



**A NEW HYBRID TOPOLOGY FOR MULTILEVEL CASCADED INVERTER  
DESIGN WITH POD MODULATION TECHNIQUE**

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**ABSTRACT**

This paper proposes a Phase Opposition Disposition (POD) strategy to achieve balanced line-to-line output voltages and to maximize the modulation index in the linear modulation range where the output voltage can be linearly adjusted in the multilevel cascaded inverter (MLCI) operating under unbalanced dc-link conditions. In these conditions, the linear modulation range is reduced, and a significant output voltage imbalance may occur as voltage references increase. In order to analyze these effects, the voltage vector space for MLCI is evaluated in detail. From this analysis, the theory behind the output voltage imbalance is explained, and the maximum linear modulation range considering an unbalanced dc-link condition is evaluated. After that, a Phase Opposition Disposition strategy is proposed to achieve output voltage balancing as well as to extend the linear modulation range up to the maximum reachable point in theory. In the proposed method, too large of a dc-link imbalance precludes the balancing of the output voltages. This limitation is also discussed. Both the simulations and the experiments for a seven-level phase-shifted modulated MLCI for electric vehicle traction motor drive show that the proposed method is able to balance line-to-line output voltages as well as to maximize the linear modulation range under the unbalanced dc-link conditions.

**Index Terms:** Harmonic injection, multilevel cascaded inverters (MLCIs), neutral voltage modulation (NVM), phase-shifted (PS) modulation, space vector pulse width modulation (PWM) (SVPWM).

**INTRODUCTION**

Multilevel inverters enable the synthesis of a sinusoidal output voltage from several steps of voltages. For this reason, multilevel inverters have low dv/dt characteristics and generally have low harmonics in the output voltage and current. In addition, the switching of very high voltages can be achieved by stacking multilevel inverter modules. Due to these advantages, multilevel inverters have been applied in various application fields. Among various topologies for multilevel inverters, the multilevel cascaded inverter (MLCI) structure is one of the prominent topologies because of its simple structure for modularization and fault-tolerant capability. Therefore, MLCIs are used for many applications, such as dynamic voltage restorer, static

synchronous compensator (STATCOM), high-voltage energy storage device, photovoltaic inverters, medium-voltage drives, electric vehicle (EV) traction drives, and so on. In MLCI applications, a modulation strategy to generate gating signals is very crucial to achieve high-performance control.

Regarding this issue, many studies have been conducted, and they are roughly categorized into multilevel selective harmonic elimination pulse width modulation (SHEPWM), multilevel carrier-based PWM, and multilevel space vector (SVPWM) methods. Generally, a carrier-based PWM or SVPWM is preferred in applications such as motor drives, where dynamic properties are very important, whereas SHEPWM is preferred in some high-power static power conversion applications. To reduce the common-mode voltage, a multilevel SVPWM has

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been proposed. The series SVPWM method has been reported to easily implement SVPWM for the MLCI. SVPWM is proposed for hybrid inverters consisting of neutral point clamp and H-bridge inverters to improve output voltage quality and efficiency. As with two-level inverters, it is also possible to implement carrier-based SVPWMs which are equivalent to traditional SVPWMs by injecting a common offset voltage to the three-phase references.

Some methods to calculate the offset voltages to achieve the optimal space vector switching sequence are addressed. The performances of a carrier-based PWM and an SVPWM are compared, and a PWM scheme is proposed to obtain an optimal output voltage in the multilevel inverter. On the other hand, MLCIs require separated dc links. Therefore, if there is one or more faults present in the dc links in each phase, or if the voltage magnitudes of the dc links are unequal, the output voltage of the MLCI can be unbalanced without proper compensation. To resolve this issue, some studies have been conducted.

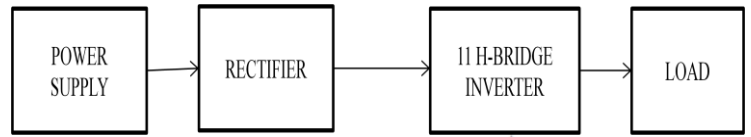
From the above equation it is shown that the available modulation index is reduced under faulty conditions on switch modules in multilevel inverters, and compensation algorithms are proposed for phase-disposition PWM and phase-shifted.

