually and simultaneously is proposed. The energy provided from these systems is variable and dependent of the climatic conditions, this make that the energy that can be delivered to the load is also variable. Then the converters used in these applications must permit to demand power to both input voltage sources simultaneously or to each one independently, depending on the availability of the voltage sources [14]. This is made traditionally with two independent converters, with a common DC bus voltage, but these increase the cost of the system. Converters with two inputs have been used as shown in Fig. 1, which permits to demand current from both inputs .Complex controller and circuits are considered in the schemes reported in literature. In this paper is presented a different converter capable to accept two low input voltages, and the power can be demanded from both converters simultaneously or independently depending on the availability of the voltage source. The operation of the converter is simple and just one controller is used [15]. The output of the boost converter is given to a self-balancing circuit use capacitors to maintain the constant voltage which is given to the level shifter circuit. The H-Bridge circuit in the system used to convert the unidirectional current into the bidirectional current [16]. The output voltage is an AC voltage derived from the hybrid voltage sources with unequal values [17].

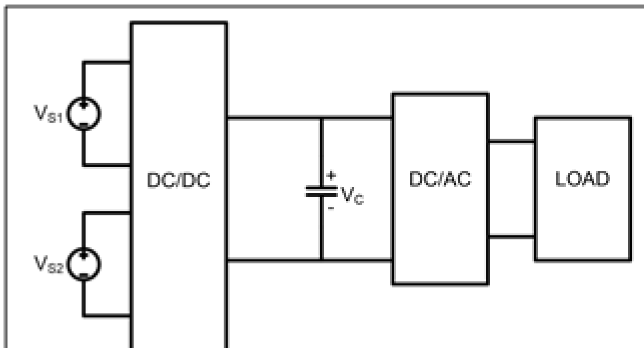


Fig.1. *DC–DC converter system with hybrid energy sources*

- *Titus Sigamani is currently working as Professor in Department of Electrical and Electronics Engineering in K.Ramakrishnan College of Engineering, Tiruchirapalli, India. PH-+919443690147. E-mail: drs.titus@gmail.com*
- *Ram Prakash Ponraj is currently working as Assistant Professor in Department of Electrical and Electronics Engineering in Saranathan College of Engineering, Tiruchirapalli, India. PH-+919487676423. E-mail: gprsahara@gmail.com*

2 PROCEDURE FOR PAPER SUBMISSION

2.1 Review Stage

BASIC MODULE

The schematic circuit diagram of the proposed double-input PWM DC/DC converter for high-/low-voltage sources is shown in Fig 2. It is consist of two input voltage sources V_{S2} and V_{S1}, and an output voltage V_O, where V_{S2} > VO > V_{S1} Power switches S_{S2} and S_{S1} are connected to the high-voltage source V_{S2} and the low-voltage source V_{S1}, respectively. When the power switches are turned OFF, power diodes D_{S2} and D_{S1} will provide the bypass path for the inductor current to flow continuously. By applying the PWM control scheme to the power switches S_{S2} and S_{S1}, the proposed double-input DC/DC converter can draw power from two voltage sources individually or simultaneously.

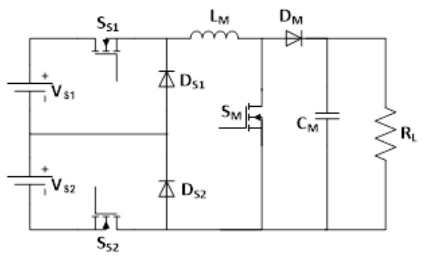
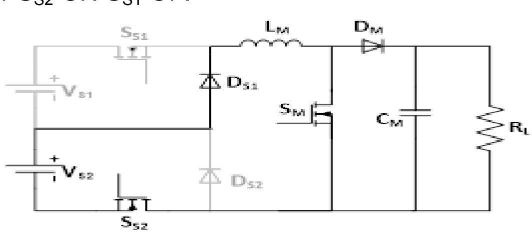


***Fig.2**. Circuit diagram of DC-DC converter system with hybrid energy sources*

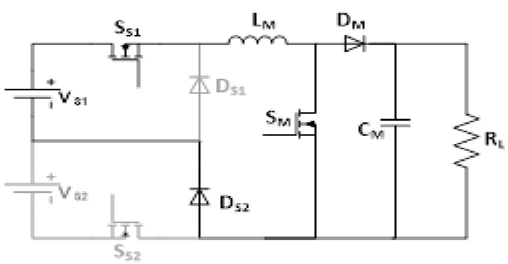
The principle of operation is two sources are connected to a single converter. One is high voltage source V_{S1} and other is low voltage source V_{S2}. Whatever be the variations in the source voltages the converter circuit will balance the voltages and maintain the constant voltage supply at the transmission end. This can be explained in detail using four modes of operation.

