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Implementation of Coupled Inductor Based 7-level Inverter with Reduced Switches

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ABSTRACT

This paper proposes implementation of coupled inductor based 7 level inverter with reduced number switches. The inverter which generates the sinusoidal output voltage by the use of coupled inductor with reduced total harmonic distortion. The voltage stress on each switching devices, capacitor balancing and common mode voltage can be minimized. The proposed system which gives better controlled output current and improved output voltage with diminished THD value. The switching devices of the system are controlled by using hysteresis current control algorithm by comparing the carrier signals with constant pulses with enclosed hysteresis band value. The simulation and experimental results of the proposed system outputs are verified using matlab/Simulink and TMS320F3825 dsp controller respectively.

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1. INTRODUCTION

In recent days multilevel inverter becomes more popular for high power and medium voltage, industrial and power quality improvement based applications. As the output of increasing the new technologies, which increases the demand in quality level of electric power and enhancement of the system [1]. The inverter power circuit is obligatory for converting the dc source into ac source applications like induction motor, servo motor, synchronous motor, etc,. Similarly for improved power semiconductor switches, the rating, power quality level and difficulties in the device also starts increasing [2]-[3]. In MLI, has acquired great industrial importance mainly due to its advantages, such as lower common mode voltage, lower voltage stress on power switches, lower dv/dt ratio to supply lower harmonic contents in output voltage and current, drastically improved dynamic performance, extended operating range, reduced line harmonics, and an adjustable power factor at the point of common coupling To control this power circuit proper pulse width control methodologies are used [4]-[6].

Nowadays the amount power quality devices are starts increasing, due to that the amount of harmonic content in the circuit also increasing. To minimize the harmonic content level less than the IEEE standard, the suitable pulse width modulation strategies has to be implemented. At the same time, to encounter the industrial or domestic applications requirement the rated power semiconductor devices are used [7]-[10].

The main drawback in the conventional inverter, voltage stress on the each power semiconductor switch is increasing [11], [12]. Due to that multilevel inverter came to action in more, even though while moving to n number of levels voltage stress in the switch, cost of the device and control methods like switching pulse generation, voltage and current control becomes more complicated. To avoid these difficulties, the implementation of n level inverter power circuit using reduced switches method [13], [14].

The [15] main task of this control technique is to force the actual current vector to reach the reference current vector. This original strategy consists in defining two hysteresis bands around the error current vector. Then, according to the location of this error vector, a selection process of the next applied vector is used to minimize the error vector [16], [17]. And based on the simple lookup tables to determine the switching time calculation and switching pulses. Finally it gives the gating pulses to recommend to inverter power circuit [18].

In this proposed method, implementation of coupled inductor based 7 level inverter with reduced number switches. The main purpose of the system to reduce the voltage ratings of power switch, reduced di/dt production, reduced harmonic distortion, multilevel output voltage with combined voltage values, lower switching frequency and cost of system is low. And coupled inductor avoid the usage of transformer and its used to synchronize with ac applications. To control this system hysteresis current control method implemented with matlab- simulink and dsp controller.

2. POWER CIRCUIT

2.1. Circuit Structure

In Figure 1 shows power circuit of 7 level inverter, which consists of dc link capacitor C_1, C_2, C_3 across the applied dc source. Power semiconductor switches S_1, S_2, S_3 and S_4 and freewheeling diodes D_1, D_2, D_3, and D_4 are used to combine the voltages to acquire the 7 level voltages. And which contains conventional 2 level VSI circuit is added with front circuit, which consists of power switches S_5, S_6, S_7, and S_8 and coupled inductor is used connect with load circuit.

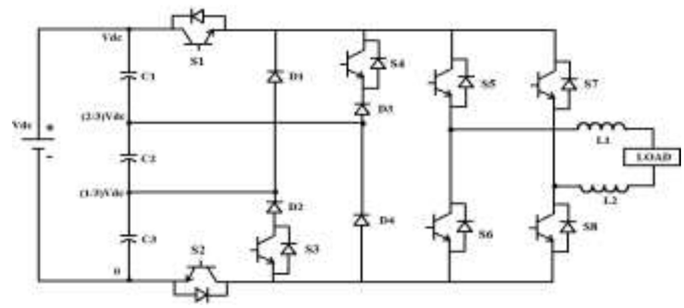


Figure 1. Power circuit of 7-level voltage inverter

2.2. Modes of Operation

From the power circuit of 7-level voltage inverter has the following seven switching mode combinations. In that mode 1-3 shows the positive voltage level switching combinations, mode 4-6 shows negative voltage level switching combinations and mode 7 shows zero voltage level switching combination.

