A Modified Method of Voltage Controller for Three Phase Induction Motor using Three Phase Voltage Source Inverter

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Abstract—A general pulse-width modulation (PWM) method for control of four-switch three-phase inverters is presented. The proposed vector PWM offers a simple method to select three or four vectors that effectively synthesize the desired output voltage, even in presence of voltage oscillations across the two dc-link capacitors.This paper offers a new analog controller, which has a fixed switching frequency as well as combined modulation and regulation. It employs a circuit-level decoupling method similar to those in and can be implemented by simple logic and an analog circuit. With the proposed controller, the three-phase inverter is proven to possess the ability to maintain good regulation of output voltages over 0%–100% rated linear or nonlinear loads, reject source voltage noise, follow abrupt reference changes, and withstand extreme load transients. The inverter under this control has low switching loss, as two of its six switches in the power converter are not operated at switching frequency at any instant.

Keywords*-PWM, SVM, Controller.*

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I. INTRODUCTION

DC to AC converters is known as Inverters. The function of an inverter is to change DC input voltage to a symmetric AC output voltage of desired magnitude and frequency. Inverters are broadly classified in to two types 1) single phase Inverters and 2) three-phase inverters. Each type can use controlled turn-on and turn-off devices such as bipolar junction transistors (BJT's), metal oxide semiconductor field effect transistors (MOSFET's), insulated gate bipolar transistors (IGBTs), metal oxide semiconductor controlled thyristors (MCTs), static induction transistors (SITs), and gate turn off thyristors (GTOs). An Inverter is called a Voltage Fed Inverter (VFI)or Voltage Source Inverter (VSI) if the input voltage is constant, a Current Fed Inverter(CFI) or Current Source Inverter(CSI) if the input current is maintained constant. Inviters are widely used in Industrial applications- Variable speed ac motor drives, Induction heating, Uninterruptible power supplies etc[1].

Pulse – Width Modulation (PWM) technique is the most efficient method for controlling the output voltage of an Inverter. In this method, a fixed DC input voltage is supplied to the Inverter and a controlled AC output voltage is obtained by adjusting the ON and OFF periods of the Inverter devices.

A. Three phase inverters

Three phase inverters are used for high power applications. Three single phase half (or full bridge) inverters can be connected in parallel to form the configuration of a Three phase inverter. The gating signals of single phase inverters should be advanced or delayed by 120^o with respect to each other to obtain the three phase balanced voltages. Though this arrangement may be preferable under certain conditions, it requires either a three-phase output transformer or separate access to each of the three phases of the load. In practice such access is generally not available. Moreover it requires twelve switching devices[2].

The most frequently used three phase inverter circuit consist of three legs , one for each legs. For this configuration, output transformers are not required. Also, this circuit uses six switching devices. Circuit is shown in figure 1

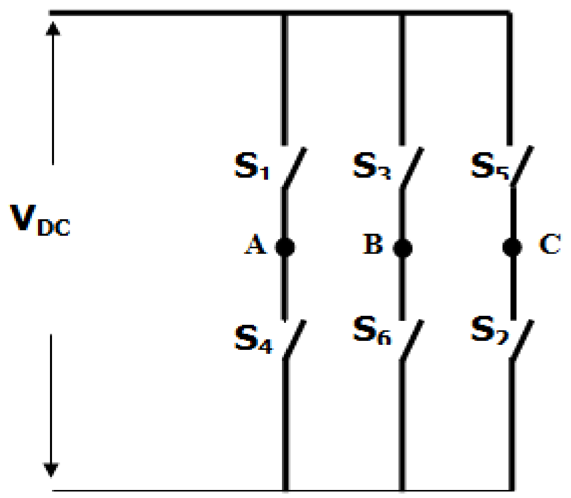

Figure 1 Three-phase voltage source inverter

In inverter terminology, a step is defined as a change in the firing from one switch to the next switch in proper sequence.

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For one cycle of 360°, each step would be of 60° interval for a six –step inverter[2]. This means that switching devices would be gated at regular intervals of 60° in proper sequence so that a three-phase ac voltage is synthesized at the output terminal of a six-step inverter.

Two types of control signals can be applied to the switches: 180° conduction or 120° conduction. The 180° conduction has better utilization of the switches and is the preferred method[1].

A typical three-phase inverter consists of a power converter and a controller, as shown in Figure 2. The power converter processes the power; it is usually implemented by a three-legged voltage source inverter (VSI) as shown in Figure 2. The controller commands the operation of the power converter and is a dominating factor that determines the performance of the inverter.

The controller usually consists of a modulator, which sends on/off commands to the VSI switches, and a voltage regulator, which minimizes the error between the voltage references and feedbacks.

