

# Simulation Model of Single-Phase Simplified Eleven-Level Inverter

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## ABSTRACT

This paper presents simulation model of a single phase simplified eleven-level inverter (SELI). Multilevel inverter offers high power capability. Its performance is highly superior to that of conventional two-level inverter due to reduced harmonic distortion, lower electromagnetic interference and higher dc link voltage. The inverter is capable of producing eleven levels of output voltages ( $V_{dc}$ ,  $4V_{dc}/5$ ,  $3v_{dc}/5$ ,  $2V_{dc}/5$ ,  $V_{dc}/5$ ,  $0$ ,  $-V_{dc}/5$ ,  $-2V_{dc}/5$ ,  $-3V_{dc}/5$ ,  $-4V_{dc}/5$ ,  $-V_{dc}$ ) from the DC supply voltage. Theoretical predictions are validated using MATLAB Simulink tool box.

## Keywords

Capacitor clamped, diode clamped, multilevel inverter, H-bridge, Simplified Eleven-level Inverter (SELI).

## 1. INTRODUCTION

In the area of power electronics, multilevel power converters are growing rapidly. The output voltage of multilevel inverters is synthesized from many discrete smaller voltage levels. It can also be viewed as voltage synthesizers. The different multilevel inverter topologies [1] are discussed. It has many advantages over two-level inverters, such as:

1. Stepped waveform with less distortion;
2. Lower switching frequency;
3. Higher efficiency;
4. Lower voltage power devices.

Though it has many advantages, there are some disadvantages too that are associated with the multilevel configurations. Like their circuit complexity which requires a large number of power switches that must be commutated in an accurately determined sequence by a dedicated control circuit; it also require a great number of auxiliary dc levels which are provided either by independent supplies or, more commonly, by a cumbersome array of capacitive voltage dividers. The complexity of the control circuit also increases due to the fact that the dc voltages have to be kept in equilibrium.

These disadvantages were huge due to the cost differences produced between multilevel and standard configurations. Multilevel converters were used only in some high power applications which include high power motor drivers, Power distribution and power conditioning. [2]-[7]. The work reports a generalized, simplified multilevel configuration as shown in Fig. 1. The topology includes an H-bridge which consists of four main switches with an auxiliary bidirectional switch [8]-[11]. This configuration significantly reduces the complexity of power circuit.

These two concepts are used in the development of the eleven-level bridge converter presented below. The lower component count and the reduced layout complexity have been achieved in the proposed configuration when compared with the other multilevel inverters presented in the literature [12], [13]. Almost a 40% of main power switches are reduced in the new configuration with no more diodes and capacitors when compared with asymmetric cascade configuration [1].

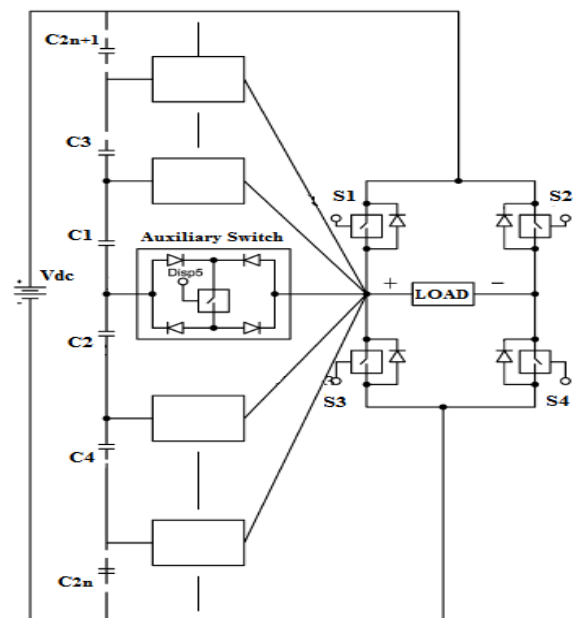


Fig 1: Generalized simplified multilevel configuration

This paper is organized as follows. First, the power circuit configuration and its advantages presented in section 2. Then, the power circuit operation includes the modes of operation is discussed in section 3. Section 4 describes the simulation results and functionality verification of the eleven-level inverter circuit. Last section concludes and the scope for further work is presented.