Mode 1: to attain the output voltage level as $+V_{dc}$, the switches S_1, S_2, S_5, and S_8 kept in ON condition. Here none of the freewheeling diode in ON condition has shown in Figure 2.a.

Mode 2: to obtain the output voltage level as $+\frac{2}{3}V_{dc}$, the switches S_1, S_3, S_5, and S_8 kept in ON condition. And here freewheeling diode D_2 in ON condition has shown in Figure 2.b.

Mode 3: to acquire the output voltage level as $+\frac{1}{3}V_{dc}$, the switches S_1, S_5, and S_8 kept in ON condition. And here freewheeling diode D_4 in ON condition has shown in Figure 2.c.

Mode 4: to generate the output voltage level as $-V_{dc}$, the switches S_1, S_2, S_6 and S_7 kept in ON condition. And none of the freewheeling diode in ON condition has shown in Figure 3.a.

Mode 5: to obtain the output voltage level as $-\frac{2}{3}V_{dc}$, the switches S_2, S_4, S_6 and S_7 kept in ON condition. And here freewheeling diode D_3 in ON condition has shown in Figure 3.b.

Mode 6: to acquire the output voltage level as $-\frac{1}{3}V_{dc}$, the switches S_2, S_6 and S_7 kept in ON condition. And here freewheeling diode D_1 in ON condition has shown in Figure 3.c.

Mode 7: to gain the output voltage level as 0, the switches S_5 and S_7 kept in ON condition. And here none of the freewheeling diode in ON condition has shown in Figure 4.

The switching combinations for 7-level output voltage level with positions of various capacitors, switches and freewheeling diodes are shown in Table 1.

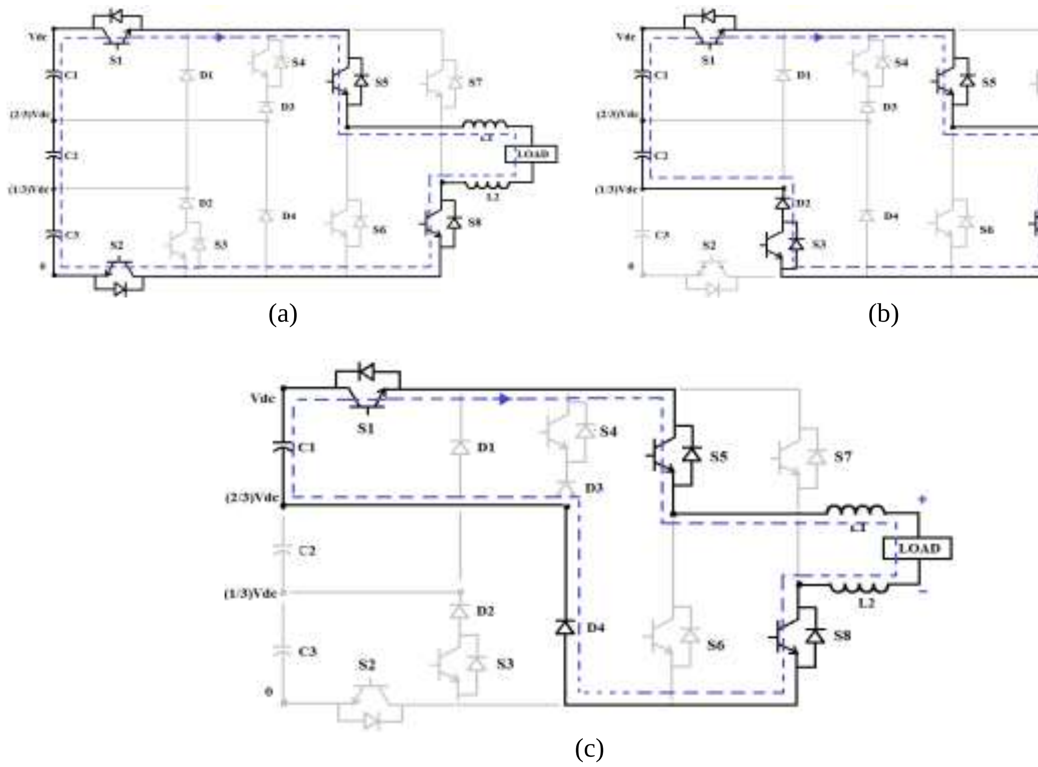


Figure 2. Positive switching voltage levels (a) + V_{dc}; (b) + (2/3)V_{dc}; (c) + (1/3)V_{dc}

