**A Three Phase 7-Level and 9-Level Reversing Voltage Multilevel Inverter**

G. Vijaykrishna* and O. Chandra Shekhar

KL University - 522502, Guntur, Andhra Pradesh, India; gudavalli.vijaykrishna@gmail.com, Sekhar.obbu@gmail.com

**Abstract**

**Objective**: This paper presents the reversing voltage strategy for a multilevel inverter to enhance the power quality of the induction motor by reducing the THD with optimal no of switches. **Method**: The SPWM-PD technique was implemented to generate gate driver signals to regulate the 7 level and 9 level, reversing voltage multilevel inverter which requires only three carrier signals instead of six in conventional multilevel inverters. **Findings**: Increasing the levels during this strategy aid in the reduction of output voltage harmonics expeditiously and improves power quality at the output of the 7 level and 9 level inverter of reversing voltage strategy. It wants a lowered quantity of total switches, which is in a position to decreases of switching losses in this process. The Three-phase reversing voltage multilevel inverter of 7 level and 9 level is accomplished for R-load and R-L load and Three Phase Induction Motor. **Improvements**: A reversing voltage multilevel inverter of 7 level and 9 level was implemented using MATLAB/Simulink software and the simulation results show 9 level inverter has better performance in terms of Low THD and better power quality compared to 7-level inverter with reverse voltage strategy.

**Keywords**: Reversing Voltage Multilevel Inverter, Phase-Disposition SPWM, Three Phase Induction Motor

**1. Introduction**

At present world, the requirement of using power electronic devices in each equipment and applications is essential. Whereas advanced power converters are creating a mark on the market of the world. Whereas Inverters subject always famed for changing a DC provide to Ac deliver. The output of the inverter has to be compelled to maintain a close to sinusoidal for economical functioning as load systems. In traditional inverters, the harmonic content is also decreased with the aid of making use of varied modulation techniques. However, the output powers of the traditional inverters are a unit confined to low-power applications.

The different classification of multilevel Inverters is Cascade inverter, diode clamped inverter and flying capacitor inverter. So, multilevel inverters are preferred for medium and high power rating applications, which provides to arise from the output power and additional results of increasing the output waved shapes nearly sinusoidal and a decrease of whole harmonic distortion. During operation of the multilevel inverter as the number of levels will increase from the output voltage that improves the power quality and it reduces the harmonic content. To overcome Multilevel Inverter (MLI) Strategy problems like, using a number of switches to perform the power conversion, difficult PWM Controlling techniques like SPWM SV PWM, SHE-PWM, increased a number of elements and voltage corresponding difficulties. Whereas power applications, such a thing is UPS, PV systems, HVDC, FACTS etc., best appropriate to reversing voltage multilevel inverter. However, multi-winding transformers manufacturing is the expense and design are rugged for using in high power applications. A novel 4-level...
inverter strategy is introduced\(^4\). It is capable of producing an even number of levels, but not zero level. For example, the strategy in with four DC sources can create only five output levels, whereas classical multilevel inverters with the same number of power supplies can create up to nine levels\(^5\). The above issues are lowered by way of a replacement method referred to as reversing voltage multilevel inverter process. The power conversion of multilevel inverters consists of common DC sources and separate DC sources, where of common DC sources are adopted for the diode-clamped inverter and flying capacitor inverter. The separate DC sources are adopted for cascade inverter and reversing voltage multilevel inverter. This strategy makes use of the separate DC sources available in order to reduce voltage balancing problems. For the period of this technique, that is dependable for generating every positive polarity waveform and negative polarity waveforms by way of reversing voltage multilevel inverter\(^6\). The reversing voltage multilevel inverter desires much less quantity of switches and devices, it needs most effective half the carriers for generating pulses of switches to utilizing PD-SPWM control technique has been developed for the duration of this paper.

### 2. Description of Reversing Voltage Multilevel Inverter

The Reversing voltage multilevel inverter that includes two parts, specifically level generation parted and polarity generates parted. The waveforms of resultant voltage in the positive sign are obtained by using High-frequency switches to the extent Level generation part. The waveforms of resultant voltage are acquired by Low-frequency switches both sign of positive or negative within the polarity generation part\(^6\). Within the new strategy, there is not to make use of all the switches in high frequency. This strategy separates output voltage into level generation and polarity generation components. The Level generation part needs high-frequency switches and polarity generation section require low-frequency switches operating at line frequency. The main concept of this inverter is to use both high frequency switches and low frequency switches and to limit the power devices voltage stress. It simply extended to higher levels by adding middle stages. The last word output voltage level is that the aid of voltage sources.

