Arduino Uno Programming based New Five Level Inverter for Photovoltaic Applications

Bhukya Nageswar Rao[1], Ashok Shrimant Hake[2], Vishal Subhash Chavan[3], Lingaraj Hadimani[4]

Department of Computer Science and Business Systems

Kolhapur Institute of Technology College of Engineering, Kolhapur, Maharashtra, India

[1]bnageswar.ee@gmail.com, [2]ashokhake2004@gmail.com, [3]vsc251044@gmail.com, [4]hadimani.lingaraj@kitcoek.in

***Abstract*—This article presents a novel five-level transformer-based inverter with inherent boosting abilities specially designed for photovoltaic applications. The key distinction of this proposed inverter lies in its three-leg configuration and a single transformer with an increasing output voltage of twice the input voltage, which results in a smaller size, more cost-effective and less complex inverter circuit. Additionally, this innovative design features fewer components, lower total voltage requirements, reduced voltage rate of change (dv/dt), and a decreased number of active devices compared to its counterparts. The article provides a comprehensive explanation of the circuit's operation and principles. It underscores the utilization of Arduino programming to generate the required control pulses for this five-level inverter. Finally, simulation results are included to validate the feasibility and performance of the proposed inverter, both in steady-state and dynamic operating conditions.**

***Index Terms*—Common arm type, inverter, Arduino uno, transformer-based inverters.**

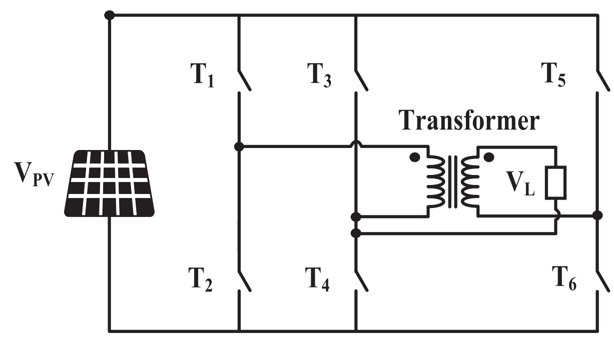

Fig. 1. Proposed Five Level Inverter.

I. Introduction

Two-level inverters are the most commonly used type, and they generate output by alternating between two distinct voltage levels produced by voltage sources [1]. Recent advancements in power transistors, specifically MOSFETs and IGBTs, have led to the increased adoption of voltage source inverters (VSIs), especially in high-power and photovoltaic applications [2]. This shift is mainly due to the improved efficiency of MOSFETs and IGBTs compared to their older counterparts. However, the voltage limitations of power transistors pose challenges for two-level inverters in these scenarios. Consequently, multilevel inverters, also known as MLIs, have gained popularity as a solution to handle higher voltage requirements effectively [3].

Multilevel inverters (MLIs) achieve voltage conversion by manipulating the output voltage across multiple distinct levels through a series of interconnected inverter modules. Their popularity has increased, especially in high-power applications that require higher voltage outputs [4]. MLIs are especially valuable in situations demanding substantial power due to their capacity to seamlessly connect with renewable energy sources like solar panels and batteries. For example, MLIs enable the efficient and effective injection of surplus solar energy into power grids [5].

The most commonly used configurations for multilevel inverters (MLIs) are the neutral point MLI, flying capacitor MLI, and cascaded H-bridge (CHB) MLI. These MLI setups have subtypes within them [6], [7]. Notably, the CHB MLI is distinct from the other two as it does not require dividing the capacitor banks into multiple halves. In the past, many designs for diode-clamped and capacitor-clamped multilevel inverters have been limited to producing three-level output voltage waveforms due to variations in input voltage [8]. These three-level inverter configurations have reached a mature stage in industry and are being manufactured to meet various levels of demand. On the contrary, the CHB MLI does not have this limitation on the output voltage level. The cascaded H-bridge multilevel inverter, also known as CHB-MLI, is based on a series connection of H-bridge inverters [9]. This configuration, compared to other MLIs operating at the same voltage level, uses fewer switches. Each H-bridge in the CHB-MLI can generate three distinct levels of output voltage using a unipolar modulation strategy. Additionally, the CHB-MLI can create its own Direct Current (DC), making it particularly useful in renewable energy applications, especially in the production of photovoltaic modules. The characteristics of the cascaded H-bridge MLI have proven to be a valuable solution for a wide range of applications [10].