## 2. POWER CIRCUIT

### 2.1 Power Circuit Advantages

A single phase simplified multilevel inverter has the following merits over other existing multilevel inverter topologies.

1. Improved output waveforms.
2. Reduced number of switches employed.
3. Less complexity of the circuit as the levels increase.

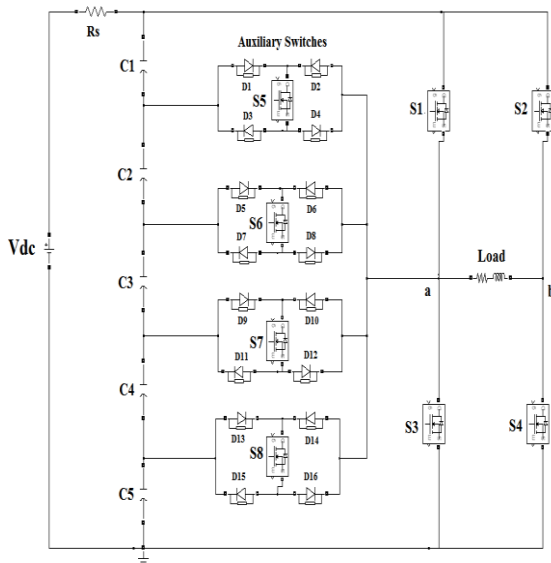
4. Smaller filter size.

5. Lower electromagnetic interference and total harmonic distortion.

In addition to this, the capacitors are connected in parallel with the main DC power supply, no significant capacitor voltage swing is produced during normal operation, avoiding a problem that can limit operating range in some other multilevel configurations.

## 2.2 Power Circuit Description

The proposed single phase simplified eleven-level inverter was developed from the five-level inverter.

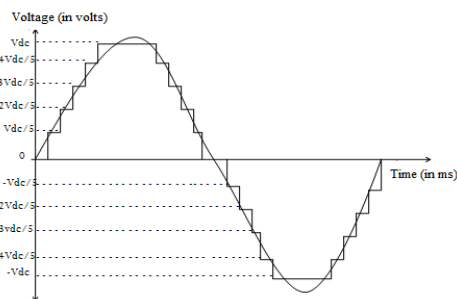


**Fig 2: Simplified Eleven-level inverter circuit**

It consists of a single phase conventional H-bridge inverter, four bidirectional switches and a capacitor voltage divider formed by  $C_1, C_2, C_3, C_4, C_5$  as shown in Fig.2. The auxiliary switches formed by the controlled switch  $S_5, S_6, S_7, S_8$  and with sixteen diodes  $D_1$  to  $D_{16}$ .

## 3. POWER CIRCUIT

The inverter is capable of producing eleven levels of output voltages ( $V_{dc}, 4V_{dc}/5, 3V_{dc}/5, 2V_{dc}/5, V_{dc}/5, 0, -V_{dc}/5, -2V_{dc}/5, -3V_{dc}/5, -4V_{dc}/5$  and  $-V_{dc}$ ) from the DC supply voltage  $V_{dc}$  shown in fig.3.



**Fig 3: Eleven-level inverter output wave form.**

There are eleven modes of operation in which two switches conduct for every modes of operation, while other switches remains in OFF position. The different voltage levels of the inverter can be synthesized from the following modes of operation and can be understood using table. I.

### 3.1 Mode I Operation

During mode I operation switches  $S_1$  and  $S_4$  are turned ON providing an output voltage level of  $V_{dc}$  volts.

### 3.2 Mode I Operation

During mode II operation switches  $S_4$  and  $S_5$  are turned ON providing an output voltage level of  $4V_{dc}/5$  volts.