For getting resultant output voltage levels at a specific line frequency, each level generation part and polarity generation part are principal and predominant. The switching modes are selected such that to lessen the switching transitions for fending off the unwanted voltage levels. This may increasingly scale back the switching power dissipation. Totally different switching modes in producing the desired levels\(^7\). The output voltage levels are generated with the aid of authorized switching sequences. The switching sequence of switches modes is chosen for levels respectively. This strategy is redundant and versatile within the switching sequence. The essential advantages are minimized whole Harmonic Distortion (THD), much less stress on the energy switches and greater efficiency. The predominant disadvantage is the excessive number of power switches which makes the control method problematic and, for this reason excessive cost. Diminished quantity of switches leads to diminished rate and complexity. This additionally results in decreased losses and extended efficiency. This paper presents a seven and nine level inverter utilizing reverse voltage strategy.

#### 2.1 Seven-Level Reversing Voltage Multilevel Inverter

![Figure 1. Reversing voltage multilevel inverter for three phases connected to the R-L load.](image-url)
This paper presents a seven-level inverter utilizing reversing voltage strategy. A seven-level inverter requires 10 switches and 3 DC energy sources to form a circuit and to generate the output voltage as shown in Figure 2. For a single-phase seven-level inverter model of the traditional multilevel inverter, twelve switches are needed, whereas the proposed strategy uses ten switches. Switching of high frequency is having phase disposition pulses and switching of low frequency may have pulses of the line frequency (50 Hz) then, the resultant output voltage is fed to the load. The association of switches commencing from S₁ to S₁₀ that are in single-phase leg is obtained by means of operation of reversing voltage multilevel inverter of 7-level as shown in Figure 2. The high-frequency switches are used to produce two positive halves of cycles within line frequency. With the assistance of the full bridge converter, the second cycle of High-Frequency Bridge will also be converted into a negative half cycle. In an effort to get alternating waveform, the requirement of a full bridge converter is crucial. With the assistance of full bridge converter, we will be able to cut down a number of switches to 12 to 10 such switch losses could also be diminished. In reversing voltage 7-level inverter, with a purpose to curb switches it needed an improved full bridge converter.

### Table 1. Switching function for voltage output seven level generation

| DC Voltage Level | Mode-1 Operation | Mode-2 Operation |
|------------------|------------------|------------------|
| 0                | 2,3,4            |                  |
| 1                | 2,3,5            | 2,4,6            |
| 2                | 1,4              | 2,6,5            |
| 3                | 1,5              |                  |

Operation of reversing voltage 7-level inverter:

The switching approach of reversing voltage 7-level inverter. The switching modes to get distinct voltage levels are:

- When switches 2-3-4 is on, output waveform produces a voltage level 0 V DC,
- When switches 2-3-5 is on, output waveform produces a voltage level +1 V DC,
- When switches 1-4 is on, output waveform produces a voltage level +2 V DC,
- When switches 1-6 is on, output waveform produces a voltage level +3 V DC.

This paper presents a nine-level inverter utilizing reversing voltage strategy. A nine-level inverter requires 12 switches and 4 DC energy sources to form a circuit and to generate the output voltage as shown in Figure 3. For a single-phase seven-level inverter model of the traditional multilevel inverter, twelve switches are needed, whereas the proposed strategy uses ten switches. Switching of high frequency is having phase disposition pulses and switching of low frequency may have pulses of the line frequency (50 Hz) then, the resultant output voltage is fed to the load. The association of switches commencing from S₁ to S₁₀ that are in single-phase leg is obtained by means of operation of reversing voltage multilevel inverter of 7-level as shown in Figure 2. The high-frequency switches are used to produce two positive halves of cycles within line frequency. With the assistance of the full bridge converter, the second cycle of High-Frequency Bridge will also be converted into a negative half cycle. In an effort to get alternating waveform, the requirement of a full bridge converter is crucial. With the assistance of full bridge converter, we will be able to cut down a number of switches to 12 to 10 such switch losses could also be diminished. In reversing voltage 7-level inverter, with a purpose to curb switches it needed an improved full bridge converter.