Mode-1 S_{S2} ON S_{S1} OFF



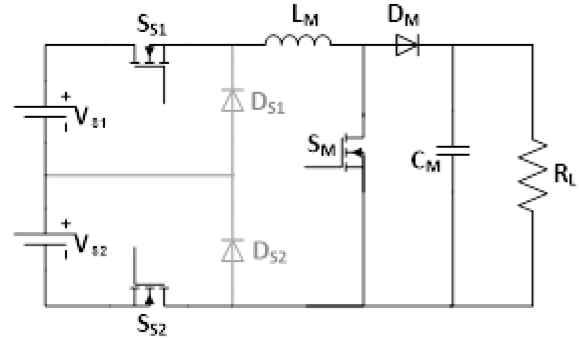
(a)

Mode-2 S_{S2} OFF S_{S1} ON



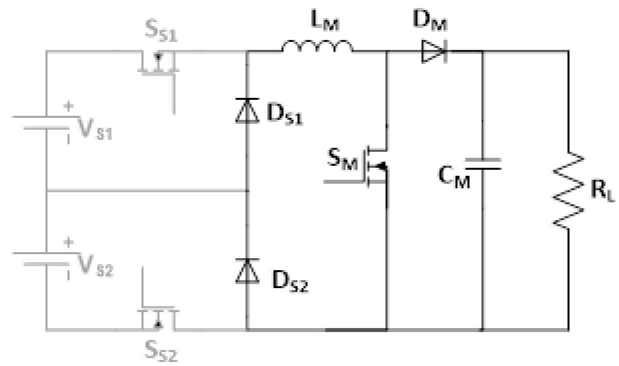
(b)

Mode-3 S_{S2} ON S_{S1} ON



(c)

Mode-4 S_{S2} OFF S_{S1} OFF



(d)

***Fig.3**.Modes of operation of DC/DC Converter*

For explaining the operating modes we are considering the simplified circuit without soft switching cell. Here V_{S2}, V_{S1} -high and low voltage sources respectively I_1, I_2 - current from the high and low voltage sources respectively. I_L, I_C and I_O are the inductor current, capacitor current and the load current respectively. According to the status of the power switches, there are four different operation modes which can be explained in Fig.3.

2.1. Design of Boost Converter

The Load of the DC/DC Converter R_L comprises of the resistance values of the switches used in the other circuits used in the system like Level decider circuit, self- balancing circuit, H-bridge and the actual load impedance used in the system.

$R_L = Load + 5R_{SW} + R_{diode}$ (1)

Where,

R_{SW} – Internal resistance of the switch used

R_{diode} - Internal resistance of the diode used

Since the forward resistance of the switches and diode is negligible, then the load resistance will be

$R_L = Load$ (2)

The duty cycle of the boost converter used in the system is calculated using the following equations [18]

Duty cycle D = $1 - \frac{V_s}{V_o}$ (3)

Output Voltage $V_o = \frac{V_s}{(1-D)}$ (4)

The minimum value of inductance L_{min} and Capacitance C_{min} are designed using the following equations

$$L_{min} = \frac{D(1-D)^2 R_L}{2f} \quad (5)$$

$$C_{min} = \frac{D}{R_L * A_r * f} \quad (6)$$

The ripple voltage with respect to the output voltage is given by,

$$A_r = ({}^{\Delta V_o}/_{V_o}) \quad (7)$$

The maximum value of load current and the change in load current value is given by,

$$I_L = \frac{V_s}{(1-D)^2 R_L} \quad (8)$$

$$\frac{\Delta I_L}{2} = \frac{V_S DT}{2L_M} \quad (9)$$

Where,

V_S – Source voltage, f – switching frequency and R_L – Load impedance and A_r – taken as 0.5% of the output voltage.

As demonstrated in this document, the numbering for sections upper case Arabic numerals, then upper case Arabic numerals, separated by periods. Initial paragraphs after the section title are not indented. Only the initial, introductory paragraph has a drop cap.

