

A Matrix Structure Multilevel Inverter with switched capacitor cells using Photo Voltaic Energy Sources for Microgrid applications

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Abstract

Power converters play a vital position in microgrid purpose by transforming and converting one voltage level to other voltage level either ac or dc in a required mode from renewable sources into ac power well suited with grid or local loads. The traditional 2- level inverters produce higher harmonic distortion due to reduced voltage levels which increase the filter size. In this context, multilevel inverters tender enhanced output voltage quality, reduced harmonics and improved efficiency suitable for microgrid applications. To overcome this, reduced count topologies came into existence with the perspective of reducing the switching retaining input dc sources which increases the cost and complexity. In this paper, a new MLI is developed to offer reduced components in its structure in a way to arrange the dc sources in matrix form with reduced isolated dc sources and improved power loss. The performance of the developed topology is analyzed in grid tied inverter configuration using PV sources. A computer based model using Matlab/Simulink is availed to validate the feasibility of developed MLI for microgrid applications.

Keywords: MLI, Optimal structure, reduced count, simulation model, 9- level MLI

1. INTRODUCTION

Multilevel inverters (MLIs) have been considered as an emerging technology for microgrid systems due to its ability in synthesizing high quality output voltage at reduced Total Harmonic Distortion (THD) and lower Electromagnetic Interference (EMI). The microgrid combines different Renewable Energy Resources (RES) such as photovoltaic panels, wind turbines, fuel cells and energy storage equipments (Battery) that requires power electronic interfaces which are efficient, modular and expandable. MLI gratifies these requirements by generating staircase ac output from several multiple dc sources improving voltage quality without the need of large size filters.

The traditional two level inverters short comings in regulating the high voltage and power demands of microgrid particularly under changeable load and generation conditions. MLIs have three types namely Neutral Point Clamped (NPC), Flying Capacitor (FC), and Cascaded H-Bridge (CHB) topologies offer improved voltage levels, modular and fault tolerant capability. Besides, recent amendments in modulation strategies like Selective Harmonic Elimination (SHE), Space Vector Modulation (SVM), and advanced carrier-less PWM techniques have appreciably improved the performance of MLI in microgrid environments.

Present research has envisaged in reducing the number of switches [1], improving energy management [2], enhancing fault detection [3] and developing control strategies for islanded and grid-connected modes [4]–[6]. Furthermore, MLI are being integrated with advanced control algorithms such as Model Predictive Control (MPC) [7], Artificial Intelligence [8], and optimization-based methods [9] to meet the dynamic demands of smart microgrid. The integration of MLI in hybrid AC/DC microgrid [10]–[12] and

their role in enhancing power quality [13], voltage stability [14] and energy efficiency [15] draw attention to their significance in future decentralized power systems.

1.2 Paradigm of arranging dc sources in Matrix structure to reduce power components

Power converters play a vital role in translating the available renewable energy power in a suitable way to the end applications or utility grid. The usage of power electronic system pollutes the utility by drawing more reactive power and operates at low power factor by introducing harmonics into the system. Several methods have been adopted to minimize or eliminate the harmonics from the grid to draw harmonic free voltage or current to the end user applications. DC/DC converters and inverters are diligently used to pump the voltage from the available dc power and converts into ac voltage with required operating frequency. Most of the renewable energy source interfaces uses two stage conversions and it requires complex control. In this work, a study about an arrangement of isolated input sources in matrix arrangement in MLI is taken to optimize the fast controlled semiconductor devices and input sources to minimum number. The main perspective of optimizing the power components required for a MLI topology is to offer minimum cost with better power quality in the load terminals. The generalized power circuit for MLI using arrangement of dc sources is shown in Fig. 1.