### 2.2 Nine Level Reversing Voltage Multilevel Inverter

![Figure 3. Reversing voltage multilevel inverter for three phases connected to the R-L load.](image-url)
and to generate the output voltage as shown in figure 4. The predominant function of this paper is to diminish the total harmonic distortion of the 9-level inverter. It also minimizes the number of power semiconductor switches than a traditional multilevel inverter. For a single-phase nine-level inverter model of a traditional multilevel inverter, sixteen switches are needed, whereas the proposed strategy uses twelve switches.

![Diagram of reversing voltage 9-level inverter for the single phase leg.](image)

**Figure 4.** Reversing voltage 9-level inverter for the single phase leg.

**Table 2.** Switching function for voltage output 9-level generation

| DC Voltage level | Mode-1 Operation | Mode-2 Operation |
|------------------|------------------|------------------|
| 0                | 2,3,4,5          |                  |
| 1                | 2,3,4,6          |                  |
| 2                | 2,3,6,8          | 2,7,5            |
| 3                | 1,5              | 2,7,6            |
| 4                | 1,6              |                  |

Operation of reversing voltage 9-level inverter:

The switching approach of reversing voltage 9-level inverter. The switching modes to get distinct voltage levels are

- When switches 2-3-4-5 is on, output waveform produces a voltage level 0 V DC,
- When switches 2-3-4-6 is on, output waveform produces a voltage level +1 V DC,
- When switches 2-3-6-8 is on, output waveform produces a voltage level +2 V DC,
- When switches 1-5 is on, output waveform produces a voltage level +3 V DC.
- When switches 1-6 is on, output waveform produces a voltage level +4 V DC.

### 3. Description of Phase Disposition Technique

In SPWM, a sinusoidal waveform is related to a carrier waveform to get gate pulses of the switches to an inverter. N-level output desires N-1 carrier per the common multilevel inverter. Desired carriers reduced to $\frac{(N-1)}{2}$ easiest by utilizing exploitation right number of levels earned in deliberate reversing voltage multilevel inverter procedure. Control procedures for this reversing voltage multilevel inverter are operated through SPWM method. Completely different PWM techniques are 1. SPWM 2. SVPWM 3. SHE-PWM techniques are in most cases used. The SPWM technique is wide used considering of a couple of advantages.

- Simple implementation
- Low harmonic content
- Less switching losses.

The level shifted modulation technique consists of three schemes

- Each carrier is in phase with each other in Phase Disposition (PD) technique.
- Each carrier waveform is 180-degree phase oppositions to its neighbour in Alternative Phase Opposition Disposition (APOD) technique.
- If the carrier waveform is above and below the point of zero references then the waveform of carrier waveform is modified to 180 degrees in Phase Opposition Disposition (APOD) technique.
In order to get the desired controlled gate pulses for deliberate circuits of making use of phase disposition method of SPWM technique\textsuperscript{7}. Throughout this reversing voltage multilevel inverter, we need like most effective three carrier waveforms that are compared with the only single sinusoidal waveform within the positive part of the one cycle. Whenever an intersection takes place between the carrier and sinusoidal there’s a formation of pulses in that area. We tend to create three pulses at that intersection part of the area. The produced pulses are changed into substitute pulses of making use of not operation (like once switch is on then it produces alternative is off), then it inclined to get the desired switching pulses and fed to the six switches to the level generation part. Ultimate pulses of a full bridge converter is created with the aid of the pulse generator is employed to get pulses of the polarity generation part. Here PD SPWM uses \((n-1)/2\) carriers to power the inverter and to control the output voltage\textsuperscript{8}. The frequency modulation index

\[
M_f = \frac{F_c}{F_m}
\]

The amplitude modulation index

\[
M_a = \frac{V_m}{\left(\frac{n-1}{2}\right) V_c}
\]