3 PROPOSED CONVERTER

The Proposed converter shown in Fig. 4 consists of a DC/DC boost converter circuit with a multilevel inverter circuit shown in Fig. 5 consists of two parts. Part 1 is Self-voltage Balancing Circuit (SBC), composed of flying capacitors C_1 and C_2 and clamping switches S_1 – S_4. Diodes D_{L1} and D_{L2} are used in the circuit to prevent the return current if R-L load used in the inverter circuit. Part 2 is a 5-level inverter topology with level generating switches S_{L1}, S_{L2} and H Bridge switches S_{11} – S_{41}.

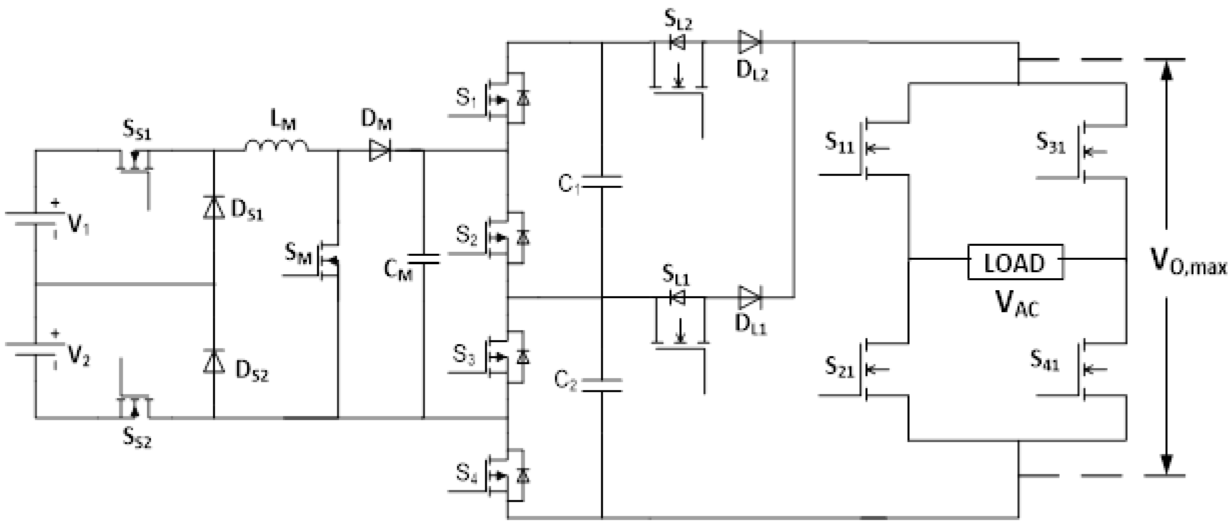


Fig.4. *Proposed DC/DC Boost Multi-level Inverter for hybrid energy system*

The Voltage across each capacitor is equal to the input voltage V_{DC}. So the overall output voltage across H-Bridge is,

$$V_{o,max} = 2V_{DC} \quad (10)$$

Since the input voltage of the self-balancing circuit is the output of the boost converter, then the output voltage of the self-balancing circuit is,

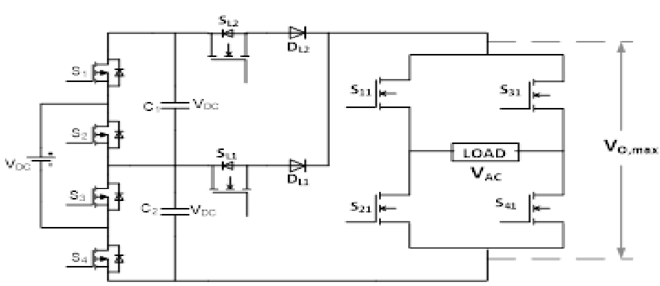
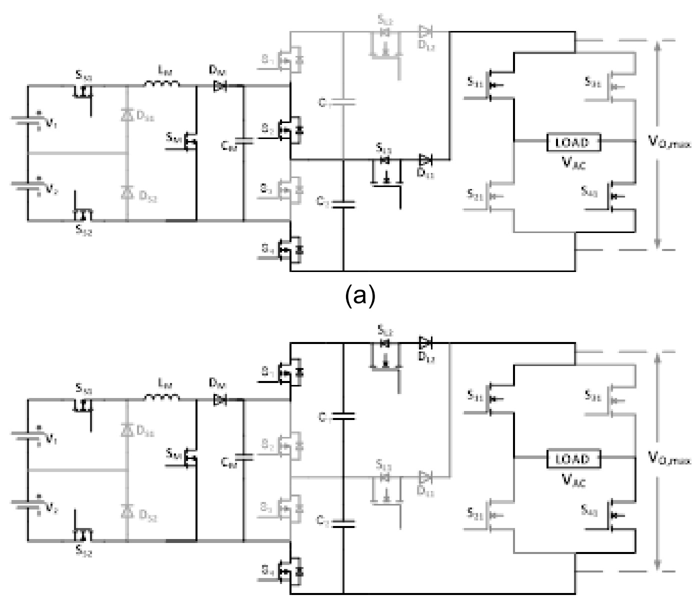