The adoption of MLIs leads to an escalation in the quantity of switches and passive elements like capacitors and diodes, thereby raising the overall complexity. Scientists are consistently striving to address these challenges by innovating new MLI configurations. Although some are mainly focused on reducing Total Harmonic Distortion (THD), others have proposed the use of cascaded MLI arrangements as a means to reduce the number of switches [11].

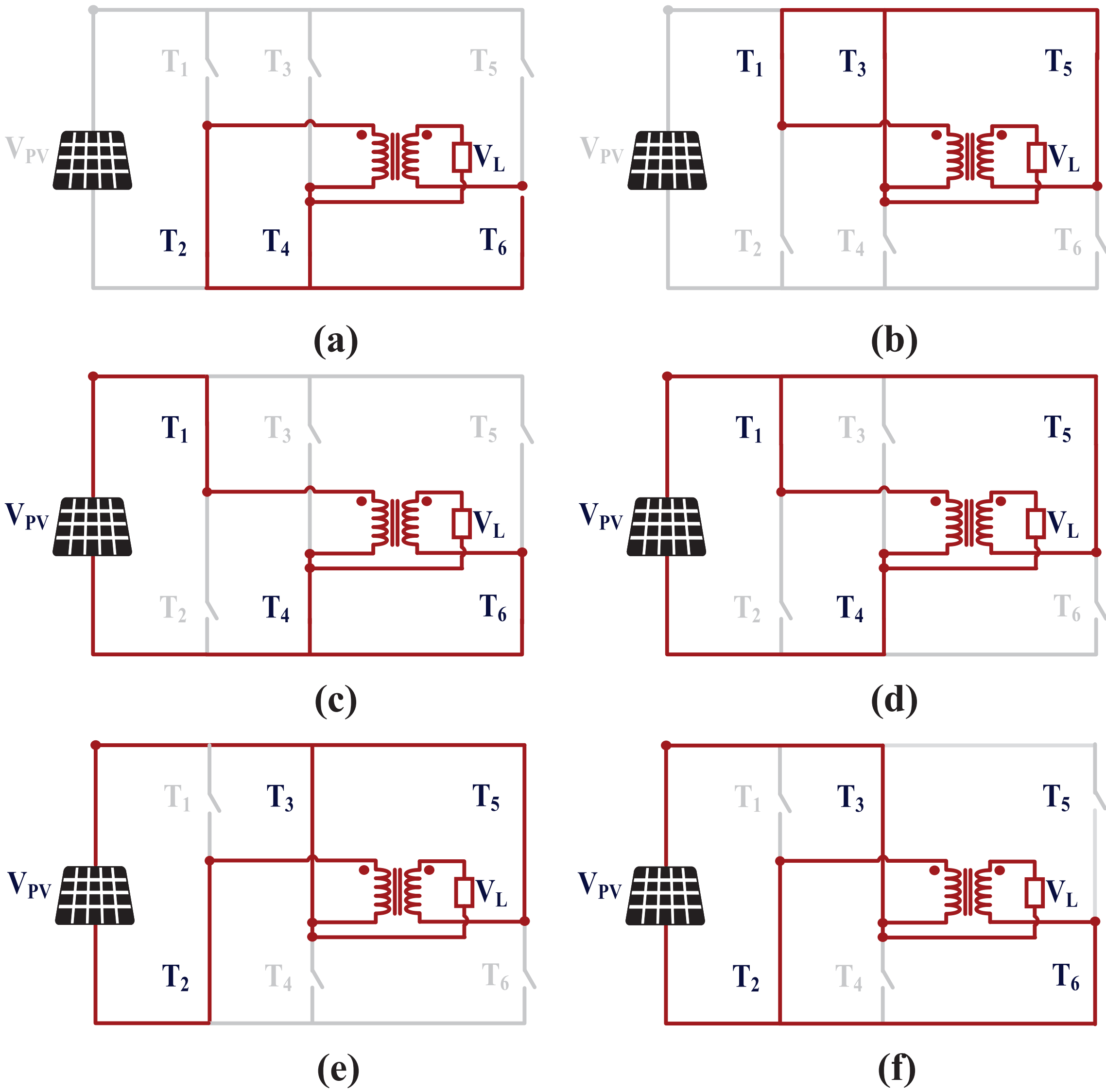

Fig. 2. Proposed inverter output voltage levels : (a) V_L = 0, (b) V_L = 0, (c) V_L = V_{PV}, (d) V_L = $2V_{PV}$, (e) V_L = $-V_{PV}$ and (f) V_L = $-2V_{PV}$

This article introduces a design for a multilevel inverter that utilizes an arrangement involving the H-bridge inverter and a single transformer with one power source. This design is referred to as the ”proposed five-level inverter. Combining these elements increases the number of voltage levels generated by the inverter, while also requiring fewer components compared to traditional multilevel inverter setups to achieve the same voltage levels. The suggested topology is constructed and simulated within the SIMULINK environment, with simulations conducted under various load conditions, and by using Arduino Uno programming, the required number of switching pulses are generated to the proposed inverter.

Here is a list of advantages provided by the proposed inverter:

- The topology has the potential to step up the input voltage.
- To produce voltages across all five levels, only six switches with a transformer are required.
- The generation of five voltage levels is ensured with at least the specified number of switches and drivers.
- Capacitors are not utilized in any manner within this topology.
- It performs effectively in photovoltaic applications.

The paper structure is outlined as follows: Section II outlines the fundamental operational principles of the proposed inverters, while Section III delves into the programming for these inverters using Arduino. Additionally, Section IV covers the implementation of simulations and discusses the results using MATLAB/Simulink. and Section V provides a summary of the research discoveries.

II. PROPOSED INVERTER STRUCTURE

The configuration depicted in Fig. 1 illustrates a five-level inverter structure that uses three half-bridges. It consists of

TABLE I
SWITCHING TABLE OF PROPOSED FIVE LEVEL INVERTER

V_L	T_1	T_2	T_3	T_4	T_5	T_6