**Figure 5.** (a) 3-carrier waveform and (b) 4-carrier waveform.

**Figure 6.** (a) Gate pulses to switches for 7-level and (b) Gate pulses to switches for 9-level.

### 4. Implementation of Three Phase Reversing Voltage Seven Level and Nine Level Inverter

It desires less quantity of switches that reduces the amount of gate drive circuits as demonstrated in the Table 3 evaluation of existing multilevel inverter strategies.
Table 3. Comparison and number of different multilevel inverter strategies for three-phase

| Strategies | DC MLI | FCMLI | CDMLI | RV MLI |
|------------|--------|-------|-------|--------|
| Switches, diodes | 6 \((n-1)\) | 6 \((n-1)\) | 6 \((n-1)\) | 3 \((n-1) + 4\) |
| Diodes | 3 \((n-1)\) \((n-2)\) | 0 | 0 | 0 |
| Dc bus capacitor/isolated supplies | \((n-1)\) \((n-1)\) \((n-1)\) \((n-1)/2\) |
| Overall numbers | \((n-1)\) \((n-1)/2\) \((n-1)/2\) \((n-1)\) \((13n + 35)/2\) |

Design parameters for three phase reversing voltage 7-level inverter and 9-level inverter:

For 7-level:
- Input DC voltage \(V_{DC} = 300 \text{ V}\)
- Reference (sinusoidal) switching frequency \(F_m = 50 \text{ Hz}\)
- Carrier (triangular) switching frequency \(F_c = 5 \text{ kHz}\)
- Three phase load = \(R = 10 \Omega; L = 15 \text{ MH}\)
- Output Voltage = 600 V p-p
- LC Filter = \(L = 10 \text{ MH}; C = 20 \mu\text{F}\)

For 9-level:
- Input DC voltage \(V_{DC} = 400 \text{ V}\)
- Three phase load = \(R = 10 \Omega; L = 15 \text{ MH}\)
- Output Voltage = 800 V p-p
- LC Filter = \(L = 10 \text{ MH}; C = 20 \mu\text{F}\)

Table 4. Induction motor parameters

| Parameter       | Value     |
|-----------------|-----------|
| Voltage         | 400 V     |
| Current         | 5.78 A    |
| Horsepower      | 5.36 H.P  |
| Frequency       | 50 Hz     |
| Speed           | 1430 rpm  |

5. Mat Lab Circuit Diagram Design and Simulation Results

The outcome of the simulation of urged technique of three phase 7-level and 9-level of reversing voltage multilevel inverter is finished by victimization MATLAB 2009b/ Simulink.

From FFT analysis, will recognize the THD of voltage output and current output values. The harmonic content material of the output voltage waveform decreases because the quantity of output voltage increases in reversing voltage multilevel inverter. In the following output, waveforms show the outcome involving output voltage, output current and Speed-Torque traits of a three-phase induction motor through utilizing reverse voltage strategy in 7-level inverter and 9-level inverter. The output waveforms of R-load and RL-load for the 7-level inverter and 9-level inverter is done through making use of reverse voltage strategy.

The output voltage and current waveforms which can be formed within the staircase type. In every 7-level inverter and 9-level inverter, it may possibly modify staircase type into sine waveform by including filters at the output of reversing voltage multilevel inverter. There are higher advantages by means of utilizing filters we are able to lessen the harmonics, make stronger the lifetime of the equipment, performance and potency are high, the power factor can also be high. During this reversing voltage multilevel inverter, generally tend to make use of Butterworth filter which is the low pass second order filters and LC filter is positioned at the output of an inverter. The output load to produce required resultant waveforms of voltage and current in a sinusoidal form. The Simulation outcome of the proposed strategy of reversing voltage multilevel inverter is performed by utilizing MATLAB.

5.1 Three phase 7-Level Reversing Voltage Multilevel Inverter
Figure 7. (a) Level generation part and (b) Polarity generation part.

Figure 8. (a) Voltage Output waveforms of 3-phase 7-level reversing voltage multilevel inverter and (b) Voltage Output waveforms of 3-phase 7-level reversing voltage multilevel inverter.

Figure 9. (a) Voltage Output waveform for 7-Level R-L load and for induction motor and (b) Current output waveforms for 7-Level R-L load and for induction motor.

Figure 10. Torque and Speed structures waveform.

The circuit diagram constructed in a MATLAB/Simulink of three phase RVMLI strategy for 7-level is simulated for different loads R, R-L and Induction motor we get the voltage and current, speed and torque output waveforms are shown in the above figures.
5.2 Three Phase 9-Level Reversing Voltage Multilevel Inverter

Figure 11. (a) Level generation part and (b) polarity generation part.

Figure 12. (a) Voltage Output waveforms of 3-phase 9-level reversing voltage multilevel inverter and (b) Current Output waveforms of 3-phase 9-level reversing voltage multilevel inverter.