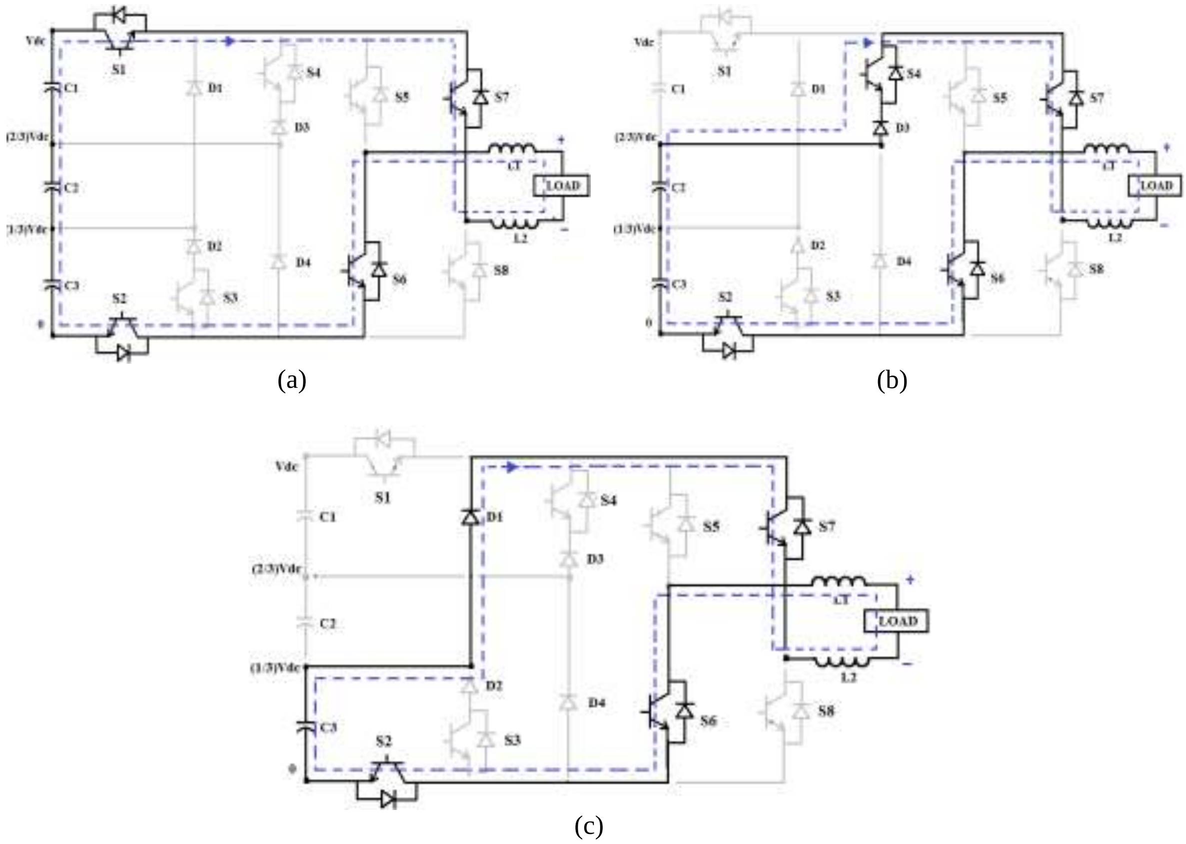


Figure 3. Negative switching voltage levels (a) - V_{dc}; (b) - (2/3)V_{dc}; (c) - (1/3)V_{dc}