$2V_{PV}$	1	0	0	1	1	0
V_{PV}	1	0	0	1	0	1
$0V_{PV}$	1	0	1	0	1	0
$0V_{PV}$	0	1	0	1	0	1
$-V_{PV}$	0	1	1	0	1	0
$-2V_{PV}$	0	1	1	0	0	1

six controllable switches and one transformer, namely T_1 to T_6, each accompanied by its intrinsic diode. Additionally, the circuit incorporates single DC sources. Within this inverter design, a three-leg inverter is used to produce five distinct output voltage levels: 2 times the DC voltage ($2V_{PV}$), the DC voltage (V_{PV}), zero volts ($0V_{PV}$), negative DC voltage ($-V_{PV}$) and negative two times the DC voltage ($-2V_{PV}$).

The five-level operations use the switching method described in Table I. The voltage levels are generated according to the configuration depicted in Fig. 2. The operational conditions are explained below:

- Fig. 2(a) also shows that the zero voltage level of the proposed inverter by turning on the switches T_2, T_4 and T_6, remaining switches are in turnoff conditions. In this scenario, the load is isolated from the input power source so that the load voltage is zero.
- Fig. 2(b) shows that the zero voltage level of the proposed inverter is reached by turning on the switches T_1, T_3 and T_5, the remaining switches are in turn-off conditions. In this scenario, the load is isolated from the input power source so that the load voltage is zero.
- Fig. 2(c) shows that the first positive voltage level of the proposed inverter when turning on the switches T_1, T_4 and T_6, the remaining switches are in turnoff conditions. In this scenario, the load is supplied by the input power source with the load voltage of V_{PV}.
- Fig. 2(d) shows that the second positive voltage level of the proposed inverter by turning on the switches T_1, T_4 and T_5, remaining switches are in turnoff conditions. In this scenario, the load is supplied by the input power source and transformer with the load voltage of $2V_{PV}$.
- Fig. 2(e) shows that the first negative voltage level of the proposed inverter when turning on the switches T_2, T_3 and T_5, the remaining switches are in turnoff conditions. In this scenario, the load is supplied by the input power source with the load voltage of $-V_{PV}$.
- Fig. 2(f) shows that the second negative voltage level of the proposed inverter by turning on the switches T_2, T_3 and T_6, remaining switches are in turnoff conditions. In this scenario, the load is supplied by the input source and transformer with the load voltage of $-2V_{PV}$.