**EXISTING METHOD**

- Neural voltage shifting technique:  
Balancing the state of charge in the energy system.
- Duty cycle modification:
- Compensate output voltage imbalance caused by single phase power fluctuations.
- Offset voltage injection:
- Balancing the output voltage but may reduces dynamic characteristics.
- Multilevel multiphase feed forward space vector modulation:  
Compensate the voltage imbalance

**EXISTING BLOCK DIAGRAM**

Fig 1.1 Model diagram of existing method



$$d_{a1}^* = d_{a2}^* = \dots = d_{aN}^* = \frac{v_{an}^*}{V_{dc\_a}}$$

$$d_{b1}^* = d_{b2}^* = \dots = d_{bN}^* = \frac{v_{bn}^*}{V_{dc\_b}}$$

$$d_{c1}^* = d_{c2}^* = \dots = d_{cN}^* = \frac{v_{cn}^*}{V_{dc\_c}}$$

**Disadvantages of existing method**

- It requires more switches
- Circuit will be large
- Harmonic distortion will be more
- Un balanced condition the efficiency will be affected
- It is complicated by using NVM and SVPWM technique in same time

**PROPOSESED METHOD**

**Block diagram**

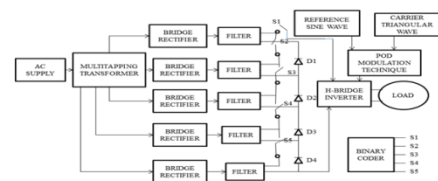


Fig 1.2 Block diagram of proposed method

### BLOCK DIAGRAM EXPLANATION

- A new hybrid topology is used for the multilevel inverter design
- Hybrid topology is the combination of diode and the multilevel inverter
- Phase opposition disposition (POD) modulation- all carrier waveforms above zero reference are in phase and are 180 out of phase with those below zero
- Harmonic distortions are reduced, when will increase the number of output levels and also reduce the switches
- Multi tapping transformer is used to divide the voltage level
- Diode bridge rectifier is used to convert AC supply to DC supply and filter is used to removes the ripples
- Binary code gives the signal to switches, when the switches are connected to H bridge inverter
- H bridge inverter is used to convert DC to AC and enables a voltage to across a load in either direction
- Phase opposition disposition (POD) modulation is used for voltage balancing.( all carrier waveforms above zero reference are in phase and are 180 out of phase with those below zero). POD produce the pulse signal to h bridge inverter

### ADVANTAGES

- Output is more efficient
- Harmonic distortions are reduced
- Balanced output voltage
- Reduced number of switches THD value is high

### BRIDGE RECTIFIER

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification.

### THE DIODE BRIDGE RECTIFIER:

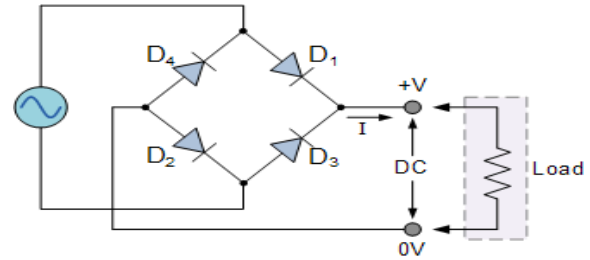
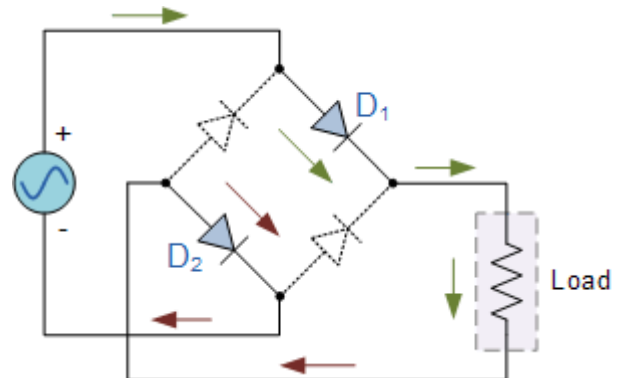


Fig 3.1 Circuit Diagram for Diode Bridge Rectifier

The four diodes labeled  $D_1$  to  $D_4$  are arranged in “series pairs” with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes  $D_1$  and  $D_2$  conduct in series while diodes  $D_3$  and  $D_4$  are reverse biased and the current flows through the load as shown below.

### THE POSITIVE HALF-CYCLE

During the negative half cycle of the supply, diodes  $D_3$  and  $D_4$  conduct in series, but diodes  $D_1$  and  $D_2$  switch “OFF” as they are now



reversing biased. The current flowing through the load is the same direction as before.