Figure 13. (a) Voltage Output waveform for 9-Level R-L load and for induction motor and (b) Current output waveforms for 9-Level R-L load and for induction motor.
5.3 THD Values For 7 and 9-Level Three Phase Reversing Voltage Multilevel Inverter

Table 5. Voltage Output and current output THD for R-Load before and after a filter.

| RVMLI     | Voltage Output(V) | THD (%) | Current Output(I) | THD (%) |
|-----------|-------------------|---------|-------------------|---------|
| 7-Level   | 298               | 18.10   | 28.81             | 2.00    |
| After Filter 7-Level | 286.1           | 2.00    | 28.62             | 2.00    |
| 9-Level   | 391.3             | 16.30   | 36.02             | 1.64    |
| After Filter 9-Level | 361.2           | 1.64    | 36.02             | 1.64    |

Table 6. Voltage Output and current output THD for Induction motor before and after a filter.

| RVMLI     | Voltage Output (V) | THD (%) | Current Output (I) | THD (%) |
|-----------|-------------------|---------|-------------------|---------|
| 7-Level   | 298               | 18.09   | 23.48             | 0.67    |
| After Filter 7-Level | 274.5           | 13.80   | 23.24             | 0.67    |
| 9-Level   | 391.5             | 16.17   | 30.97             | 0.77    |
| After Filter 9-Level | 340.4           | 11.17   | 30.8              | 0.77    |

6. Conclusion

On this paper, Reversing Voltage is applied to improve multilevel performance with the aid of compensating the hazards in substitute multilevel inverters. This strategy improves output voltage, reduces utilizing a number of semiconductor switches and voltage stress on semiconductor switches. This paper makes use of carrier based SPWM scheme using Phase Disposition process and would manage output voltage and frequency and minimize the harmonic add-ons. It plays a consequential position of the potency of an overall converter. A three phase 7-level and 9-level inverters with reversing voltage strategy are developed and output voltage and current waveforms are observed for each R and RL loads. The reversing voltage multilevel inverters have become an effective and functional resolution for greater output levels and it suggests that the entire harmonic distortion outcome shows that growing to level at output voltage waved shapes to diminish the harmonics contents of the output. The simulation outcome, the output voltage waveform offers better harmonics profile. It may be observed that there is a great reduction in THD values when compared to seven level reversing voltage inverter. Simulation outcomes exhibit the efficiency of nine-level reversing voltage inverter with elevated THD.

Throughout this paper, simulation end results are presented for three phase 7-level multilevel inverter and 9-level multilevel inverter of reversing voltage strategy.

7. References

1. Martins GM, Pomilio JA, Buso S, Spiazzi G. Three phase low-frequency commutation inverter for renewable energy systems. IEEE Trans Ind Electron. 2006 Oct; 53(5):1522–8.
2. Daher S, Schmid J, Antunes FLM. Multilevel inverter topologies for stand-alone PV systems. IEEE Trans Ind Electron. 2008 Jul; 55(77):2703–12.
3. Teodorescu R, Blaabjerg F, Pedersen JK, Cengelci E, Enjeti PN. Multilevel inverter by cascading industrial vsi. IEEE Trans Ind Electron. 2002 Aug; 49(4):832–8.
4. Perantzakis GS, Xepapas FH, and Manias SN. A novel four-level voltage source inverter-influence of switching strategies on the distribution of power losses. IEEE Trans Power Electron. 2007 Jan; 22(1):143–49.
5. Mondal G, Gopalkumar K, Tekwani PN, Lev E. A reduced switch-count five-level inverter with common-mode voltage
elimination for an open-end winding induction motor drive. IEEE Trans Ind Electron. 2007 Aug; 54(4):2344–51.
6. Najafi E, Yatim AHM. Design and implementation of a new multilevel inverter topology. IEEE Trans Ind Electron. 2012 Nov; 59(11):4148–54.
7. Rashid MH. Power Electronics. Pearson Education Inc.; 2004. p. 912.
8. Radan A, Shahrinia AH. Evaluation of carrier based PWM methods for multilevel inverters. Proc IEEE ISIE; 2007. p. 389–94.
9. Ramesh Babu S. Comparative Analysis of Cascaded Multilevel Inverter for Phase Disposition and Phase Shift Carrier PWM for Different Load. Indian Journal of Science and Technology. 2015 Apr; 8(S7):251–62.