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# A novel impedance source fed H-type flying capacitor multilevel inverter

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**ABSTRACT**

In this paper, simulation using MATLAB/SIMULINK is performed with bipolar triangular fixed amplitude multi-carrier Phase Disposition (PD) PWM strategy with sine wave, Third Harmonic Injection, 60-degree Pulse Width Modulation and stepped wave reference for the chosen impedance Source based H-Type flying capacitor Multilevel Inverter (ISBH-Type FCMLI). The root means square value of the fundamental component and Total Harmonic Distortion of the output voltage which are the most important performance indices for the chosen inverter topologies are evaluated presented and compared for various references through duty ratios. From the simulation results it is observed that for various references the THD is almost similar but the root mean square value in terms of voltage is more for THI, 60-degree PWM and stepped wave reference with phase disposition strategy. The results are obtained for ma (amplitude modulation index) < 1 (under amplitude modulation index), ma=1 (normal amplitude modulation index) and ma > 1 (over amplitude modulation index).



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## 1. INTRODUCTION

Multilevel Inverter (MLI) is made up of multiple switches. Multilevel inverter [1] enables the use of environmental friendly energy sources like solar cells and fuel cells. The main feature of this MLI is its ability to reduce the voltage stress on each power device due to the utilization of multiple levels on the DC bus. Two switches of the same leg cannot be switched ON simultaneously which will lead to short circuit. It has very narrow output voltage range. Boosting of output is not possible. I.e the output side voltage is less than or equal to the input side voltage. Related gate drive is required for each switch. Provides second order filter, suppresses current and voltage ripples. Impedance source inverter has both inductor and capacitor in the dc link it provides constant high impedance voltage source. It provides impedance source coupling to the inverter on one port and DC source on other port. It's a Transformer less network, so simple. A detailed literature survey was made on the proposed work [1-28]. Based on the diffeternt author works the study is made and identified the problems. The solution for the problems was focused to address the issue. The proposed work will be used for both static and dynamic loads applications like drives [7, 14].

## 2. IMPEDANCE SOURCE FED MULTILEVEL INVERTER

Figure 1 displays the traditional inveter. The conventional system will give only less number of voltage levels with more amount of distortion in the supply [2]. Figure 2 shows the need for boosting the input voltage. Combination of passive elements is used to boost or buck the output. Figure 3 gives

the impedance network fed to the inveter circuit. The special type of switches used as bidirectional switches. Figure 4 displays the H-type FCMLI. Table 1 shows H-type flying capacitor multilevel inverter.

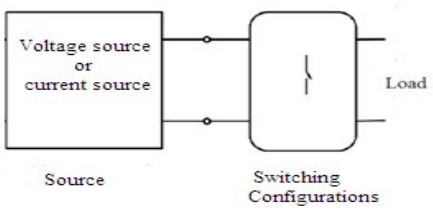



Figure 1. Traditional multilevel inverter

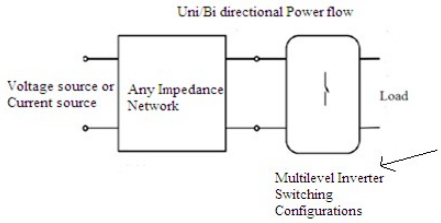



Figure 2. Impedance network fed multilevel inverter

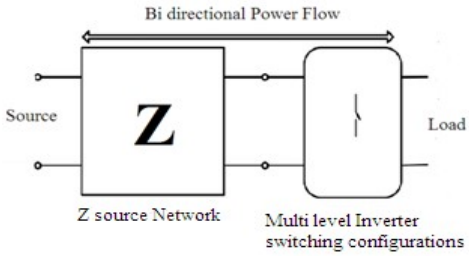



Figure 3. Z source fed multilevel inverter

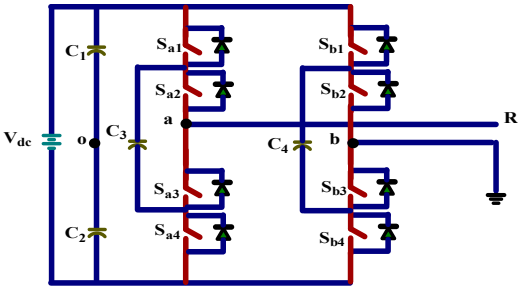



Figure 4. H-type FCMLI

Table 1. H-type flying capacitor multilevel inverter - switch states and output voltage levels