Fig 3.2 Circuit Diagram for positive half cycle

**THE NEGATIVE HALF-CYCLE**

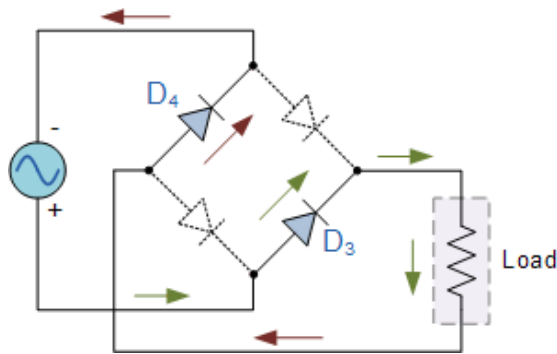


Fig 3.3 Circuit Diagram for negative half cycle

As the current flowing through the load is unidirectional, so the voltage developed across the load is also unidirectional the same as for the previous two diode full-wave rectifier, therefore the average DC voltage across the load is  $0.637V_{max}$ .

**TYPICAL BRIDGE RECTIFIER**

However in reality, during each half cycle the current flows through two diodes instead of just one so the amplitude of the output voltage is two voltage drops ( $2 \times 0.7 = 1.4V$ ) less than the input  $V_{MAX}$  amplitude. The ripple frequency is now twice the supply frequency (e.g. 100Hz for a 50Hz supply)

Although we can use four individual power diodes to make a full wave bridge rectifier, pre-made bridge rectifier components are available “off-the-shelf” in a range of different voltage and current sizes that can be soldered directly into a PCB circuit board or be connected by spade connectors.

The image to the right shows a typical single phase bridge rectifier with one corner cut off. This cut-off corner indicates that the terminal nearest to the corner is the positive output terminal or lead with the opposite (diagonal) lead being the negative output lead. The other two connecting leads are for the input alternating voltage from a transformer secondary winding.

**FULL-WAVE RECTIFIER WITH SMOOTHING CAPACITOR**

**SMOOTHING CAPACITOR**

We saw in the single phase half-wave rectifier produces an output wave every half cycle and that it was not practical to use this type of circuit to produce a steady DC supply. The full-wave bridge rectifier however, gives us a greater mean DC value ( $0.637 V_{max}$ ) with less superimposed ripple while the output waveform is twice that of the frequency of the input supply frequency. We can therefore increase its average DC output level even higher by connecting a suitable smoothing capacitor across the output of the bridge circuit as shown below.

**FULL-WAVE RECTIFIER MODEL**

Smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage. Generally for DC power supply circuits the smoothing capacitor is an Aluminum Electrolytic type that has a capacitance value of 100uF or more with repeated DC voltage pulses from the rectifier charging up the capacitor to peak voltage

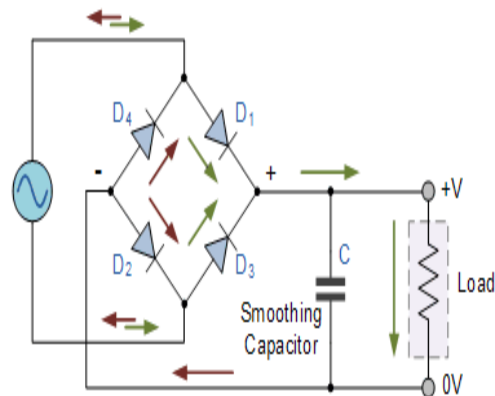


Fig 3.4 Circuit Diagram for Full-wave Rectifier with Smoothing Capacitor

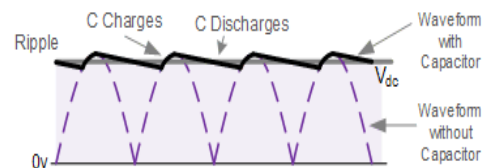


Fig 3.5 Waveform Diagram for Full-wave Rectifier with Smoothing Capacitor

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However, there are two important parameters to consider when choosing a suitable smoothing capacitor and these are its Working Voltage, which must be higher than the no-load output value of the rectifier and its Capacitance Value, which determines the amount of ripple that will appear superimposed on top of the DC voltage.

Too low a capacitance value and the capacitor has little effect on the output waveform. But if the smoothing capacitor is sufficiently large enough (parallel capacitors can be used) and the load current is not too large, the output voltage will be almost as smooth as pure DC. As a general rule of thumb, we are looking to have a ripple voltage of less than 100mV peak to peak.

The maximum ripple voltage present for a Full Wave Rectifier circuit is not only determined by the value of the smoothing capacitor but by the frequency and load current.

### 3.4 Bridge Rectifier Ripple Voltage

$$V_{(\text{ripple})} = I_{(\text{load})} / (f \times C), \text{ Volts} \quad (3.1)$$

Where, I is the DC load current in amps, f is the frequency of the ripple or twice the input frequency in Hertz, and C is the capacitance in Farads.