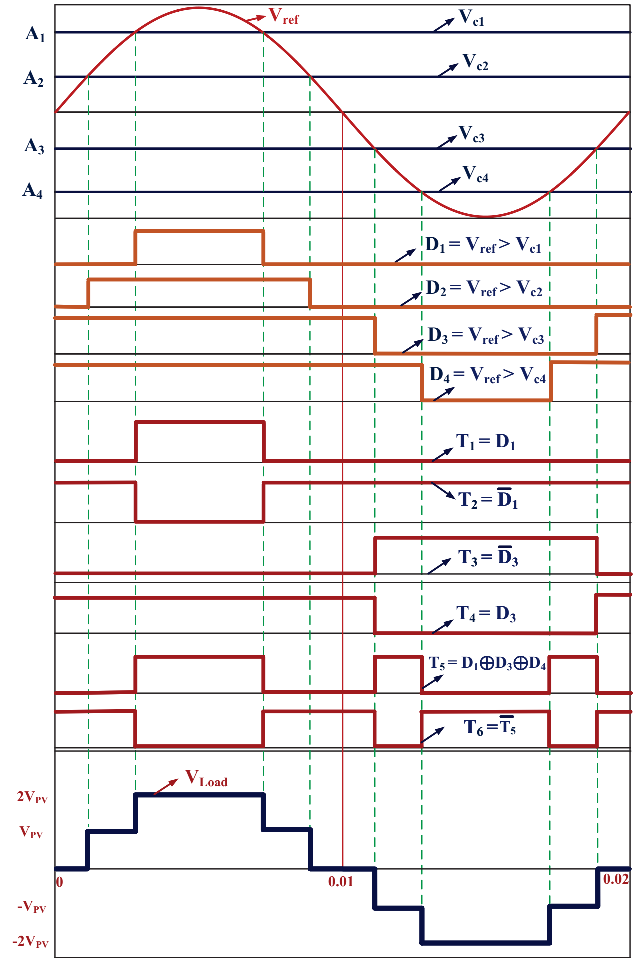

Fig. 3. Switching scheme of the proposed inverter

III. ARDUINO UNO PROGRAMMING FOR PROPOSED INVERTER

The Arduino Uno is used as a microcontroller-based tool or platform to generate switching signals for all switches within the proposed five-level inverter. Consequently, the functionalities of the Arduino Uno are contingent on the specific code loaded into it. The programming codes required to generate the pulse signals needed to control the six power semiconductor devices within the inverter are created using the Arduino software integrated development environment (IDE). Figure 3 illustrates the anticipated switching pulses for all the switches in the proposed five-level inverter, and Table II offers a comprehensive overview of the programming code.

IV. RESULTS AND DISCUSSIONS

A multilevel inverter was designed in the present analysis, and its operation was simulated using MATLAB/Simulink. Table III outlines the specific requirements that need to be satisfied when working with MATLAB/Simulink. The sinusoidal