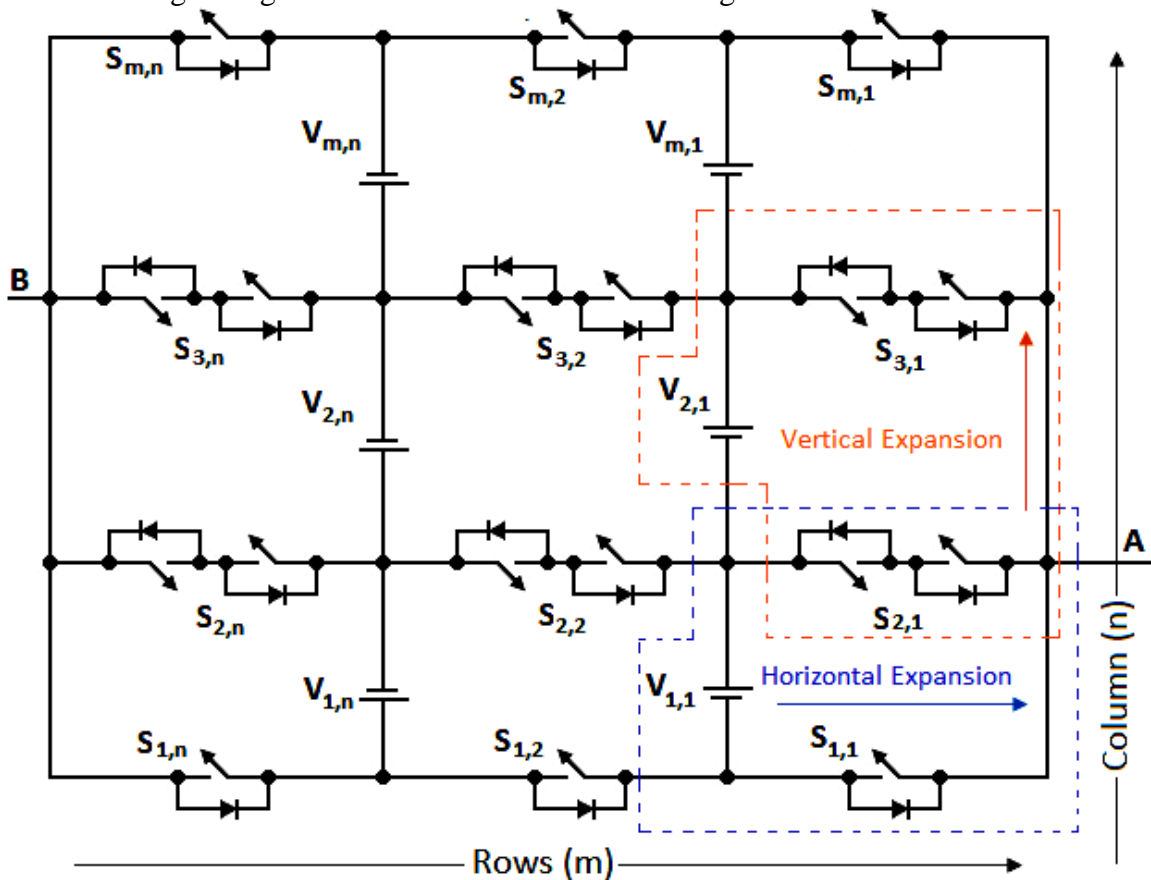


Fig. 1 Generalized topology for Matrix structure MLI

The circuit shown in Fig. 1 composed of isolated dc sources ($V_{1,1}$ - $V_{m,n}$) and unidirectional switches ($S_{1,1}$ - $S_{1,n}$ and $S_{m,1}$ - $S_{m,n}$), bidirectional switches ($S_{2,1}$ - $S_{2,n}$) are used to connect the voltage sources in matrix structure to produce voltage level more than 3 [16]. The circuit has the flexibility of expanding in horizontal and vertical direction to elevate its size to increase the voltage levels. It is observed that the

cell expansion decides the switch count in current flow path to alleviate power loss. The horizontal expansion in the structure uses only two semiconductor devices in the passage of current flow compared with vertical expansion. Therefore, the circuit with $(2 \times n)$ is optimized to give lesser switches in the path of load current with improved output voltage. It is in this direction of the proposed work, the structure is analyzed with 2 rows and 'n' columns. The circuit can be examined in different perspectives like expanding the structure and varying the magnitude of the isolated dc sources to optimize the voltage levels with reduced switches as constraints.

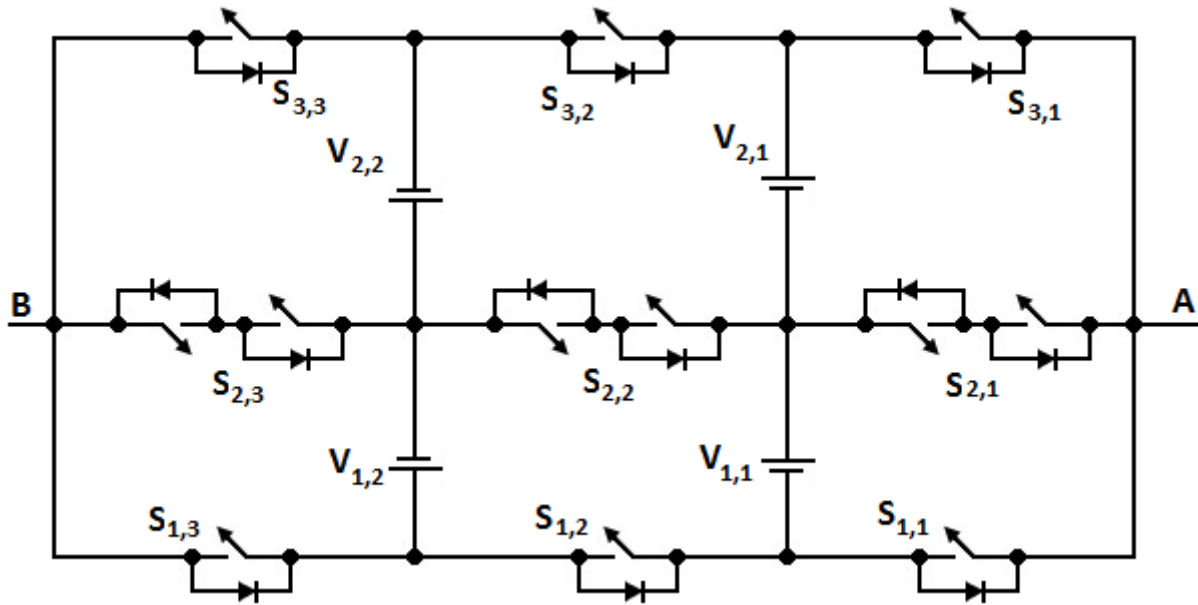


Fig. 2 Matrix structure (2×2)