The main advantages of a full-wave bridge rectifier is that it has a smaller AC ripple value for a given load and a smaller reservoir or smoothing capacitor than an equivalent half-wave rectifier. Therefore, the fundamental frequency of the ripple voltage is twice that of the AC supply frequency

(100Hz) where for the half-wave rectifier it is exactly equal to the supply frequency (50Hz).

The amount of ripple voltage that is superimposed on top of the DC supply voltage by the diodes can be virtually eliminated by adding a much improved  $\pi$ -filter (pi-filter) to the output terminals of the bridge rectifier. This type of low-pass filter consists of two smoothing capacitors, usually of the same value and a choke or inductance across them to introduce a high impedance path to the alternating ripple component

Another more practical and cheaper alternative is to use an off the shelf 3-terminal voltage regulator IC, such as a LM78xx (where "xx" stands for the output voltage rating) for a positive output voltage or its inverse equivalent the LM79xx for a negative output voltage which can reduce the ripple by more than 70dB (Datasheet) while delivering a constant output current of over 1 amp.

### SCHEMATIC OF A WHEATSTONE BRIDGE

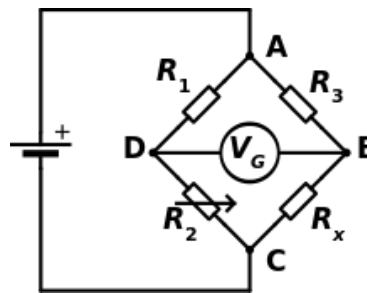


Fig 3.6 Circuit Diagram for Full-wave Rectifier with Smoothing Capacitor

The best-known bridge circuit, the Wheatstone, was invented by Samuel Hunter Christie and popularized by Charles Wheatstone, and is used for measuring resistance. It is constructed from four resistors, two of known values  $R_1$  and  $R_3$  (see diagram), one whose resistance is to be determined  $R_x$ , and one which is variable and calibrated  $R_2$ . Two opposite vertices are connected to a source of electric current, such as a battery, and a galvanometer is connected across the other two vertices. The variable resistor is adjusted until the galvanometer reads zero. It is then known that the

ratio between the variable resistor and its neighbor R1 is equal to the ratio between the unknown resistor and its neighbor R3, which enables the value of the unknown resistor to be calculated.

The Wheatstone bridge has also been generalized to measure impedance in AC circuits, and to measure resistance, inductance, capacitance, and factor separately. Various arrangements are known as the Wien Bridge, Maxwell Bridge and Heaviside. All are based on the same principle, which is to compare the output of two potentiometers sharing a common source.

In power supply design, a bridge circuit or bridge rectifier is an arrangement of diodes or similar devices used to rectify an electric current, i.e. to convert it from an unknown or alternating polarity to a direct current of known polarity.

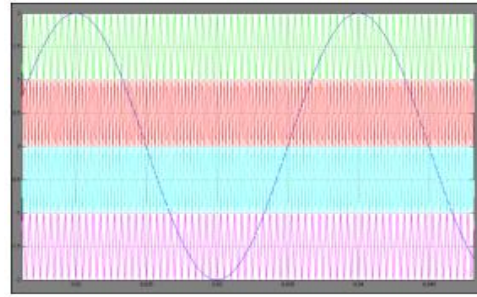
## PHASE OPPOSITION DISPOSITION

In Phase Opposition Disposition (POD), the carrier signal above the zero axis all the carrier wave have same frequency, same amplitude and in phase each other. But the below the zero axis all the carrier wave have same frequency, same amplitude and in phase but all carrier wave have phase shifted 180 degree compare to the above zero axis carrier waveform.

## PHASE OPPOSITION DISPOSITION PULSE WIDTH MODULATION

### SINUSOIDAL PULSE WIDTH MODULATION

For phase opposition disposition (POD) modulation all carrier waveforms above zero reference are in phase and are 180° out of phase with those below zero. The figure demonstrates the sine-triangle method for a five level inverter. Therein, the phase modulation signal is compared with four (N-1 in general) triangle waveforms.