| $S_{a1}$ | $S_{a2}$ | $S_{a3}$ | $S_{a4}$ | $S_{b1}$ | $S_{b2}$ | $S_{b3}$ | $S_{b4}$ | $V_{ao}$ | $V_{bo}$ | $V_{ab}=V_{RN}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | -1/2 $V_{dc}$ | 1/2$V_{dc}$ | -$V_{dc}$ |
| 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | -1/2 $V_{dc}$ | 0 | -1/2 $V_{dc}$ |
| 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1/2 $V_{dc}$ | -1/2 $V_{dc}$ |
| 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | -1/2 $V_{dc}$ | 1/2 $V_{dc}$ |
| 1 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 1/2 $V_{dc}$ | 1/2 $V_{dc}$ | 0 |
| 0 | 0 | 1 | 1 | 0 | 0 | 1 | 1 | -1/2 $V_{dc}$ | -1/2 $V_{dc}$ | 0 |
| 0 | 1 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | -1/2 $V_{dc}$ | -1/2 $V_{dc}$ |
| 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1/2 $V_{dc}$ | 0 | 1/2 $V_{dc}$ |
| 1 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | -1/2 $V_{dc}$ | 1/2 $V_{dc}$ |
| 1 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1/2 $V_{dc}$ | -1/2 $V_{dc}$ | $V_{dc}$ |

## 3. MODULATION SCHEME

The gate pulse is generated by comparing the reference signal with carrier frequency. The scheme developed based on CFD technic (Control Freedom Degree) [25]. Figure 5 shows the carrier arrangement of sinusoidal, third harmonic, 60 degree and stepped wave reference with phase disposition carrier.

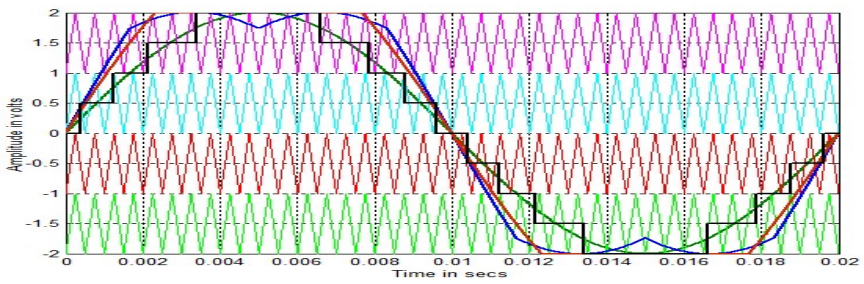



Figure 5. Sample carrier arrangement of sinusoidal, third harmonic, 60 degree and stepped wave reference with phase disposition carrier

## 4. Z-SOURCE BASED MULITILEVEL INVERTER

Figure 6 shows the basic view of impedance source based H type flying capacitor multilevel inverter. The choice of multilevel inverter depends on the applications. This combination of Z source and multilevel inverter provides unique features [27-28]. Z source multilevel inverter [15, 17-24] composed of DC source, Z network and single H bride inverter [26]. Figure 6 displays the power circuit of Z source based multilevel inverter. Voltage stress problem in conventional Z source inverter is overcome by Z source multilevel inverter. Voltage source and current source inverters can either buck or boost the voltage but Z source based multilevel inverter can able to both buck and boost the given voltage. Figure 6 shows the cascaded five level Z-source based multilevel inverter (ZSMLI). It has separate DC sources for each module with same voltage level. Presence of impedance network between DC source and main circuit overcome the limitations of traditional inverters.In traditional voltage source inverter the AC output voltage is below the DC input voltage and the dead time has to be introduced for both upper and lower devices which lead to distortion of output waveform. But the Z-source multilevel inverter can buck and boost the given input voltage.