The circuit shown in Fig. 1 is configured into (2×2) matrix structure with four dc sources ($V_{1,1}$, $V_{1,2}$, $V_{2,1}$, $V_{2,2}$) and switches ($S_{1,1}$ - $S_{1,3}$), ($S_{2,1}$ - $S_{2,3}$) and ($S_{3,1}$ - $S_{3,3}$) respectively. The switches ($S_{2,1}$ - $S_{2,3}$) are bidirectional IGBTs which conducts current in both directions in each level of conduction. The developed circuit shown in Fig.2 produces 9- level output with three current carrying switches. It is highly in contrast with CHBMLI which requires 8 switches for carrying the current in each level of operation. This reduction in count authenticates the developed circuit has lower power loss. The main drawback of this Matrix arrangement is requiring isolated dc sources which increases the inverter cost and reduced its feasibility for practical applications. It is noticeable that the dc sources can be acquired from PV sources which are irradiation dependent and needs dedicated control schemes to obtained constant dc voltage at the input terminals of matrix structure. The structure enjoys the freedom of utilizing renewable energy sources or capacitors at the input side which are highly sensitive in its characteristics. The matrix structure arrangement can be examined by employing dc capacitors to reduce isolated dc sources and its modes of operation become entirely different from matrix structure shown in Fig. 1. Fig. 2 is reconfigured by replacing the isolated voltage sources ($V_{1,2}$ and $V_{2,2}$) by capacitors ($C_{1,2}$ and $C_{2,2}$) respectively. The modified circuit is shown in Fig. 3.