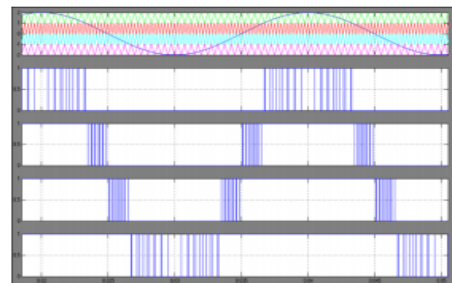


**Fig 4.1 Waveform model for Phase opposition disposition sinusoidal pulse width modulation.**

The rules for the phase opposition disposition method, when the number of level  $N=5$  are

- The  $N - 1 = 4$  carrier waveforms are arranged so that all carrier waveforms above zero are in phase and are 180° out of phase with those below zero.
- The converter is switched to  $+ V_{dc} / 2$  when the reference is greater than both carrier waveforms.
- The converter is switched to zero when the reference is greater than the lower carrier waveform but less than the upper carrier waveform.
- The converter is switched to  $- V_{dc} / 2$  when the reference is less than both carrier waveforms.

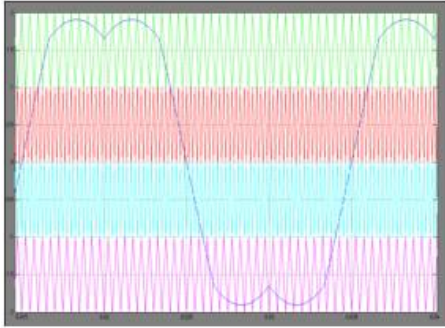
In this technique, carrier waves with variable switching frequencies of 2KHz and 4KHz are compared with the reference wave of 50Hz as shown in Fig.



**Fig 4.2 Waveform model for Phase opposition disposition sinusoidal pulse width modulation generation.**

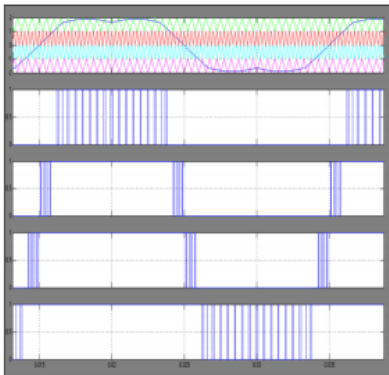
### SINUSOIDAL WITH ZERO SEQUENCE PULSE WIDTH MODULATION

Fig. shows the sinusoidal pulse width modulation with zero sequence in which a triple n harmonic voltage is added to each of the reference waveforms.



**Fig 4.3 Waveform model for Phase opposition disposition sinusoidal with zero sequence pulse width modulation.**

In this technique, carrier waves with variable switching frequencies of 2KHz and 4KHz are compared with the reference wave of 50Hz as shown in Fig.

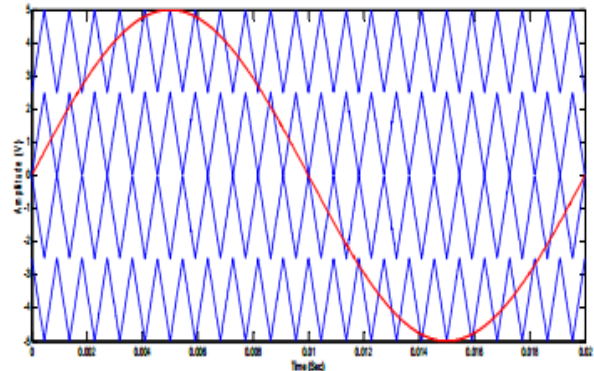


**Fig 4.4 Phase opposition disposition sinusoidal with zero sequence pulse width modulation generation.**

In this method all the carriers have the same frequency and the adjustable amplitude (different or unequal amplitudes). But all the carriers above the zero value reference are in phase among them but in

opposition (180 degrees phase shifted) with those below. Carrier and reference wave arrangements are as shown in Fig. 6.2.

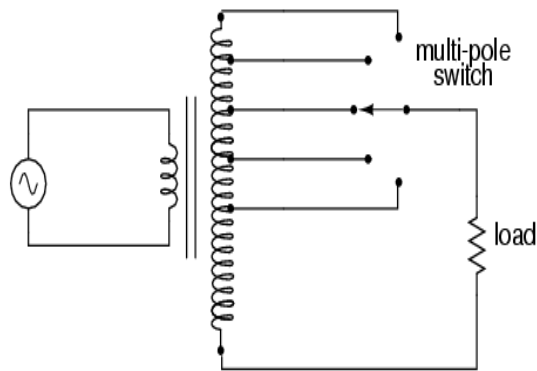
The converter is switched to  $+V_{dc} / 2$  when the sine wave is higher than both carrier waveforms, the converter switches to  $+V_{dc} / 4$  when the sine wave is lower than the uppermost carrier waveform and greater than all other carrier, the converter is switched to zero when the sine wave is greater than the lower carrier waveform but less than the upper carrier waveform, the converter switches to  $-V_{dc} / 4$  when the sine wave is higher than the lowermost carrier waveform and lesser than all other carriers and the converter is switched to  $-V_{dc} / 2$  when the sine wave is less than both carrier waveforms.