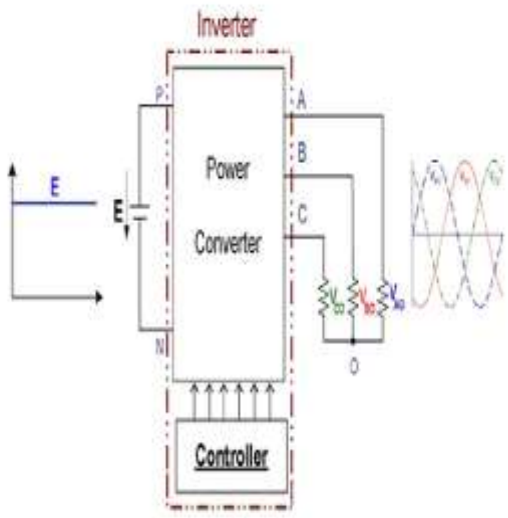

Figure 2 Functional Block Diagram of three-phase three-wire inverter

B. *Voltage controllers (modulators) of three phase inverters*

The following modulators are most commonly used for three phase inverters

1. Sinusoidal PWM
2. Third harmonic PWM
3. 60° PWM
4. Space Vector modulation

From the above four methods Sinusoidal PWM (SPWM) and Space Vector modulation (SVM) are most the commonly used ones.

C. *Sinusoidal PWM (SPWM)*

The generation of gating signals with sinusoidal PWM is shown in fig 1. There are three sinusoidal reference waves (V_{ra}, V_{rb} ,V_{rc}) each shifted by 120° . A carrier wave is compared with the reference signal corresponding to a phase to generate the gating signals for that phase. Comparing the carrier signal V_{cr} with the reference phases V_{ra}, V_{rb}, V_{rc} produces g1,g3, and g5 respectively as shown fig 3.3.1 .The instantaneous line –to-line output voltage is V_{ab} = Vs(g1-g3)[3].The output voltage as shown in fig 3 , is generated by eliminating the condition that two switching devices in the same arm cannot conduct at the same time.

The SPWM combines three independent single-phase sinusoidal controllers. They have the advantage of a simple realization, where only analog components are needed. However, power loss is high as all six switches are operated at switching frequency, and three sets of controllers are needed due to the independent control of each phase.

D. *Space vector modulation (SVM)*

Space Vector Modulation (SVM) is quite different from the PWM methods. With PWM's, the inverter can be thought as three separate push-pull driver stages, which create each phase waveform independently. SVM, however, treats the inverter as a single unit. The inverter can be driven to eight states as shown in table 1.Modulation is accomplished by switching the states of the Inverter. The control strategies are implemented in digital systems. SVM is a digital modulating technique where the objective is to generate PWM load line voltages. This is done in each sampling period by properly selecting the switch states of the inverter and the calculation of the appropriate time period for each state. The selection of the states and their time periods are accomplished by the space vector transformation.

Table 1 States of an Inverter

A	**B**	**C**
0	0	0
$\mathbf{V_{dc}}$	0	0
$\mathbf{V_{dc}}$	$\mathbf{V_{dc}}$	0
0	$\mathbf{V_{dc}}$	0
0	$\mathbf{V_{dc}}$	$\mathbf{V_{dc}}$
0	0	$\mathbf{V_{dc}}$
$\mathbf{V_{dc}}$	0	$\mathbf{V_{dc}}$
$\mathbf{V_{dc}}$	$\mathbf{V_{dc}}$	$\mathbf{V_{dc}}$

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The switching states of the inverter can be represented by; binary values 1 when a switch is turned on and 0, when a switch is tuned off.

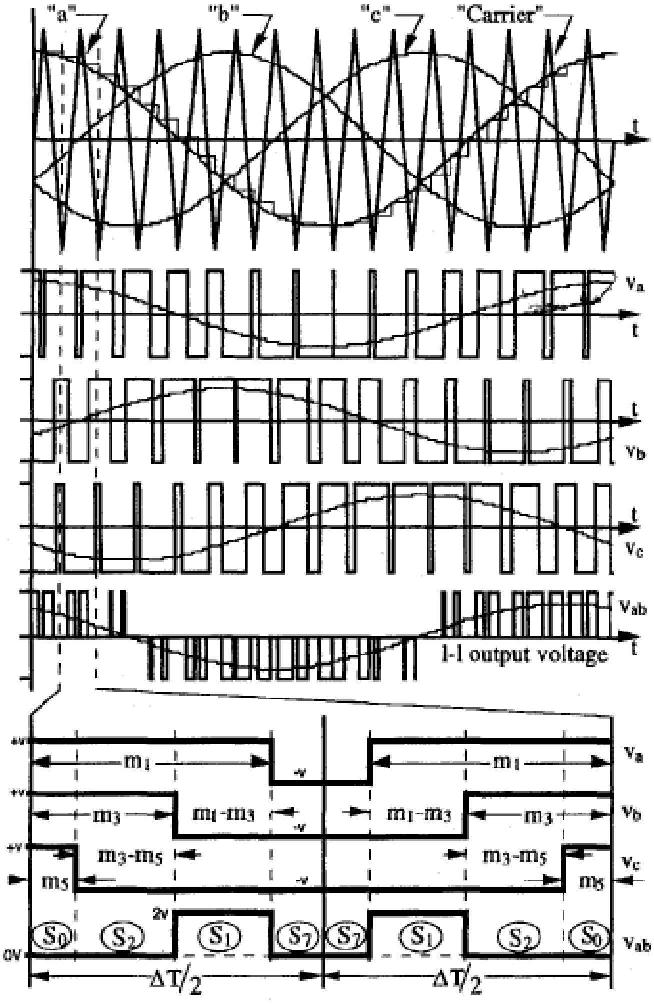
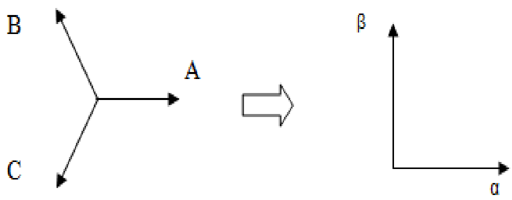