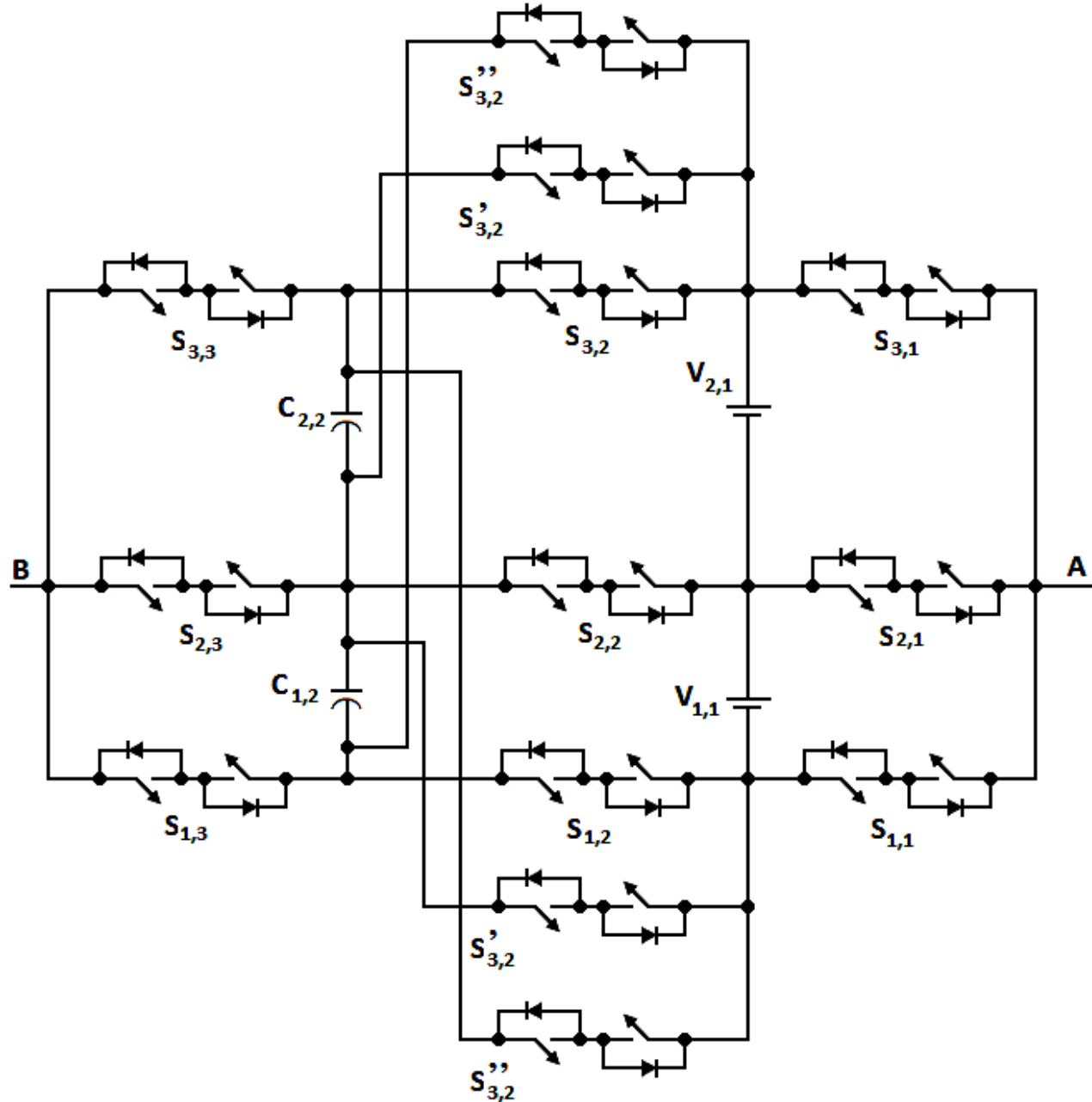


Fig. 3 Modified 9- level matrix topology with switched capacitors

The generalized MLI topology presented in Fig. 1 is optimized to produce predefined voltage levels by considering minimal dc sources and switching devices to ensure less implementation cost. The main purpose of three- phase MLI integrated with grid tied system as shown in Fig. 5 is to elevate the operating voltage to higher level acquired from input low voltage available from renewable energy or zero emission dc sources. For simplicity, the fuel cell is represented in the form of dc sources which can be configured to operate in asymmetrical dc voltages. The MLI composed of six IGBTs and three bidirectional IGBTs with four dc sources forms a modular structure. The dc sources are arranged in same direction using these IGBTs to achieve same and opposite direction of connecting the voltage sources to obtain all voltage levels. The dc sources are taken with the values of 1:1 ratio in the same wing thereby having

(1:1) in the capacitor voltages to obtain 9- level output voltage. Since the output voltage is closer to sine wave and it requires low pass filter to smoothen the output voltage.

In the past two decades, Fuel cells are frequently used in Multilevel Inverter (MLI) topologies due to its reliability and stable DC energy source replacing Photo Voltaic (PV) cells in microgrid applications. As PV cells which depends on sunlight, whereas fuel cells gives steady power generation that ensures constant output voltage even under varying weather conditions. Fuel cells also produce less voltage fluctuation compared to PV cells and a dc- dc boost converter is employed to produce steady input voltage under varying weather conditions. The functional block diagram of the proposed microgrid system is shown in Fig.4. The developed system composed of Fuel Cell, dc-dc boost converter and proposed optimized MLI topology. The dc-dc boost converter is used to produce constant input voltage at the MLI due to variation at the output of fuel cell. The boost converter uses Proportional- Integral (PI) controller by taking feedback output voltage and compared with reference voltage to produce PWM pulses for the required output voltage. The MLI used in the system is optimized to produce 9- level stepped voltage to offer better quality voltage with low harmonic distortion integrated to the microgrid with lesser filter components.

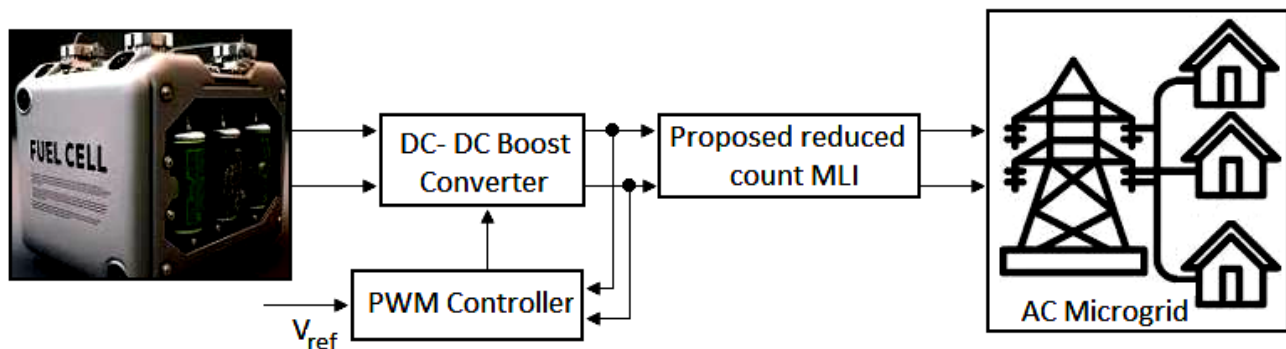


Fig. 4 Fuel Cell Fed Microgrid connected optimized 9- level MLI.