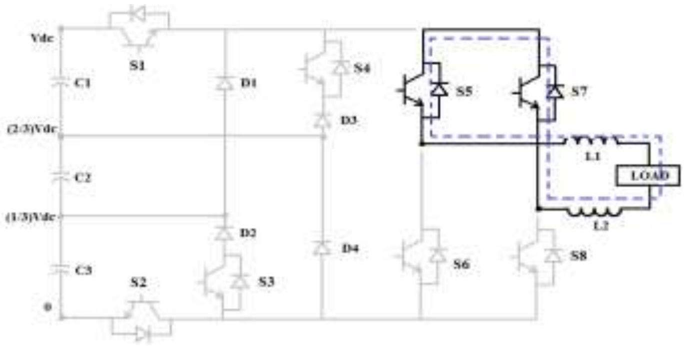
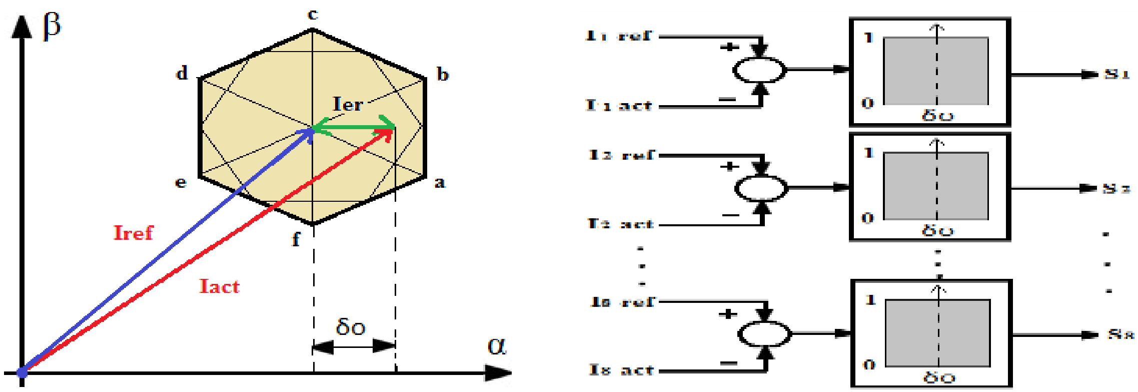


Figure 4. Zero switching voltage level (V_O=0)

3. HYSTERESIS CURRENT CONTROL

In order to analyze the correct multilevel operation, the control system has to perform two error bands. It must generate the correct voltage vector and hence the correct multilevel output waveform. At the same time, it must maintain the same voltage across the dc link capacitors. The hysteresis current control decides on the magnitudes of error for an 'n' inverter can be linked with number of bands around the reference vectors. Based on the error current value the hysteresis band h and h_1 will be decided, the output voltage level of the proposed system depends on the variation of hysteresis band. The error decided by difference between the variation actual current measured from the system and reference current value.



(a) (b)

Figure 5. HCC (a) schematic diagram; (b) error current

Table 1. Switching combinations for 7-level output voltage

Output voltage level	Capacitors ON	Switches ON	Freewheeling diode ON
+ V_{dc}	C1, C2, C3	S1, S2, S5, S8	-
+ $\frac{2}{3}$ V_{dc}	C1, C2	S1, S3, S5, S8	D2
+ $\frac{1}{3}$ V_{dc}	C1	S1, S5, S8	D4
0	-	S5, S7	-
- V_{dc}	C1, C2, C3	S1, S2, S6, S7	-
- $\frac{2}{3}$ V_{dc}	C2, C3	S2, S4, S6, S7	D3
- $\frac{1}{3}$ V_{dc}	C3	S2, S6, S7	D1

The hysteresis current control schematic diagram and error current calculation is shown in Figure 5a and Figure 5b. The HCC control is applied for 7-level power inverter circuit to obtain the output voltage levels are + V_{dc}, + $\frac{2}{3}$ V_{dc}, + $\frac{1}{3}$ V_{dc}, 0, - V_{dc}, - $\frac{2}{3}$ V_{dc}, - $\frac{1}{3}$ V_{dc}. The output voltage of the inverter related the R-L load express in the following Equation 1. And Figure 6 shows the output voltage changes based on error current variation using hysteresis current control for proposed inverter.