TABLE II

ARDUINO UNO PROGRAMMING CODE FOR THE PROPOSED INVERTER.

```
#define PI 3.14159265358979323846264338327 95
#define pinT1 3 #define pinT2 5
#define pinT3 6 #define pinT4 9
#define pinT5 10 #define pinT6 11
#define A1 4 #define A2 2
#define A3 -2 #define A4 -4
void setup() { pinMode(pinT1,OUTPUT);
pinMode(pinT2,OUTPUT); pinMode(pinT3,OUTPUT);
pinMode(pinT4,OUTPUT); pinMode(pinT5,OUTPUT);
pinMode(pinT6,OUTPUT); Serial.begin(9600);
} void loop() { for (int t=0;t<360;t++)
{ float y1=6*sin((100*PI*t)+180);
Serial.print(y1); Serial.print(" ");
int value1,value2,value3,value4,value5,value6;
if( A1 < y1) { value1=HIGH; }
else { value1=LOW;} if( A2 < y1) { value2=HIGH;}
else{ value2=LOW;} if( A3 < y1){value3=HIGH;}
else{ value3=LOW;} if( A4 < y1) { value4=HIGH;}
else{value4=LOW;} if( A2 < y1) {value5=LOW;}
else { value5=HIGH; }if( A3 < y1){ value6=LOW;}
else{ value6=HIGH;}
digitalWrite(pinT1,value2); digitalWrite(pinT2,value5);
digitalWrite(pinT3,value6); digitalWrite(pinT4,value3);
int result; if(value1==LOW && value3==LOW && value4==LOW)
{result=LOW;}
else if(value1==LOW && value3==LOW && value4==HIGH)
{result=HIGH;}
else if(value1==LOW && value3==HIGH && value4==LOW)
{result=HIGH;} else if(value1==LOW && value3==HIGH
&& value4==HIGH) {result=LOW;}
else if(value1==HIGH && value3==LOW && value4==LOW)
{result=HIGH;} else if(value1==HIGH && value3==LOW
&& value4==HIGH) {result=LOW;}
else if(value1==HIGH && value3==HIGH && value4==LOW)
{result=LOW;}
else if(value1==HIGH && value3==HIGH && value4==HIGH)
{result=HIGH;}
digitalWrite(pinT5,result);int comp;
if(result==HIGH){comp=LOW;}else{comp=HIGH;}
digitalWrite(pinT6,comp);}}
```

TABLE III

SIMULATION PARAMETERS

Items	Value
DC Link Voltage (V_{PV})	50 V
Transformer	1:1 ratio
Load Voltage (V_L)	100 V (Peak)
Output Frequency	50 Hz
Load resistance and inductance	R=20 Ω, L=30 mH

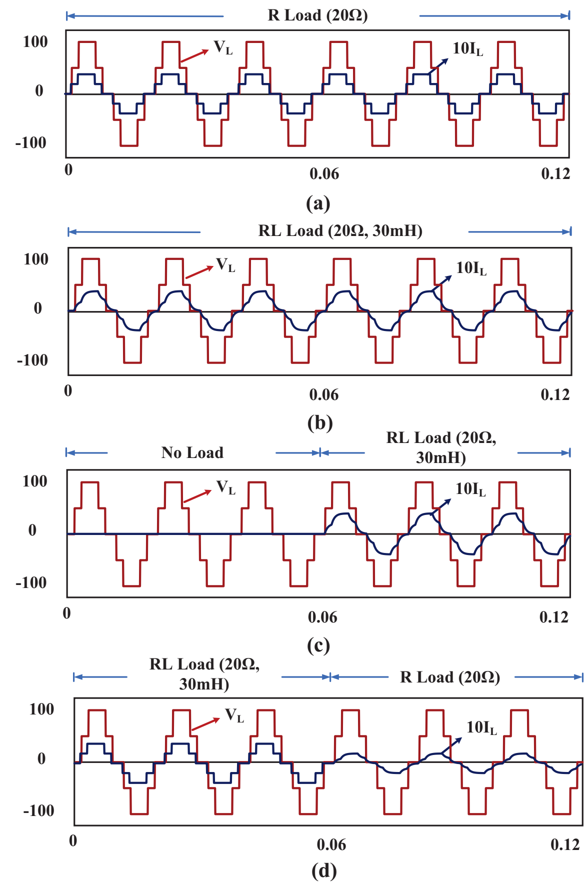

Fig. 4. Simulation results for (a) Load voltage for R Load, (b) Load current for R load, (c) Load voltage for RL load and (d) Load current for RL Load.