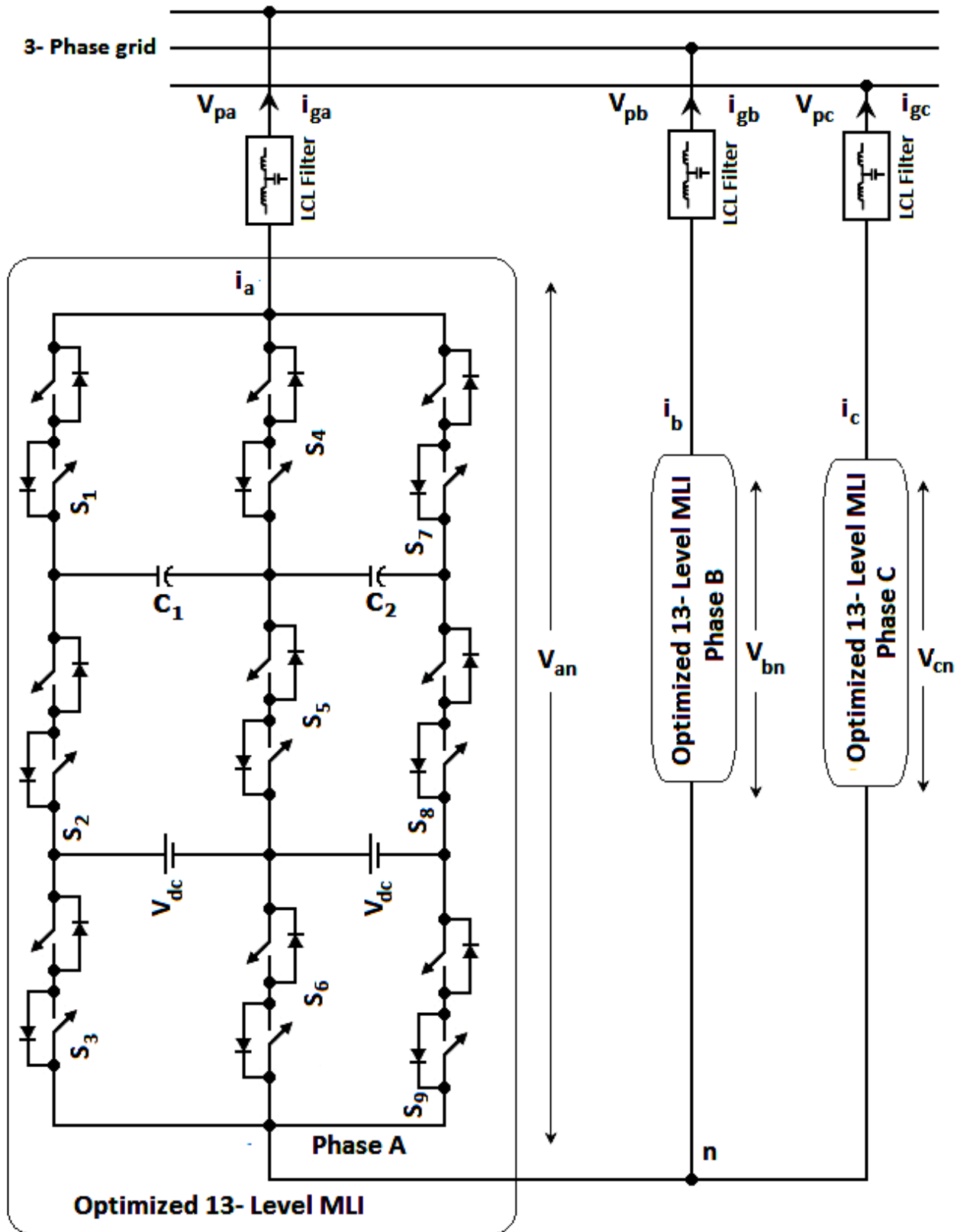


Fig. 5 Optimized 13- Level reduced count MLI
I. Simulation and Experimental results

The functionality of the presented MLI is studied in Matlab/Simulink with the following specifications: input dc voltage= 75V, switching frequency= 2 kHz and RL load of 100Ω and L= 100mH respectively. MCPWM method is used to synthesize the 9- level output voltage. The switching patterns are obtained by taking six triangle carriers and compared with reference sine wave of frequency 50Hz. The PWM generation for single phase topology has two folds: one is base PWM generation and the other is required PWM is produced by performing suitable logic function following the switching operation using base PWM pulses as depicted in Fig. 6. Figs. 7 and 8 represent output voltage and inductive load current for single phase 9- Level MLI. The same PWM generation methodology is followed to generate required switching pulses for three phase topology. The phase voltages and line currents for the star connected load is shown in Figs. 9 and 10 respectively. The experimental prototype for optimized 9- level inverter and the representative load voltage is shown in Fig. 11 and 12. The simulation results accorded with experimental results.