$$V_{inv} = R_i + L\frac{di}{dt} + V_b \quad (1)$$

From Figure 6 the variation 7-level inverter power circuit output voltage obtained, when variation occur in the current error. When it attains the point c, the voltage reaches maximum in positive is $+V_{dc}$. Then it reaches the point i, the voltage reaches maximum in negative range. Similarly, the output voltage varies from positive voltage level to negative voltage level obtained, when the error current variation occurs from point a to l. The following equations based on the variation of hysteresis band value the actual current changes occur in the proposed system to maintain the error value in the system.

$$I_{8\_error} = I_{8\_ref} - I_{8\_act} \quad (2)$$

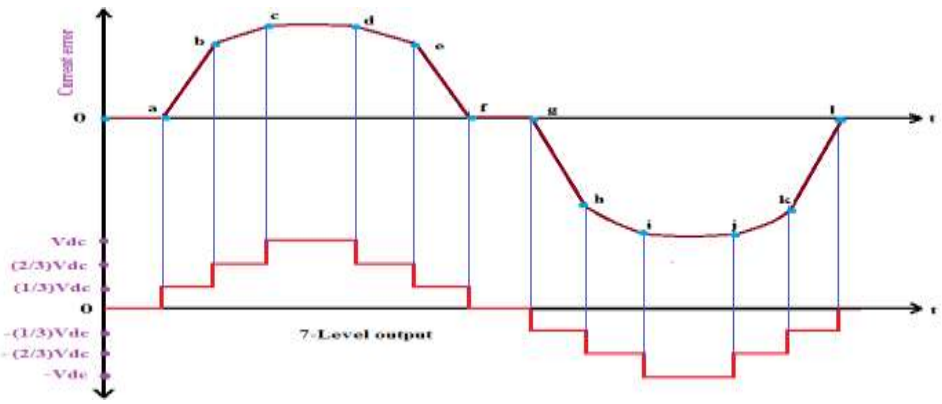


Figure 6. Hysteresis current control for 7-level inverter circuit

Hysteresis current control, which is a nonlinear control method, possesses high performance, simple realization circuit, high stability, inherent current-limiting capability, and fast dynamic response hysteresis band real-time regulation is,

$$\text{Hysteresis band (h)} = \frac{u_g(U_{pv} - 2u_g)}{U_{pv}.L.f_s} \quad (3)$$

represent the error current value for three phase ac currents.

$$I_{1\_error} = I_{1\_ref} - I_{1\_act} \quad (4)$$

$$I_{2\_error} = I_{2\_ref} - I_{2\_act} \quad (5)$$

4. SIMULATION RESULTS

The performance of the 7-level inverter power system validated by using MATLAB simulation under different hysteresis band operating conditions. The simulation results are obtained with the following elements: dc link capacitors are C1 = C2 = C3 = C4= 100 micro Farad, and split inductor L =5 mH and applied voltage of Vs = 200 V; the hysteresis band constants are $h_1 = 0.3$ and $h_2 = 0.3$. The motor is a 1HP induction motor with a rated voltage of 220V and current of 5A. An open loop constant V/f control is used to regulate the motor speed and the dc-link voltage is set at 200V.

In the proposed system, the output voltage and current with coupled inductor based 7-level inverter with 163.3 V and 32.24 A respectively shown in Figure 7. In Figure 8 shows the THD analysis of output voltage and current of 0.06% and 2.17% respectively. Coupled inductor which avoids the usage of transformer and the coupled inductor current waveform is shown in Figure 9.