pulse width modulation (SPWM) technique was employed to generate the switching signals for the proposed inverter. In SPWM, the reference signal takes the form of a sinusoidal waveform, while each of the four carrier signals is triangular. Decision signals are then derived by comparing the carrier signals with the reference signals. The suggested inverter can be generated by performing logical operations on these decision signals in the correct sequence. Subsequently, these switching pulses are dispatched to each switch within the proposed inverter to produce a load voltage with five distinct levels. Figure 3 displays all the switch pulses used in the proposed inverter. In Figure 4, the results of simulations con-

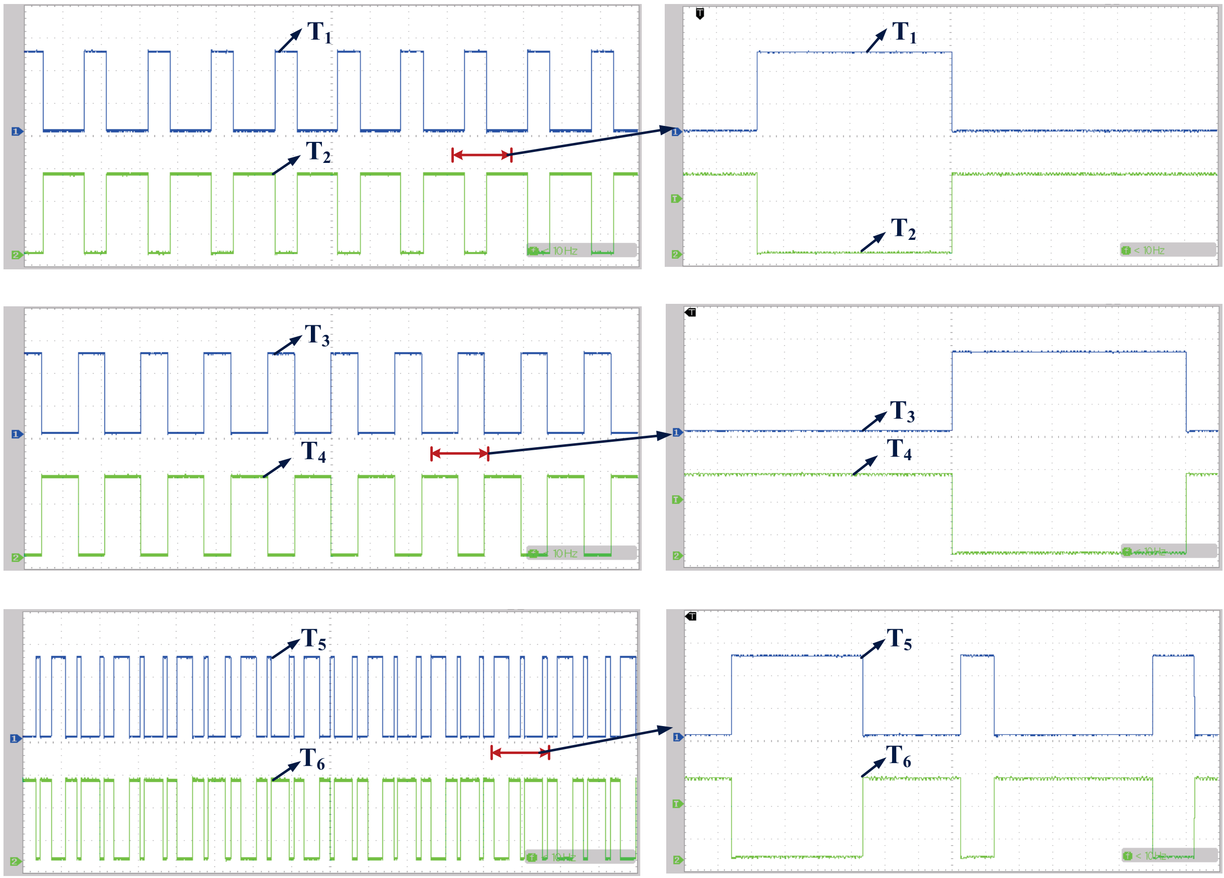

Fig. 5. Switch pulses for all the switches generated by Arduino Uno.