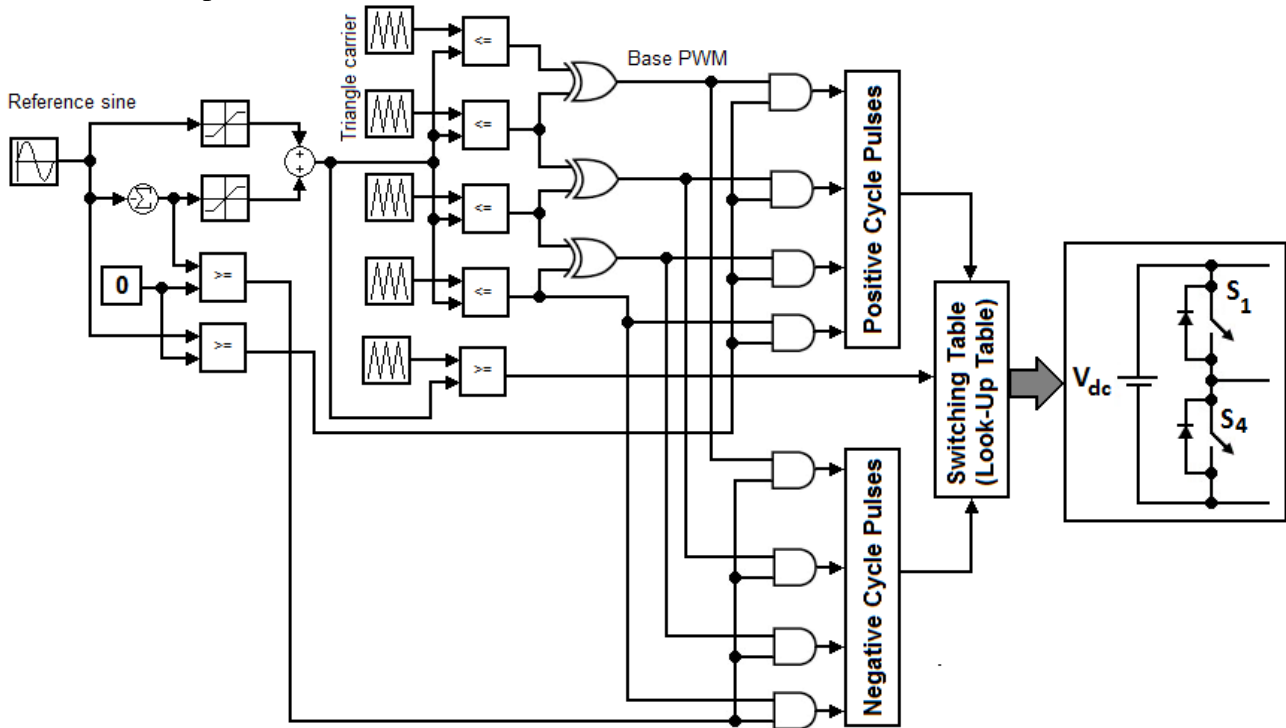


Fig. 6 PWM Generation for 9- level Proposed inverter

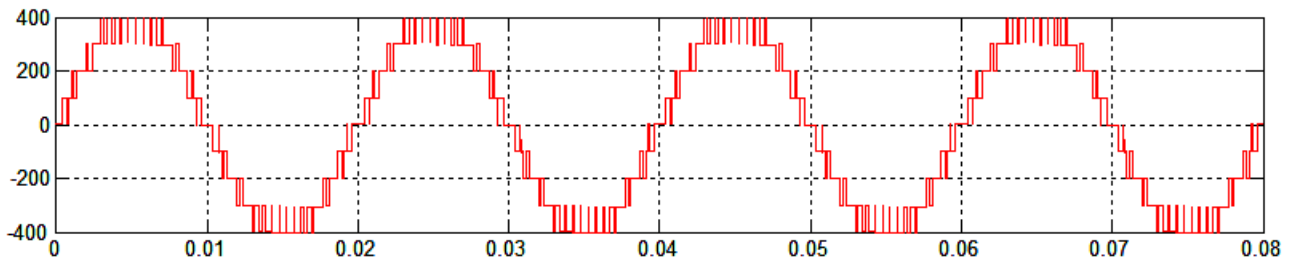


Fig. 7 Output voltage for 9- Level inverter

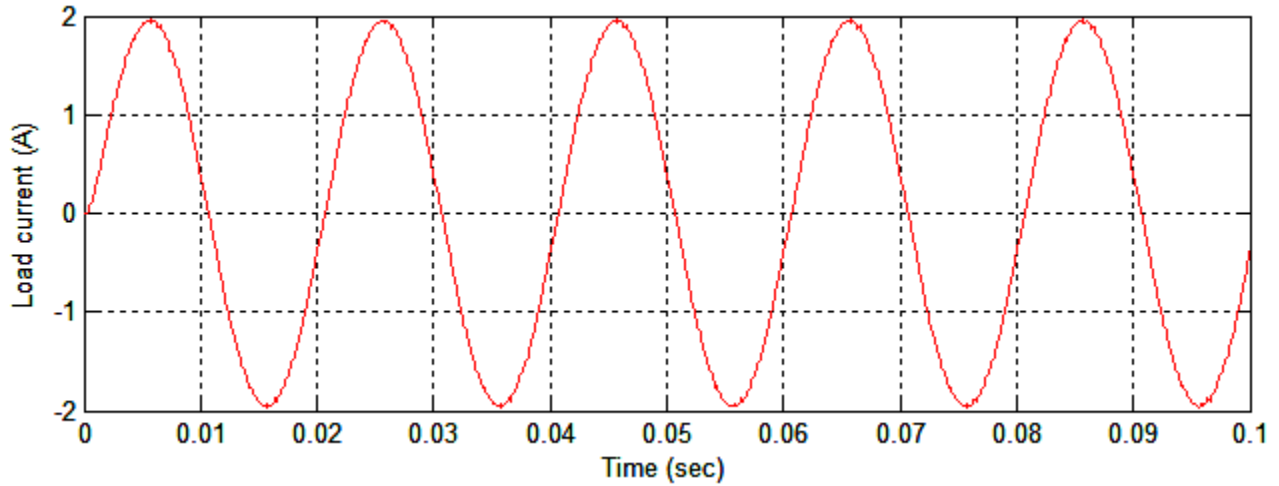


Fig. 8 Inductive load current for 9- level inverter

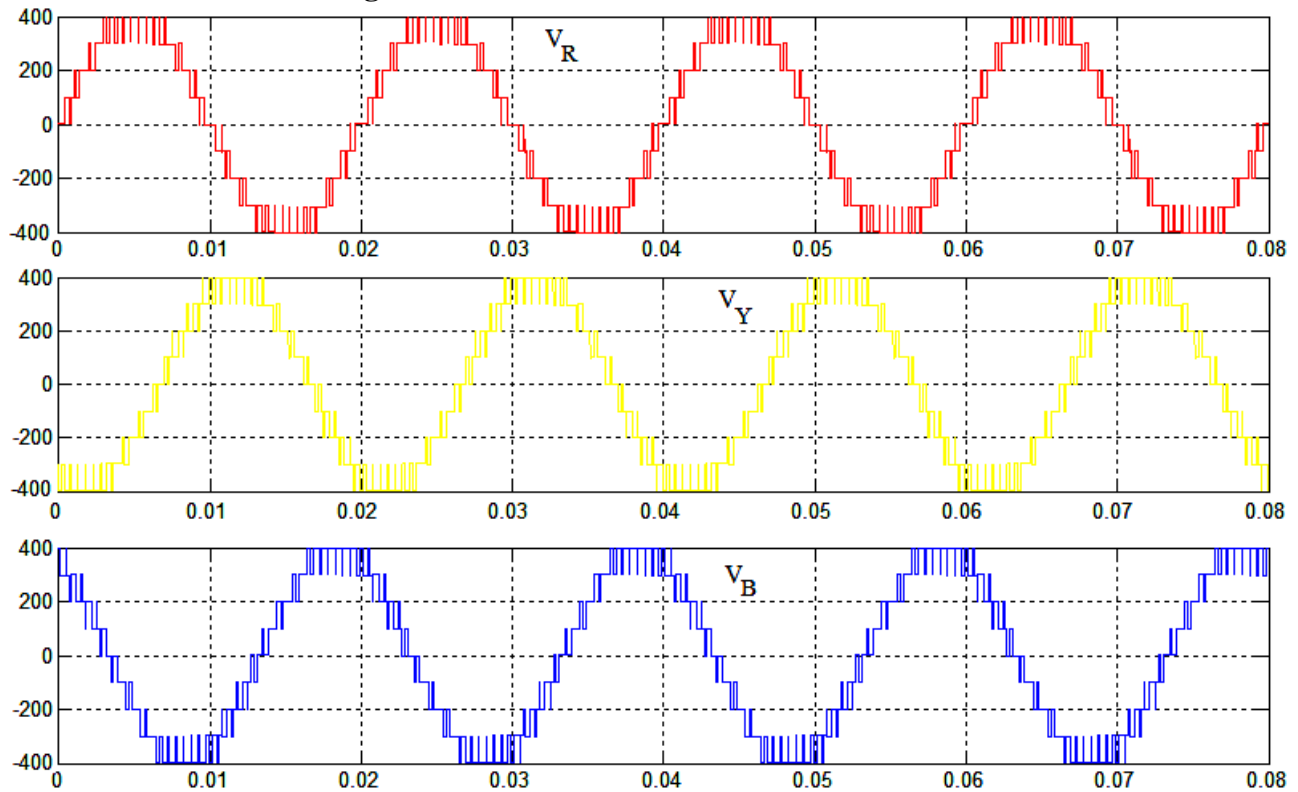


Fig. 9 Three Phase voltage of the proposed topology

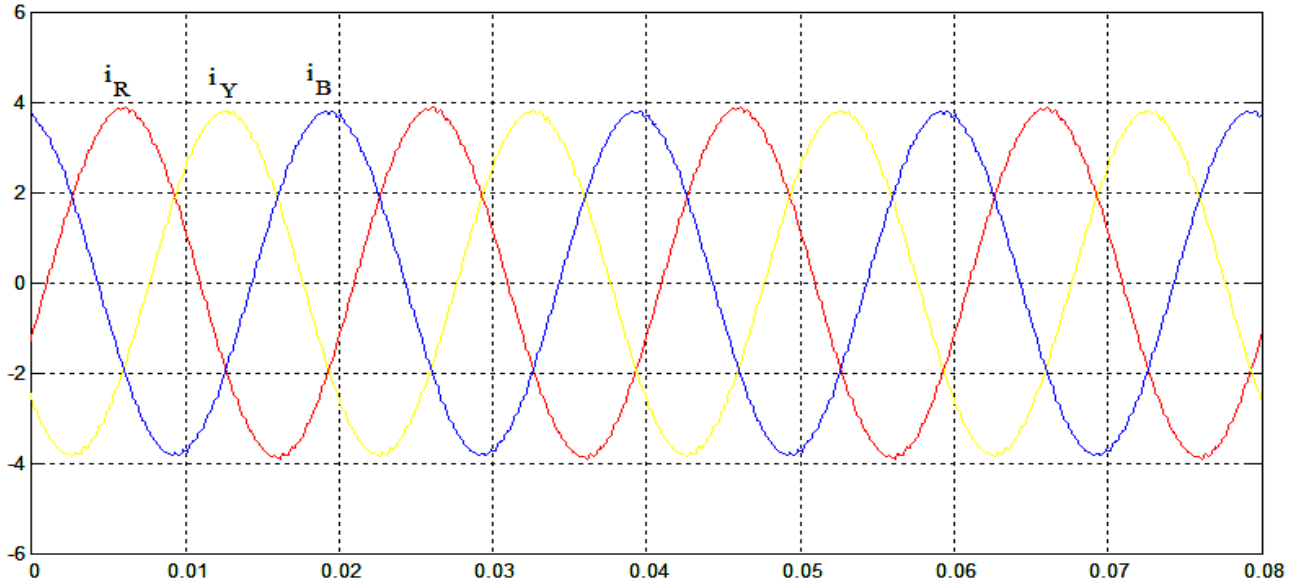


Fig. 10 Three Phase line currents of the proposed topology