Fig.5. *Self-balancing Multi-level Inverter circuit*

$$V_o = \frac{2V_S}{(1-D)} \quad (11)$$

Thus the peak voltage across the inverter is boosted a minimum of 2 times the input voltage. The various modes of operation of the proposed converter when both the inputs are ON is shown in Fig.6.



(a)

(b)

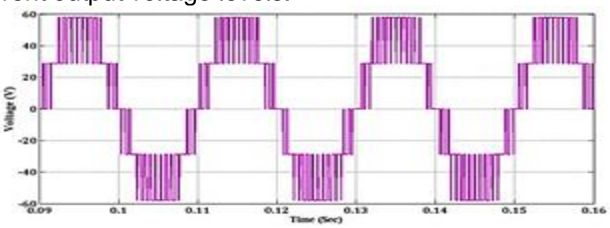
Fig.6 *Modes of operation of proposed converter at Positive half cycle* of output voltage (a) $V_{AC}= V_1+V_2$ (b) $V_{AC}= 2(V_1+V_2)$

Fig. 6(a) shows the operation mode of the converter circuit for $V_o = V_{DC}$ where V_{DC} is the voltage across the capacitor C_2. Fig. 6(b) shows the operation mode of the converter circuit for $V_o = 2V_{DC}$ wher V_{DC} is the voltage across the capacitor C_2. By using the H-Bridge inverter circuit, the output of the level shifter circuit is converted in to AC Voltage.

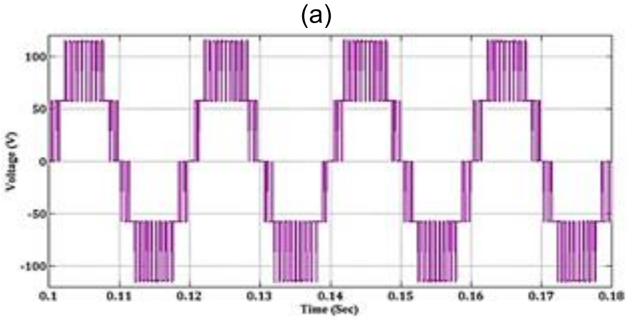
$$V_{AC,pp} = 2 * V_{O,max} \quad (12)$$

4 SIMULATION AND HARDWARE RESULTS

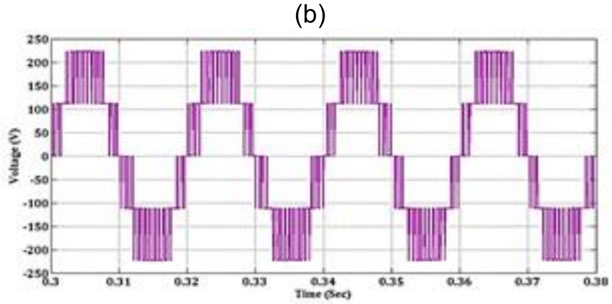
The simulation of the proposed converter circuit was developed for a load impedance of 35Ω and 10mH. The capacitor and inductor values of the boost converter were 66 μF and 8 mH for a switching frequency of 10 kHz. The ripple value was taken s 0.5% of the output voltage. The input voltage V_{S1} and V_{S2} are 30V each. Fig. 7 show the output voltage waveforms of proposed 5-level inverter system with different output voltage levels.