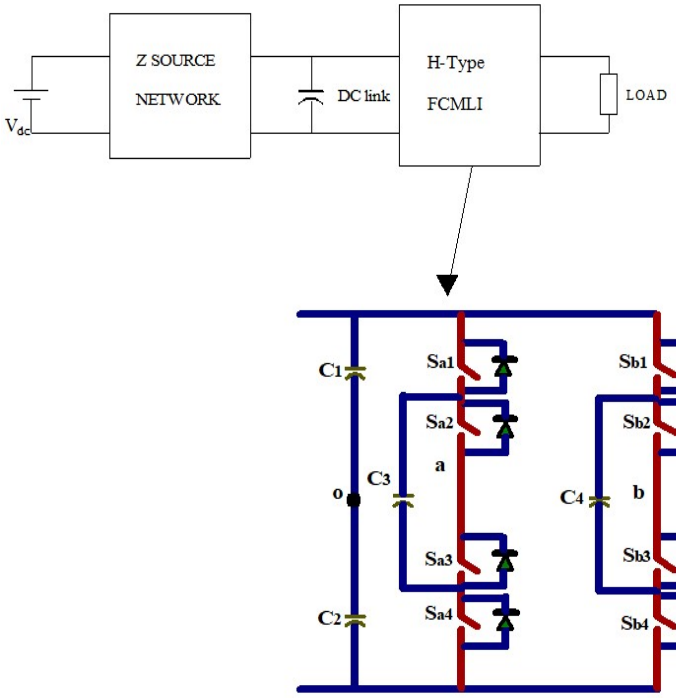


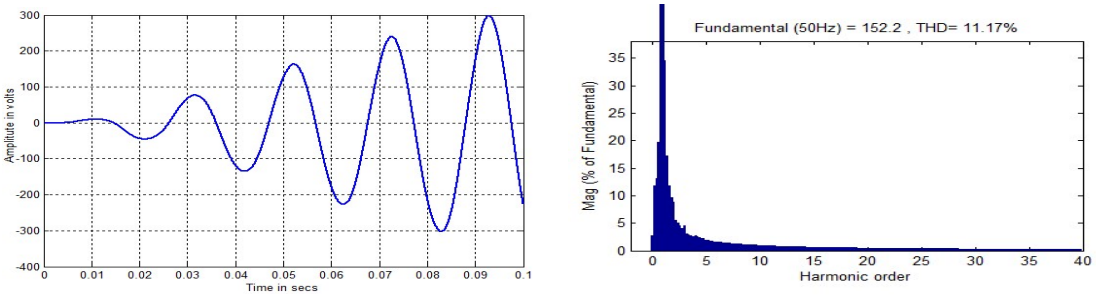

Figure 6. Z-source based multilevel inverter

## 5. SIMULATION RESULTS

The simulated output voltage is shown for only one sample value of $m_a$=1. The following parameter values are used for simulation: $V_{dc}$ = 100V, R(load) = 10 ohms, $C_1$ = $C_2$ = $C_3$ and $C_4$ = 1000 e-3 Farad, $f_c$ =2000 Hz and $f_m$ = 50 Hz. Figures shows the sample five level output voltage generated by PDPWM [10,12] strategy with sine, THI, 60 degree and stepped wave reference and its FFT plot is shown in below Figures. Table 3 to Table 6 show the comparison of %THD, $V_{RMS}$ (fundamental), Vpeak and DC componenet for PDPWM strategies with various references.

### 5.1. Impedance source multilevel inverter with sine reference

Figure 7 (a) and Figure 7 (b) represent the output voltage and harmonic spectrum of Z-source based H-type FCMLI for sinusoidal reference with PDPWM Strategy [16]. An output voltage and THD obtained are shown in Figure 7 (a).

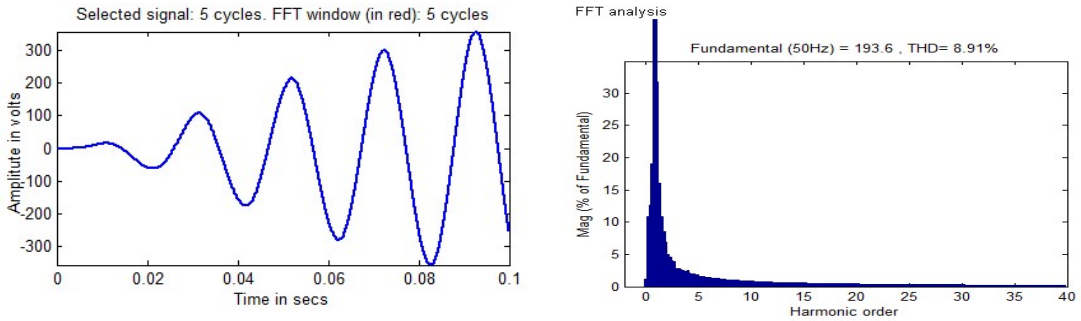



(a) Output voltage (b) Harmonic spectrum

Figure 7. Impedance source multilevel inverter with sine reference

### 5.2. Impedance source multilevel inverter with THI reference

Figure 8 (a) and Figure 8 (b) show the output voltage waveform and harmonic spectrum of Z-source based H-type FCMLI for THI reference [11, 13] with PDPWM Strategiy. An output voltage and THD are obtained that is shown in Figure 8 (a) and Figure 8 (b).