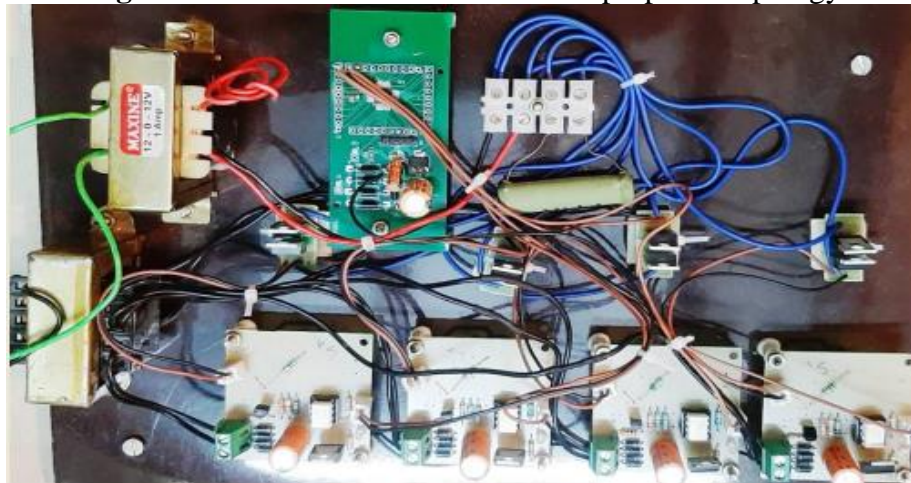


Fig. 11 Experimental Prototype

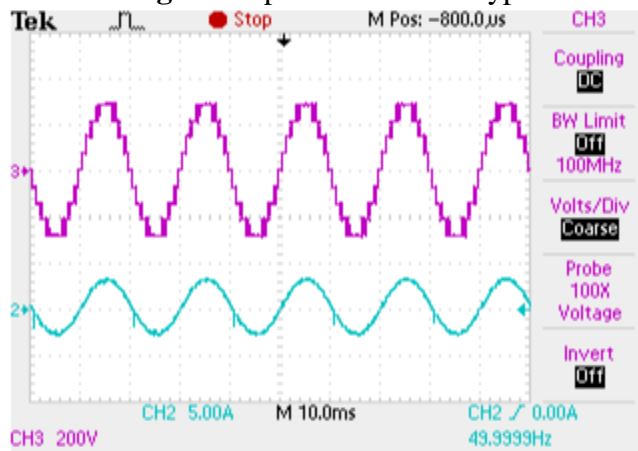


Fig. 12 Combined Output voltage and inductive load current for single phase 9- level inverter

III.Conclusion

This article introduces a new multilevel inverter topology optimized to produce 9- voltage levels using fewer components designed for microgrid applications and it operates efficiently with unequal DC sources. Due to its modular structure, the proposed MLI module can be cascaded to achieve higher output voltages while reducing semiconductor stress and component count. The modular nature also enhances reliability by allowing alternate paths in case of a switch or driver failure. A key benefit of this design is its ability to generate both positive and negative voltages without the need for an output H-bridge circuit.

IV. References

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