### MULTITAPPING TRANSFORMER

A Multi Tap Transformer is a step up or down transformer that has multiple taps on either the primary winding or the secondary winding. A Multi Tap Transformer provides flexibility in your input and output voltage requirements.

Multi Tap Transformers are used in heating element applications. The resistance of the heating elements increases with age which results in reduced current thru the heating element. To restore the heating element current back to its original value, the voltage applied to the heating element must be increased. Multi tap transformer connections provide the additional taps to compensate for the change.



**Fig 5.1 Model diagram of Multi tapping transformer**

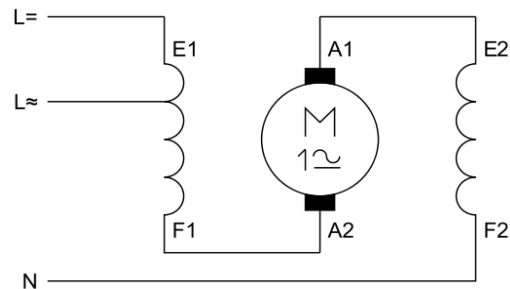
Multi tap transformers are also used in compensating for the variation of input power voltages to a customer facility. Input power to the equipment changes due to the load conditions as well as the proximity of the utility power to the customer facility and many other causes. This results in a mismatched input voltage to a customer facility. The multi tap transformer wiring configurations would be able to provide necessary taps to compensate for the variation of input voltages.

L/C Magnetics can provide Multi Tap Transformers as an open core and coil unit or enclosed in a corrosion resistant power coated enclosure. We can also install the transformer in a NEMA 4 enclosure or a stainless steel enclosure. L/C Magnetics builds custom designed multi tap transformers with taps on the primary side and taps on the secondary side. The transformers can be used for single phase or three phase applications. Click the photos for additional details. If these units do not meet your exact requirements, we will be glad to offer a redesigned transformer.

## UNIVERSAL MOTOR

The universal motor is so named because it is a type of electric motor that can operate on both AC and DC power. It is a commutated series-wound motor where the stator's field coils are connected in series with the rotor windings through a commutation. It is often referred to as an AC series motor. The universal motor is very similar to a DC

series motor in construction, but is modified slightly to allow the motor to operate properly on AC power. This type of electric motor can operate well on AC because the current in both the field coils and the armature (and the resultant magnetic fields) will alternate (reverse polarity) synchronously with the supply. Hence the resulting mechanical force will occur in a consistent direction of rotation, independent of the direction of applied voltage, but determined by the commutation and polarity of the field coils.



**Fig 7.1 Model diagram of Universal Motor**

Universal motors have high starting torque, can run at high speed, and are lightweight and compact. They are commonly used in portable power tools and equipment, as well as many house hold appliances. They're also relatively easy to control, electromechanically using tapped coils or electronically.

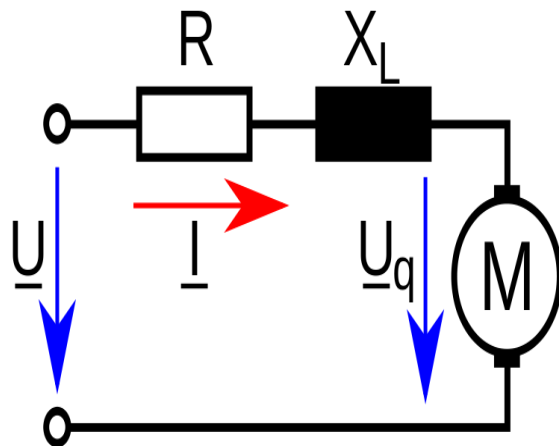
## PROPERTIES

Not all series wound motors operate well on AC current. If an ordinary series wound DC motor were connected to an AC supply, it would run very poorly. The universal motor is modified in several ways to allow for proper AC supply operation. There is a compensating winding typically added, along with laminated pole pieces, as opposed to the solid pole pieces found in DC motors. Even when used with AC power these types of motors are able to run at a rotation frequency well above that of the mains supply, and because most electric motor properties improve with speed, this means they can be lightweight and powerful. However, universal motors

are usually relatively inefficient- around 30% for smaller motors and up to 70-75% for larger ones.