**Table 1. Switching combinations required to generate the eleven-level output**

Voltage Level	Switches							
	S1	S2	S3	S4	S5	S6	S7	S8
$V_{dc}$	1	0	0	1	0	0	0	0
$4V_{dc}/5$	0	0	0	1	1	0	0	0
$3V_{dc}/5$	0	0	0	1	0	1	0	0
$2V_{dc}/5$	0	0	0	1	0	0	1	0
$V_{dc}/5$	0	0	0	1	0	0	0	1
0	1	1	0	0	0	0	0	0
$0^*$	0	0	1	1	0	0	0	0
$-V_{dc}/5$	0	1	0	0	1	0	0	0
$-2V_{dc}/5$	0	1	0	0	0	1	0	0
$-3V_{dc}/5$	0	1	0	0	0	0	1	0
$-4V_{dc}/5$	0	1	0	0	0	0	0	1

### 3.3 Mode I Operation

During mode III operation switches  $S_4$  and  $S_6$  are turned ON providing an output voltage level of  $3V_{dc}/5$  volts.

### 3.4 Mode I Operation

During mode IV operation switches  $S_4$  and  $S_7$  are turned ON providing an output voltage level of  $2V_{dc}/5$  volts.

### 3.5 Mode I Operation

During mode V operation switches  $S_4$  and  $S_8$  are turned ON providing an output voltage level of  $V_{dc}/5$  volts.

### 3.6 Mode I Operation

This mode of operation has two possible switching combinations. Either switches  $S_3$  and  $S_4$  are ON or  $S_1$  and  $S_2$  are ON providing an output voltage level of 0 volts.

### 3.7 Mode I Operation

During mode VII operation switches  $S_2$  and  $S_5$  are turned ON providing an output voltage level of  $-V_{dc}/5$  volts.

### 3.8 Mode I Operation

During mode VIII operation switches  $S_2$  and  $S_6$  are turned ON providing an output voltage level of  $-2V_{dc}/5$  volts.

### 3.9 Mode I Operation

During mode IX operation switches  $S_2$  and  $S_7$  are turned ON providing an output voltage level of  $-3V_{dc}/5$  volts.

### 3.10 Mode I Operation

During mode X operation switches  $S_2$  and  $S_8$  are turned ON providing an output voltage level of  $-4V_{dc}/5$  volts.

### 3.11 Mode I Operation

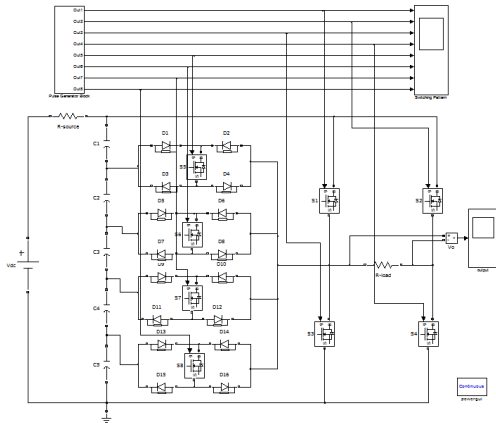
During mode XI operation switches S2 and S3 are turned ON providing an output voltage level of  $-V_{dc}$  volts.

In the eleven-level inverter circuit five capacitors in the capacitive voltage divider are connected directly across the dc supply voltage  $V_{dc}$ , and since all switching combinations are activated in an output cycle, the dynamic voltage balance between the five capacitors is automatically restored.

## 4. SIMULATION RESULTS

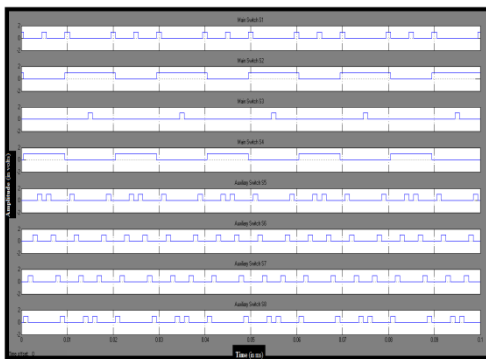
The simulation model of the single-phase simplified eleven-level inverter (SELI) using MATLAB Simulink tool box is shown in Fig.4. This model, developed using the Simulink power system block set, comprises of components such as power electronic devices (MOSFETs) and elements such as capacitors and resistors.