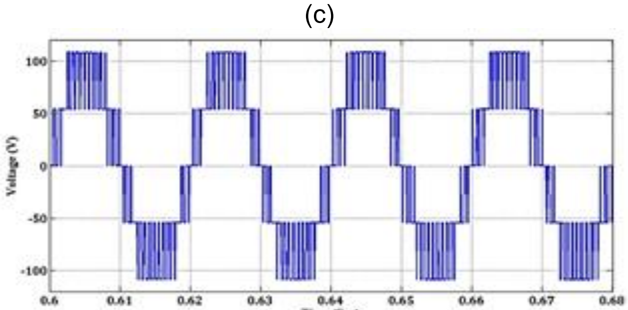
(a)



(b)



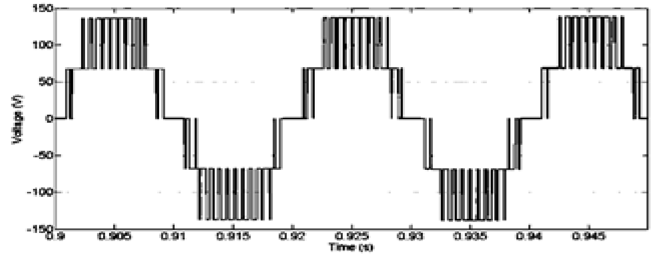
(c)



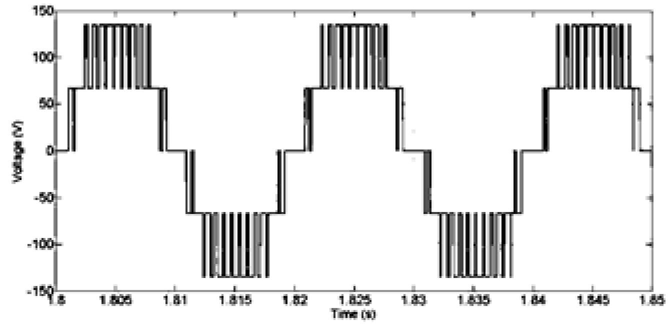
(d)

Fig. 7. *Operating modes of proposed 5-Level Inverter (a) with one DC source at zero percent duty ratio (b) with two DC sources at zero percent duty ratio (c) With Two Sources at 50% duty ratio (d) With One Source at D=50%*

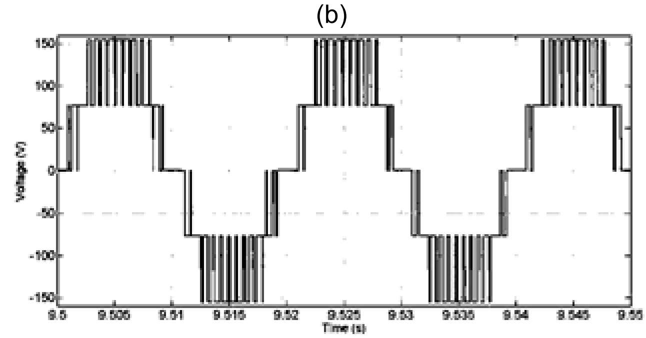
With intelligent power controller[19] it is possible to program for decision making and generate required output voltage from the available DC sources either without boost operation or with boost operation.



(a)



(b)

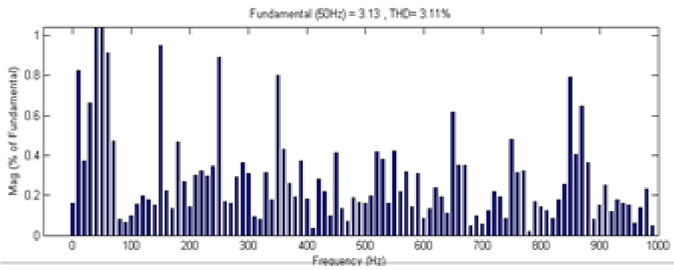


(c)

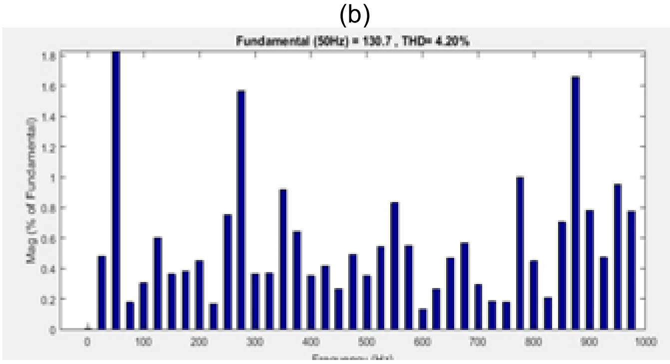
Fig. 8 *output voltage waveforms of 5-level inverter with one DC source at different duty ratios with variable input voltages. (a)V_{S1} = 50 V. (b)V_{S2} = 75 V (c)V_{S1}+ V_{S2} = 125 V*

Fig. 9 a,b and c shows the current waveform at 50% duty ratio and its THD values of output parameters for the aforesaid load specifications. THD value for load voltage is 4.20% and that of current is 3.13% which makes promising for efficient operation of proposed 5-level inverter.