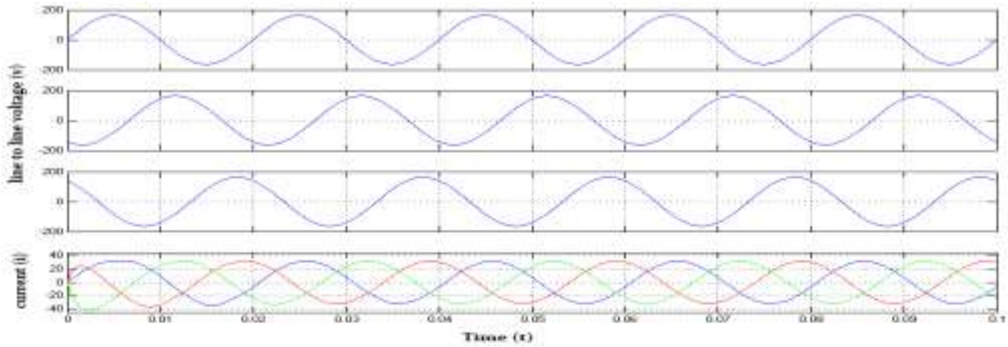
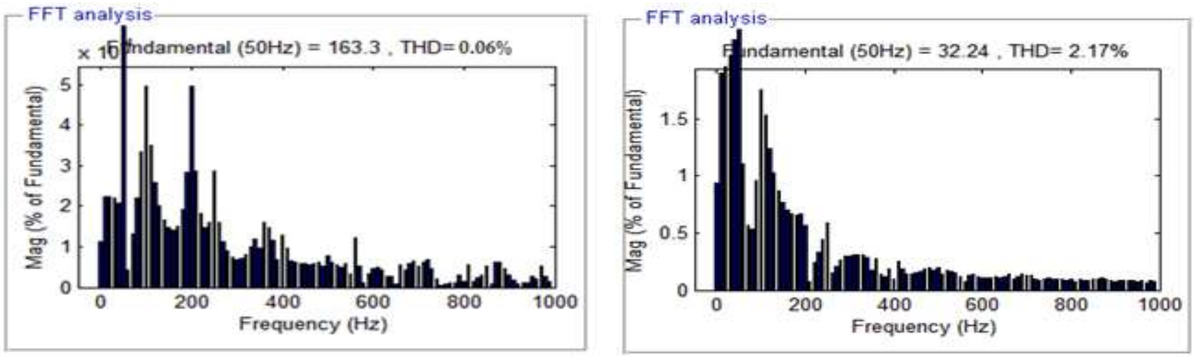


Figure 7. Output voltage and current with coupled inductor based 7-level inverter



(a) (b)

Figure 8. THD analysis (a) output voltage (b) output current

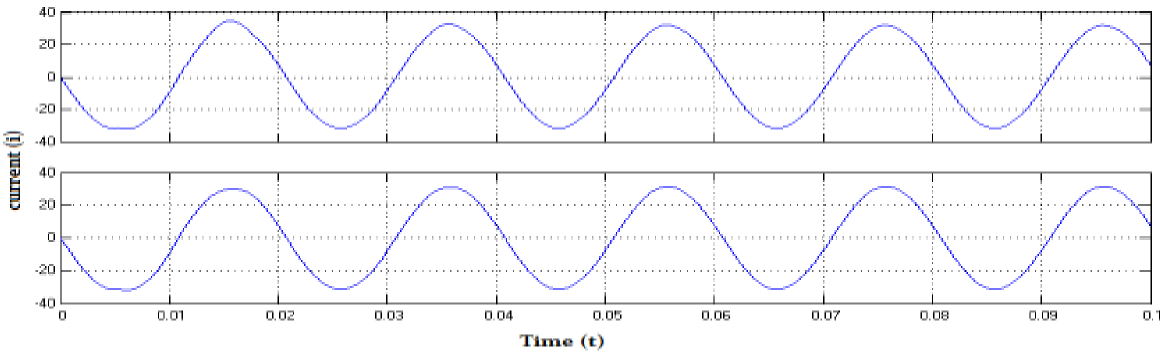


Figure 9. Coupled inductor output current waveform

In Figure 10 shows the comparison of reference current and actual current of the proposed system. And in Figure 11 shows the output current comparison of Sinusoidal pulse width modulation and Hysteresis current control. Figure 12 shows the X-Y chart of hysteresis band variation to obtain the 7-level proposed output waveform and the comparison of various parameters like dc source, DC link capacitors, Power switches, Freewheeling diodes, Voltage Utilization and THD level for different multilevel inverter topologies are shown in Table 2.