The PWM signals for each of the switching devices in the power circuit come from the PWM block. This block includes all the PWM signals required for switches are multiplexed on a single bus to the eleven-level inverter power circuit. The switching sequence required to generate eleven levels of output voltage for the simplified eleven-level inverter (SELI) circuit is shown in Fig. 5.



**Fig 4: Single-phase SELI Simulation circuit.**

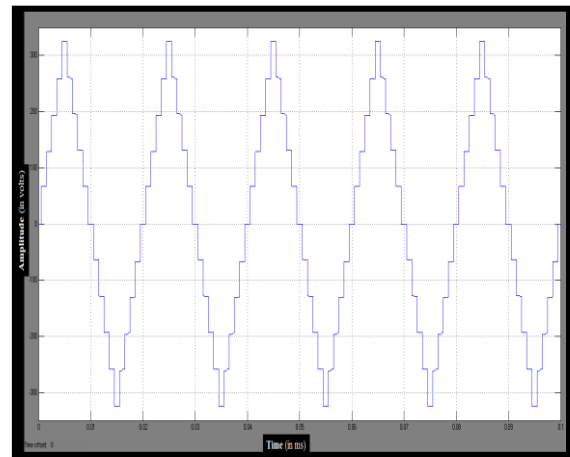
Switching Sequence for Switches: S1-S8



**Fig 5: Switching sequence required for SELI circuit.**

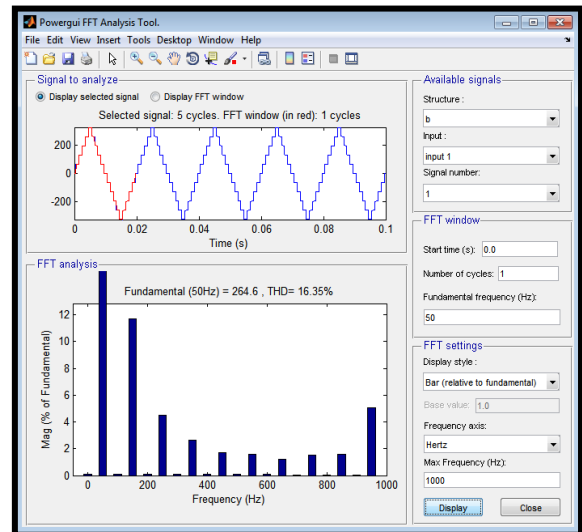
Fig. 6 shows the simulated eleven-level output voltage waveform of the SELI circuit.

Eleven-Level Output Voltage



**Fig 6: Simulated output voltage waveform of the simplified eleven-level inverter (SELI) circuit**  
 $(V_{dc}$  bus = 325V; Load: R = 20KΩ,  
 Vertical: 100V/d. Horizontal: 10ms/div)

It is clearly visible that the simulated output waveform is very close to the ideal output defined for a simplified eleven-level inverter (SELI) circuit. The eleven-levels of voltages are  $V_{dc} = 325V$ ,  $4V_{dc}/5 = 260V$ ,  $3V_{dc}/5 = 195V$ ,  $2V_{dc}/5 = 130V$ ,  $V_{dc}/5 = 65V$ ,  $0V$ ,  $-V_{dc}/5 = -65V$ ,  $-2V_{dc}/5 = -130V$ ,  $-3V_{dc}/5 = -195V$ ,  $-4V_{dc}/5 = -260V$ ,  $-V_{dc} = -325V$ .



**Fig 7: Total Harmonic Distortion for SELI**

The Total Harmonic Distortion (THD) of the eleven-level inverter is observed that 16.35% and fundamental voltage is 264.6V(50Hz) that has been illustrated in Fig. 7.

## 5. CONCLUSION

This paper presented a simulation model of a single-phase simplified eleven-level inverter with resistive load using MATLAB Simulink tool box. The inverter model developed was shown to provide accurate results and provided valuable insight into eleven-level inverter performances.

A further development of the eleven-level inverter, able to be applied to any number of voltage levels within the power switches maximum voltage, is now under consideration.

## 6. ACKNOWLEDGMENTS

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