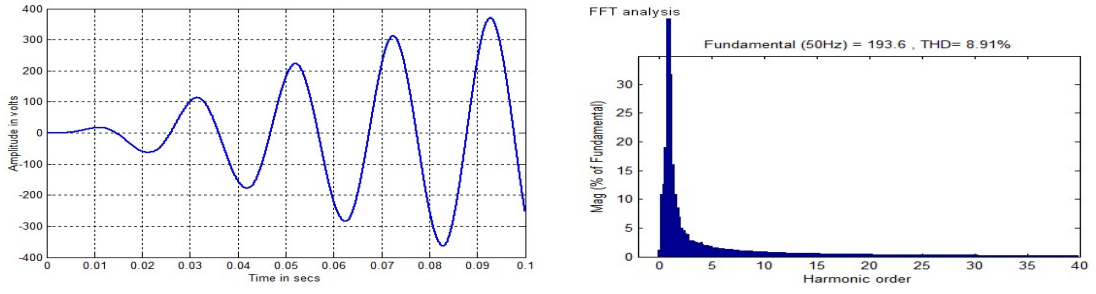



(a) Output voltage (b) Harmonic spectrum

Figure 8. Impedance source multilevel inverter with THI reference

### 5.3. Impedance source multilevel inverter with 60 degree reference

Figure 9 shows the output voltage and harmonic spectrum of Impedance Source multilevel Inverter with 60 degree reference. An output voltage and THD are obtained which shown in Figure 9 (a) and Figure 9 (b).

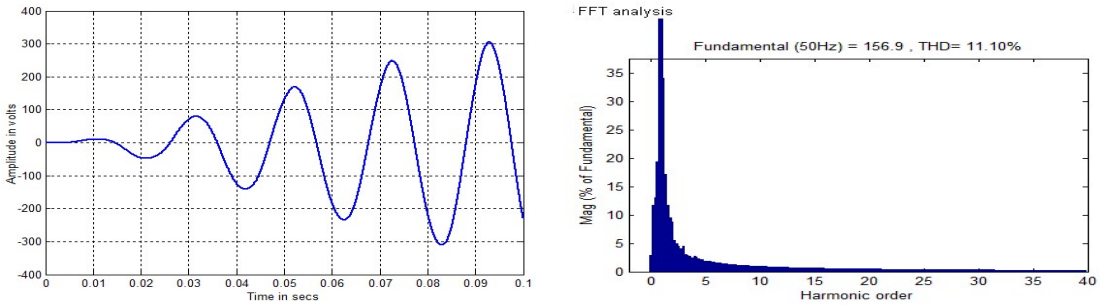



(a) Output voltage (b) Harmonic spectrum

Figure 9. Sample FFT plot for impedance source multilevel inverter with 60 degree reference

### 5.4. Impedance source multilevel inverter with stepped wave reference

Figure 10 displays the output voltage and harmonic spectrum of Impedance Source multilevel Inverter with stepped wave reference. An output voltage and THD is obtained which shown in Figure 10 (a) and Figure 10 (b).




(a) Output voltage (b) Harmonic spectrum

Figure 10. Impedance source multilevel inverter with stepped wave reference

In this analyse presence of RMS output voltage and THD in the output waveform is observed for various topologies by varying modulation index. The following tables represent measurements across multilevel inverter. Table 2 shows the simulation values. Table 3 and Table 4 show the measurement across MLI for L = 3mH, C = 4700µF and L = 3mH, C = 470µF. Table 5 and Table 6 represent the measurement across MLI for L = 250µH, C = 500µF and L = 160µH, C =1000µF.

Table 2. Simulation values chosen

| Component | Values Chosen |
|---|---|
| Input Voltage | 100 V |
| Impedance Network | $L_1$ = 3mH<br>$L_2$= 3 mH<br>$C_1$ = 4700 micro farad<br>$C_2$ = 4700 micro farad |
| H-Type FCMLI | Bus Capacitor ($C_1$) = 1000$e^{-6}$<br>Bus Capacitor ($C_2$) = 1000$e^{-6}$<br>MOSFET<br>Clamping capacitor $C_1 = C_2$ = 100 $e^{3}$ |
| AC Filter | L = 3$e^{-3}$ H<br>C = 4700$e^{-6}$ |
| Load | R = 10 ohm |