One useful property of having the field windings in series with the armature winding is that as the speed increases the counter EMF naturally reduces the voltage across, and current through the field windings, giving field weakening at high speeds. This means that the motor has no theoretical maximum speed for any particular applied voltage. Universal motors can be and are generally run at high speeds, 4000-16000 rpm, and can go over 20,000 rpm. By way of contrast, AC synchronous and squirrel cage induction motors cannot turn a shaft faster than allowed by the power line frequency. In countries with 60 Hz(cycle/Sec) AC supply, this speed is limited to 3600 RPM.

Universal motors' armatures typically have far more coils and plates than a DC motor, and hence less windings per coil. This reduces the inductance.



**Fig 7.2 Equivalent circuit diagram of Universal Motor**

Motor damage may occur from over-speeding (running at a rotational speed in excess of design limits) if the unit is operated with no significant mechanical load. On larger motors, sudden loss of load is to be avoided, and the possibility of such an occurrence is incorporated into the motor's protection and control schemes. In some smaller applications, a fan blade attached to the shaft often acts as an artificial load to limit the motor speed to a safe level, as well as a means to circulate cooling

airflow over the armature and field windings. If there were no mechanical limits placed on a universal motor it could theoretically speed out of control in the same way any series-wound DC motor can.

An advantage of the universal motor is that AC supplies may be used on motors which have some characteristics more common in DC motors, specifically high starting torque and very compact design if high running speeds are used.

## APPLICATIONS

Operating at normal power line frequencies, universal motors are often found in a range less than 1000 watts. Universal motors also form the basis of the traditional railway traction motor in electric railways. In this application, the use of AC to power a motor originally designed to run on DC would lead to efficiency losses due to eddy current heating of their magnetic components, particularly the motor field pole-pieces that, for DC, would have used solid (un-laminated) iron. Although the heating effects are reduced by using laminated pole-pieces, as used for the cores of transformers and by the use of laminations of high permeability electrical steel, one solution available at the start of the 20th century was for the motors to be operated from very low frequency AC supplies, with 25 and 16 2/3 Hz (the latter subsequently re-designated 16.7 Hz) operation being common. Because they used universal motors, locomotives using this design could operate from a third rail or overhead wire powered by DC. As well, considering that steam engines directly powered many alternators, their relatively low speeds favored low frequencies because comparatively few stator poles were needed.

In the past, repulsion-start wound-rotor motors provided high starting torque, but with added complexity. Their rotors were similar to those of universal motors, but their brushes were connected only to each other. Transformer action induced current into the rotor. Brush position relative to field poles meant that starting torque was developed by rotor repulsion from the field poles. A centrifugal mechanism, when close to running speed, connected all commutator bars together to create the equivalent of a squirrel-cage rotor. As well, when close to

operating speed, better motors lifted the brushes out of contact.

Their high speed makes them useful for appliances such as blenders, vacuum cleaners, and hair dryers where high speed and light weight are desirable. They are also commonly used in portable power tools, such as drills, sanders, circular and jig saws, where the motor's characteristics work well. Many vacuum cleaner and weed trimmer motors exceed 10,000 RPM, while many Dermal and similar miniature grinders exceed 30,000 RPM.

Universal motors also lend themselves to electronic speed control and, as such, were an ideal choice for domestic washing machines. The motor can be used to agitate the drum (both forwards and in reverse) by switching the field winding with respect to the armature. The motor can also be run up to the high speeds required for the spin cycle. Nowadays, variable-frequency drive motors are more commonly used instead.

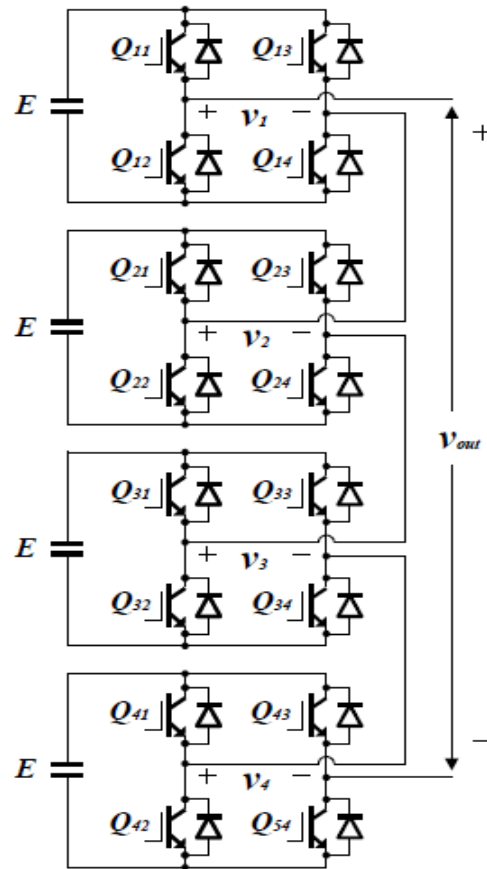
### MULTILEVEL CASCADED H-BRIDGE INVERTER

The cascaded H-bridge multilevel inverter has been researched for high voltage applications since it has advantages in number of components, high reliability, and modularity. The main purpose of a multilevel inverter is the generation of a high voltage using lower voltage rating devices connected in series. Also it has the potential to get a high quality output voltage by producing multi output voltage levels. However, it increases the number of switching devices and other components, which results in an increase of complexity problems and system cost.