(a)



(b)



(c)

Fig. 9 *(a) Current waveform of 5-level inverter for single DC source at 50% duty ratio. (b) THD window for the current waveform. (c) THD window for the output voltage waveform.*

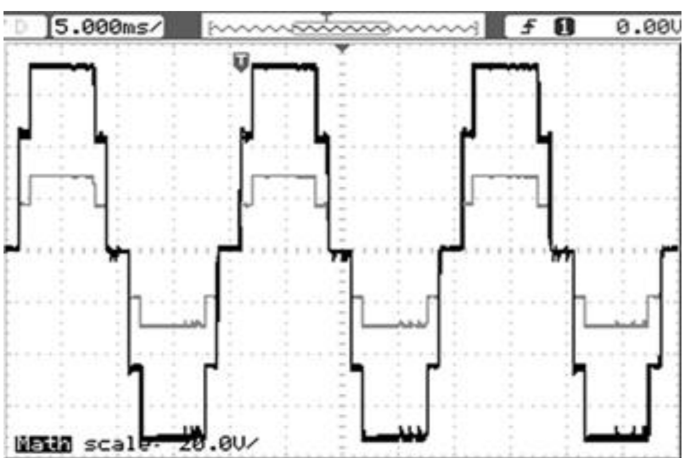


Fig.10*. output voltage and current of proposed Inverter*

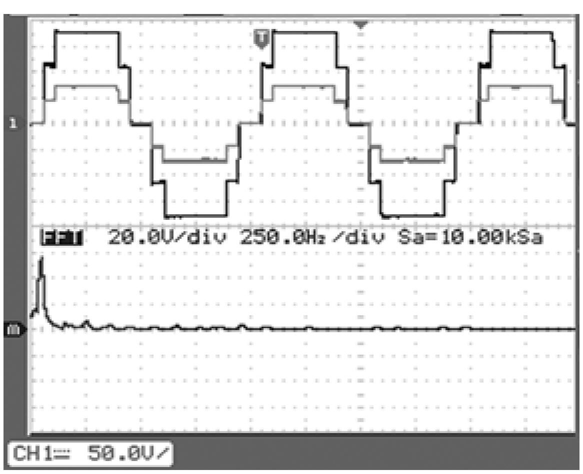


Fig.10*. FFT spectrum of output voltage of proposed Inverter*

To validate the output of the simulation, the experimental hardware setup was developed and the triggering gate pulses were generated using Microcontroller. IRF840 MOSFET switches are used in the proposed converter due to its small input current requirement, high switching speed and the switching times are of the order of nanoseconds. Fig 10 describes the output voltage of 5-level with unequal inputs. Total voltage of 75 V peak is achieved using two different voltage inputs of 50V and 25V for V_{S1} and V_{S2} respectively. A current of 1.4A is achieved through a resistive load of 60Ω. The FFT spectrum of output voltage up to 50th order is given in Fig.11 and it is clear that the higher order harmonics are negligible and the domination of 5^{th} and 13^{th} order harmonics present which would be suppressed using output filters easily.

5 CONCLUSION

This paper presented a multilevel inverter system for hybrid energy applications suitable for micro grid system that integrates two unequal electric sources to the load. Significantly, availability of at least one source can drive the load uninterruptedly by boosting the voltage to the load requirement. Operation of proposed 5-level inverter system is presented and the performance was validated with the help of MATLAB/Simulink. The output results obtained from the simulation are also presented which ensures satisfactory operation of proposed multilevel inverter system and it was ensured that the proposed topology is suitable for hybrid system integration with the load. The hybrid system may be the combination of any of the renewable energy sources like Solar and DC output Wind energy, Solar and Battery system, and Solar and Fuel cell system.