ducted on the recommended five-level inverter are graphically represented. This proposed inverter is capable of delivering a load voltage and current that can be adjusted to one of five different levels, as depicted in Fig. 4(a) for R load. Moreover, Fig. 4(b) presents the load waveforms for the RL load in the proposed circuit. Additionally, Fig. 4(c) & (d) illustrates the load current and voltage that the proposed inverter under the dynamic conditions. Based on the outcomes of these simulations, it has been determined that the presented inverter is suitable for photovoltaic applications. The proposed inverter employs an Arduino Uno as the component responsible for generating all the switching pulses, enabling the generation of a voltage that can be adjusted to five distinct levels. Figure 5 provides a visual representation of the pulses generated by the switches $\mathrm{T}_1 - \mathrm{T}_6$ in the suggested inverter.

V. Conclusion

This article introduces a five-level inverter with a common arm transformer design that utilizes only six switches and a single transformer to achieve a doubled voltage gain. The article provides a thorough explanation of the circuit's structure and how it operates. The key advantages of this inverter design include its minimal component count, reduced number of active switches, lower overall cost, and a smaller physical footprint. Additionally, the article emphasizes using Arduino programming to generate the necessary control signals for this five-level inverter. Furthermore, it discusses the validation of the inverter through simulation results, demonstrating its practicality and performance under both steady-state and transient operating conditions.

References

[1] D. G, M. H. Khan, and B. Mangu, "Novel nine-level dual boost capacitor based inverter with single dc source," in *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*, 2023, pp. 1–5.

[2] D. G, B. Mangu, and M. H. Khan, "A capacitor-based boost nine-level inverter with less switching device count," in *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*, 2023, pp. 1–5.

[3] S. Behara, N. Sandeep, and U. R. Yaragatti, "Design and implementation of transformer-based multilevel inverter topology with reduced components," *IEEE Transactions on Industry Applications*, vol. 54, no. 5, pp. 4632–4639, 2018.

[4] B. H. Krishna, K. K. Vanukuru, and J. Subrahmanyam, "Design of a new transformer based multilevel inverter with single source for pv applications," in *2022 International Conference on Futuristic Technologies (INCOFT)*, 2022, pp. 1–6.

[5] B. Nageswar Rao, Y. Suresh, B. Shiva Naik, J. Venkataramanaiah, K. Aditya, and A. Kumar Panda, "A novel single source multilevel inverter with hybrid switching technique," *International Journal of Circuit Theory and Applications*, vol. 50, no. 3, pp. 794–811, 2022.

[6] A. P. Monteiro, F. A. da Costa Bahia, C. B. Jacobina, and R. P. R. de Sousa, "Cascaded transformers-based multilevel inverters with npc," *IEEE Transactions on Industrial Electronics*, 2021.

[7] J.-J. Shieh, K.-I. Hwu, and Y.-Y. Li, “Analysis and modeling of a single-power-source t-type 7-level single-phase dc-ac inverter with voltage gain of 3,” *Energies*, vol. 15, no. 21, 2022.

[8] S. Salehahari, E. Babaei, S. H. Hosseini, and A. Ajami, “Transformer-based multilevel inverters: analysis, design and implementation,” *IET Power Electronics*, vol. 12, no. 1, pp. 1–10, 2019.

[9] T. Debela, J. Singh, and V. K. Sood, “Evaluation of a grid-connected reduced-component boost multilevel inverter (bmli) topology,” *International Journal of Circuit Theory and Applications*, 2022.

[10] B. N. Rao, Y. Suresh, A. K. Panda, B. S. Naik, and V. Jammala, “Development of cascaded multilevel inverter based active power filter with reduced transformers,” *CPSS Transactions on Power Electronics and Applications*, vol. 5, no. 2, pp. 147–157, 2020.

[11] B. N. Rao, Y. Suresh, B. S. Naik, and K. Aditya, “A novel seven level inverter with common-leg configuration by employing transformers,” in *2022 IEEE 3rd Global Conference for Advancement in Technology (GCAT)*, 2022, pp. 1–6.