Table 3. Output voltage THD for various modulation indicies

| Modulation Type | Modulation Index | Sine Reference | THI Reference | 60 degree Reference | Stepped wave reference |
|---|---|---|---|---|---|
| Over Modulation Index ($m_a$>1) | 1.4 | 9.11 | 8.26 | 8.38 | 8.89 |
| | 1.3 | 9.39 | 8.33 | 8.40 | 9.16 |
| | 1.2 | 9.76 | 8.38 | 8.52 | 9.83 |
| | 1.1 | 10.27 | 8.44 | 8.71 | 10.48 |
| Normal Modulation Index ($m_a$=1) | 1 | 7.78 | 9.02 | 8.91 | 11.10 |
| Under Modulation Index ($m_a$<1) | 0.9 | 7.54 | 10.69 | 10.40 | 12.48 |
| | 0.8 | 15.63 | 13.05 | 13.06 | 14.96 |
| | 0.7 | 17.26 | 14.66 | 14.67 | 16.75 |
| | 0.6 | 18.45 | 15.98 | 16.83 | 18.76 |

Table 4. $V_{rms}$ (fundamental) output voltage for various modulation indices

| Modulation Type | Modulation Index | Sine Reference | THI Reference | 60 degree Reference | Stepped wave reference |
|---|---|---|---|---|---|
| Over Modulation Index ($m_a$>1) | 1.4 | 135.2 | 141.8 | 141.1 | 135.8 |
| | 1.3 | 132.4 | 141.6 | 140.8 | 133 |
| | 1.2 | 127.9 | 141.1 | 140 | 125.7 |
| | 1.1 | 121 | 140.2 | 138.6 | 118.3 |
| Normal Modulation Index ($m_a$ =1) | 1 | 87.96 | 132.5 | 136.9 | 111 |
| Under Modulation Index ($m_a$<1) | 0.9 | 80.73 | 105.3 | 112.8 | 86.84 |
| | 0.8 | 52.63 | 71.9 | 76.9 | 55.99 |
| | 0.7 | 31.53 | 46.33 | 50.76 | 33.24 |
| | 0.6 | 28.78 | 28.62 | 24.97 | 15.66 |

Table 5. Vpeakoutput voltage for various modulation indices

| Modulation Type | Modulation Index | Sine Reference | THI Reference | 60 degree Reference | Stepped wave reference |
|---|---|---|---|---|---|
| Over Modulation Index ($m_a$>1) | 1.4 | 191.2 | 200.6 | 199.6 | 192.1 |
| | 1.3 | 187.2 | 200.2 | 199.1 | 188.1 |
| | 1.2 | 180.9 | 199.5 | 198 | 177.7 |
| | 1.1 | 171.2 | 198.3 | 196.1 | 167.2 |
| Normal Modulation Index ($m_a$ =1) | 1 | 124.4 | 187.4 | 193.6 | 156.9 |
| Under Modulation Index ($m_a$<1) | 0.9 | 114.2 | 148.9 | 159.5 | 122.8 |
| | 0.8 | 74.5 | 101.7 | 108.7 | 79.18 |
| | 0.7 | 44.59 | 65.52 | 71.79 | 47.01 |
| | 0.6 | 30.52 | 48.21 | 35.31 | 22.15 |

Table 6. DC componenet output voltage for various modulation indices

| Modulation Type | Modulation Index | Sine Reference | THI Reference | 60 degree Reference | Stepped wave reference |
|---|---|---|---|---|---|
| Over Modulation Index ($m_a$>1) | 1.4 | 0.90 | 2.87 | 2.29 | 1.57 |
| | 1.3 | 0.66 | 2.94 | 2.33 | 0.97 |
| | 1.2 | 0.08 | 2.24 | 1.95 | 0.79 |
| | 1.1 | 0.95 | 1.95 | 1.47 | 2.10 |
| Normal Modulation Index ($m_a$ =1) | 1 | 2.37 | 1.65 | 1.19 | 2.80 |
| Under Modulation Index ($m_a$<1) | 0.9 | 7.54 | 3.99 | 3.73 | 6.35 |
| | 0.8 | 13.54 | 13.67 | 12.57 | 12.24 |
| | 0.7 | 15.84 | 17.45 | 16.40 | 14.06 |
| | 0.6 | 17.98 | 21.09 | 19.99 | 16.99 |

## 6. CONCLUSION

The performance of Impedance source based flying capacitor multilevel Inverter with sinusoidal, third harmonic injection, 60 degree and stepped wave reference and PDPWM strategyare analysed in this work. Simulation was carried out for the proposed topologies using PWM technique. RMS values of output voltage and THD are observed using FFT analysis in MATLAB/Simulink environment. From the analysis of each proposed topology by varying impedance network values (L and C) are developed.From the simulation results it is found that for differenent references the THD is almost similar but the root mean square value in terms of voltage is more for THI, 60 degree PWM and stepped wave reference with phase disposition strategy. The results are observed for various values of $m_a$ (Amplitude Modulation Index) like under amplitude modulation index, normal amplitude modulation index and over amplitude modulation index.

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