REFERENCES

[1] Jose Rodriguez, et.al., "The Age of Multilevel Converters Arrives", IEEE Industrial Electronics Magazine, pp- 28-39, June 2008. doi:10.1109/MIE.2008.923519

[2] Ilhami Colak, et.al., "Review of multilevel voltage source inverter topologies and control schemes, Energy Conversion and Management", pp.1114–1128, 2011. doi:10.1016/j.enconman.2010.09.006

[3] Mariusz Malinowski, et.al., "A Survey on Cascaded Multilevel Inverters, IEEE Transactions on Industrial Electronics", Vol. 57, No. 7,pp. 2197-2206, July 2010. doi:10.1109/tie.2009.2030767

[4] Prabaharan,et.al., "A comprehensive review on reduced switch multilevel inverter topologies,modulation techniques and applications", Renewable and Sustainable Energy Reviews · April 2017, doi: 10.1016/j.rser.2017.03.121

[5] Y. Suresh, et.al., "Investigation on cascade multilevel inverter with symmetric, asymmetric, hybrid and multi-cell configurations", Ain Shams Engineering Journal, vol.8, pp. 263–276, 2017. doi:10.1016/j.asej.2016.09.006

[6] J. Venkataramanaiah, et.al., "A review on symmetric, asymmetric, hybrid and single DC sources based multilevel inverter topologies", Renewable and Sustainable Energy Reviews vol. 76, pp. 788–812, 2017. doi:10.1016/j.rser.2017.03.066

[7] S. Edwin Jose, S. Titus, "A Level Dependent Source Concoction Multilevel Inverter Topology with a Reduced Number of Power Switches", Journal of Power Electronics, Vol. 16, No. 4, pp. 1316-1323, July2016. doi:10.6113/jpe.2016.16.4.1316

[8] Ebrahim Babaei, et.l., Symmetric and asymmetric multilevel inverter topologies with reduced switching devices, Electric Power Systems Research vol. 86, pp. 122– 130, 2012. doi:10.1016/j.epsr.2011.12.013
[9] M.Nandhini Gayathri, et.al., “Performance Evaluation of Modified Cascaded Multilevel Inverter”, Journal of Applied Sciences, 14,15, pp. 1750-1756, 2014. doi:10.3923/jas.2014.1750.1756
[10] K.Anish, P.Ramprakash, Performance Evaluation of Sub-Multilevel Cell Cascaded Multilevel Inverter Using Different PWM Techniques, Intl. Journal of Applied Engineering Research, Vol. 9, No. 8, pp. 961-975, 2014.
[11] Jian Cao, Nigel Schofield, Ali Emadi, ”Battery balancing methods, a comprehensive review” Vehicle Power and Propulsion Conference 2008, VPPC’08. IEEE,2008.
[12] Viju Nair et al., “Novel Symmetric 6-Phase Induction Motor Drive Using Stacked Multilevel Inverters with a Single DC Link and Neutral Point Voltage Balancing”, IEEE Transactions on Industrial Electronics, no.99, pp.1-12,2016. doi: 10.1109/TIE.2016.2637884.
[13] Miaosen Shen,et.al., “Multilevel DC–DC Power Conversion System With Multiple DC Sources”, IEEE Transactions on Power Electronics, Vol. 23, No. 1, Jan 2008. doi:10.1109/TPEL.2007.911875
[14] Babaei Ebrahim, Abbasi Okhtay, “Structure for multi-input multi-output dc–dc boost converter”, IET Power Electronics, Vol.9, No.1,pp.9-19,2016. doi:10.1049/iet-pel.2014.0985
[15] Fan Zhang,et.al., “Study of the Multilevel Converters in DC-DC Applications”, IEEE Power Electronics Specialists Conference, 2004. doi:10.1109/PESC.2004.1355682
[16] Manjunatha Budagavi Matam, Ashok Kumar Devarasetty Venkata, Vijaya Kumar Mallapu,”Analysis and implementation of impedance source based Switched Capacitor Multi-Level Inverter”,Engineering Science and Technology, an International Journal,Vol. 21, No. 5,2018,pp.869-885,doi: 10.1016/j.jestch.2018.08.003.
[17] Nimrod Vazquez, et.al., “A Double Input DC/DC Converter for Photovoltaic/Wind Systems”, IEEE explore,2008.
[18] Daniel W.Hart, Power Electronics, Mc Graw Hill, 2010.
[19] Sundaramurthy, R, Sigamani, T. “FITF-PDM: Unified controller design for non-isolated bidirectional DC-DC converter”, Int Trans Electr Energ Syst.,Vol.28, No.3, 2018;. doi:10.1002/etep.2508.