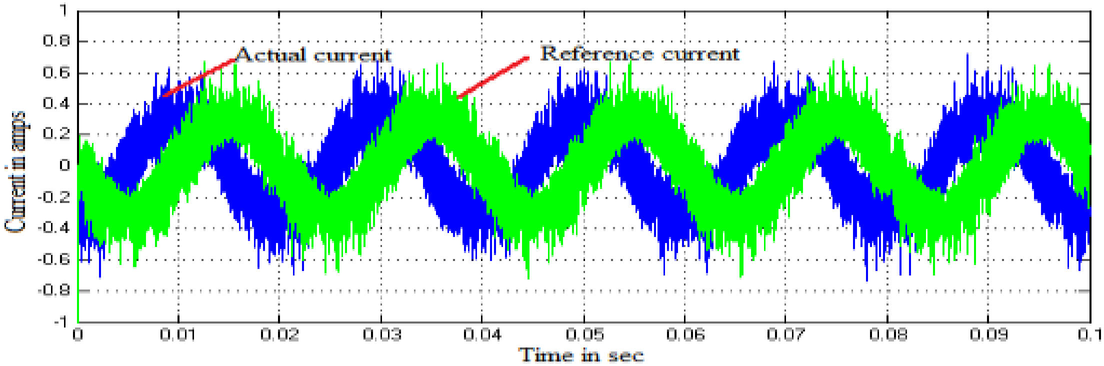


Figure 10. Comparison of reference current and actual current

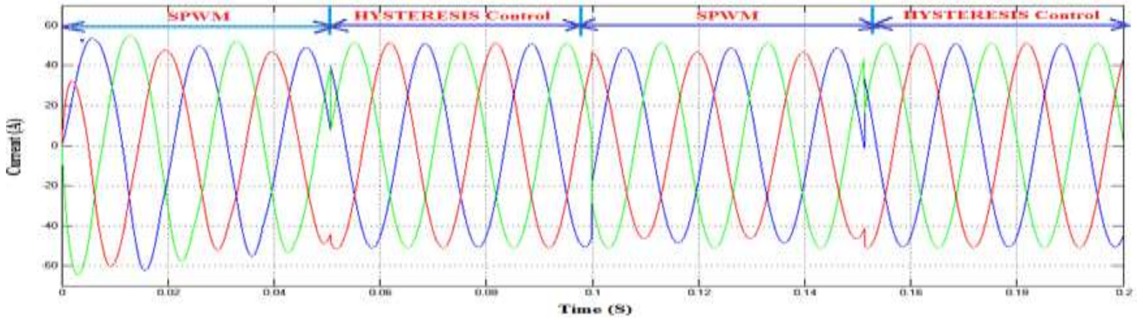


Figure 11. Output current comparison of SPWM and Hysteresis control

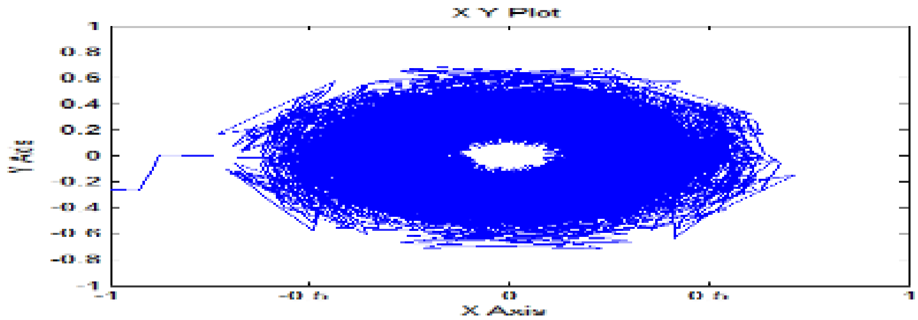


Figure 12. X-Y chart of hysteresis band variation

Table 2. Result discussion for different topologies for 7-level output voltage

Features/Topologies	Proposed	Diode clamped	H-bridge	Flying capacitor
DC source	1	1	3	1
DC link capacitors	3	6	3	2
Power switches	8	12	12	12
Freewheeling diodes	4	10	0	0
Voltage Utilisation	91%	88%	88%	87%
THD level	0.06%	1.2%	1.6%	1.2%

5. EXPERIMENTAL SETUP

To confirm the simulation results of the 7-level inverter proposed system, experimental setup of coupled inductor based 7-level inverter with reduced switches for hysteresis current control with hysteresis band variation designed and tested. Input supply of 200 V ac is converted to 162.4 V dc using proposed inverter system.