### PROPERTIES

Many multilevel inverter configurations have been researched to get a sinusoidal-like output voltage wave with minimum circuit components. However, the configuration has brought a weakness in usage of high voltage applications due to its complexity in switch control and voltage stress (same as its input voltage source).

Fig shows a circuit configuration of a general cascaded H-bridge multilevel inverter. Each H-bridge module has an independent DC voltage source of  $E$ . Every output terminal of H-bridge cells is connected in series. So the output voltage can be obtained by Eq. (8.1). And the number of output voltage levels is obtained by Eq. (8.2).



**Fig 8.1 Circuit configuration of a conventional cascaded H-bridge multilevel inverter**

$$V_{out} = \sum_{n=1}^k v_n = V_1 + V_2 + V_3 + V_4 \tag{8.1}$$

$$N = 2k + 1 \tag{8.2}$$

Where  $k$  is the number of H-bridge cells.

To reduce the number of switches, a multilevel inverter using a cascaded transformer has been introduced. A multilevel inverter employing a

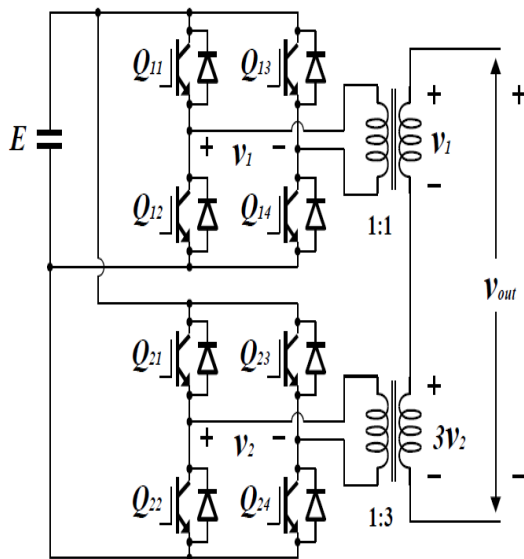
cascaded transformer. It has a single DC voltage source, two H-bridge cells, and two transformers. Since each secondary of the transformer is connected in series, the output voltage becomes the instantaneous sum of every secondary voltage of both transformers as given in Eq. (10.3). As well, the number of output voltage levels is determined by Eq. (8.4).

$$V_{out} = \sum_{n=0}^{k-1} 3n \cdot V_n + 1 = V_1 + 3 \cdot V_2 \quad (8.3)$$

$$N = 3^k \quad (8.4)$$

Where  $k$  is the number of transformers.

In Eq. (8.3),  $v_n$  can be  $E$ ,  $0$ , or  $-E$ ; therefore,  $v_{out}$  can produce  $-4E$ ,  $-3E$ ,  $-2E$ ,  $-E$ ,  $0$ ,  $E$ ,  $2E$ ,  $3E$ ,  $4E$  by mixing of each secondary voltage of the transformers.



**Fig 8.2 Circuit configuration of a multilevel inverter having a cascaded transformer**

From above figure 8.2, we can find that this multilevel inverter saves 8 switches and 3 DC voltage sources compared with the prior approach given in Fig.8.1. It automatically achieves galvanic isolation between a source and loads by the cascaded transformer.

## CONCLUSION AND FUTURE WORK

The POD technique for MLCIs under unbalanced dc-link conditions has been proposed in

this paper. In order to analyze the maximum synthesizable voltage of MLCIs, the voltage vector space has been analyzed using the switching function. From the analysis, the maximum linear modulation range was derived.

The proposed POD technique is applied to achieve the maximum modulation index in the linear modulation range under an unbalanced dc-link condition as well as to balance the output phase voltages. Compared to the previous methods, the proposed technique is easily implemented and improves the output voltage quality under unbalanced dc-link conditions. The number of output levels increased in the design so that the harmonic distortions are reduced and also reduce the switches.

Both simulation and experimental results based on the IPM motor drive application verify the effectiveness of the proposed method. I have planned to design a hardware module for this proposed work in phase II.

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