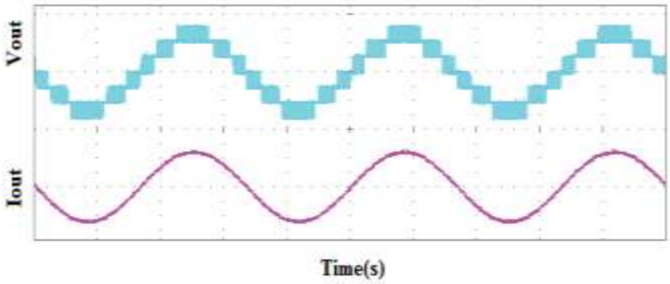


Figure 13. Output voltage & current of proposed system at modulation index 0.98

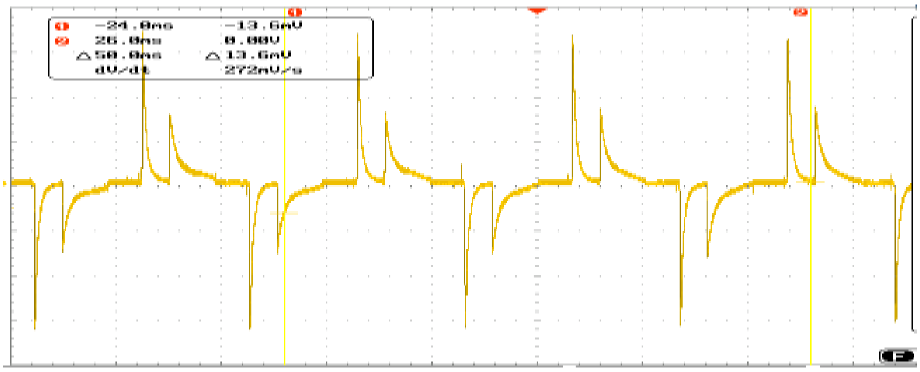
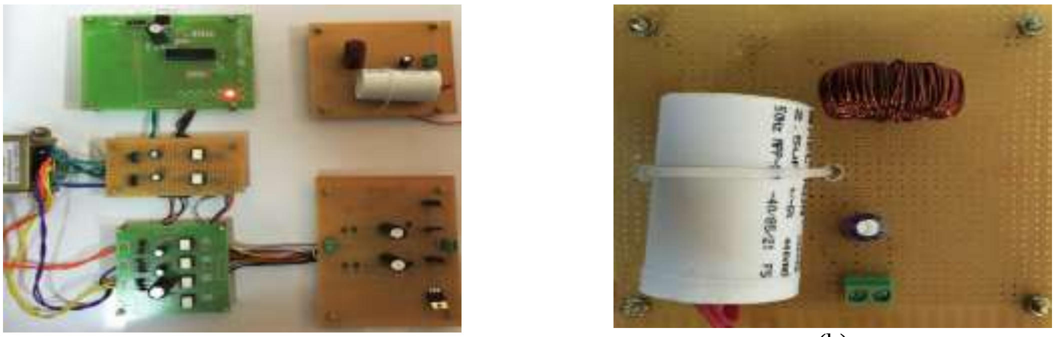


Figure 14. Output current of proposed system at modulation index 0.89



(a) (b)

Figure 15. Snapshot of hardware setup (a) driver circuit and power switches (b) coupled inductor

At modulation index 0.98, the staircase output voltage of 162.4 V is obtained at the proposed 7-level inverter and sinusoidal output for the same attained by using coupled inductor between the inverter and load system at is shown in Figure 13. In Figure 14 shows the output current of 5.9 A at modulation index of 0.89. Figure 15a shows the hardware setup of coupled inductor based 7-level inverter with IRF 840 MOSFET switches were used for the Inverter legs and coupled inductor is shown in Figure 15b. The output waveforms are obtained on Digital Storage Oscilloscope (DSO). Hysteresis current control is implemented using dsp controller fed with 5V dc voltage.

6. CONCLUSION

Implementation of transformer less coupled-inductor based 7-level inverter power circuit with high consistency and low-leakage current characteristics has been presented in this paper. The proposed inverter features low device voltage stress and constant common-mode voltage, which exists in the traditional 7-level inverter power circuit structure. At the same time, it can escape the shoot-through problem and current control of inverter attained by using hysteresis current control, which guarantee for reducing of capacitor balancing and eliminating of common mode voltage. The proposed inverter can achieve high efficiency, low cost, low leakage current and high reliability to satisfy the requirements of the transformerless inverter.

a. Achieved current control and voltage control of 7-level proposed inverter system with THD of 2.17% & 0.06% respectively.
b. Avoid the shoot through problem and CMV problem in this proposed system
c. Proposed system avoids the usage of Transformer.

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