Figure 3 Switching patters for sinusoidal PWM

E. Space transformation

Any three functions of time that satisfy $U_a(t) + U_b(t) + U_c(t) = 0$, can be represented in a two dimensional space. Since, $V_A + V_B + V_C$ at any instant is equal to zero. So it can be represented as a single point in a two dimensional plane. This Single point is called Space Vector. The three phases can be transformed into two phases[4]



$$V\alpha = V_A \cos 0 + V_B \cos 120 + V_C \cos 240$$

$$= V_A - (V_B/2) - (V_C/2)$$

$$= (3/2)\, V_A$$

$$V\beta = V_A \sin 0 + V_B \sin 120 + V_C \sin 240$$

$$= V_B(\sqrt{3}/2) - (V_C(\sqrt{3}/2))$$

$$= (\sqrt{3}/2)(V_B - V_C)$$

F. Implementation of space vector

The space vector can be implemented in four steps.

- Sector identification
- Switching vector determination
- Switching time calculation
- Optimization of switching sequence

i) Sector identification

Of the eight states of an inverter two states are zero vectors and the remaining six vectors are active vectors. These active vectors can be represented as the six vectors of a hexagon. The figure 5 is shown below.

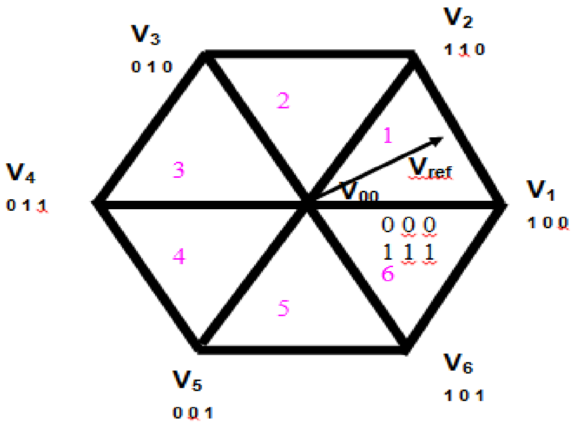


Figure 5 Sector Identification

There are six sectors identified by comparing the three instantaneous reference voltages.

$V_a > V_b > V_c$ --------------- Sector 1
$V_b > V_a > V_c$ --------------- Sector 2
$V_b > V_c > V_a$ --------------- Sector 3
$V_c > V_b > V_a$ --------------- Sector 4
$V_c > V_a > V_b$ --------------- Sector 5
$V_a > V_c > V_b$ --------------- Sector 6

ii) Switching vector determination

The vector which is to be switched is determined from the lookup table. The lookup table is made in accordance with the sectors.

iii) Switching Time calculation

In this section, the time for switching each vector is calculated. Consider a vector V_{ref} in sector-1, Let T_s be the total

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switching time for Vector V_{ref} , Let T_1 , T_2, T_3 be the switching time for vectors V_1 and V2.

$$V_{ref} * T_s = V_1 * T_1 + V_2 * T_2$$
$$V_{ref} *\cos\theta *T_s= V_1*\cos 0 * T_1 + V_2*\cos 60* T_2$$
$$V_{ref} *\sin\theta *T_s = V_1*\sin 0 * T_1 + V_2*\sin 60* T_2$$

Simplifying these two equations and find T_1 and T_2

$$T_o = T_s – (T_1 + T_2)$$

T_o is the time interval of Zero vector

For Sinusoidal PWM, this duty cycle computation is simplified by the sine-triangle comparison

iv) Optimization of switching sequence

The space vector sequence should assure that the load line voltages have the quarter wave symmetry to reduce even harmonics in their spectra. To reduce the switching frequency, it is also necessary to arrange the switching sequence in such a way that switching only one inverter leg at a time performs the transition from one to the next. Although there is not a systematic approach to generate a space vector sequence these conditions are met by the sequence V_z, V_n, V_n +1, V_z (Where V_z is alternatively chosen between V_0 and V_7). For example, if the reference vector falls in sector1, the switching sequence is V_0, V_1, V_2, V_7, V_7, V_2, V_1, and V_0. The time interval T_z (=T_0 = T_7) can be split and distributed at the beginning and at the end of the sampling period Ts. In general the time intervals of the null vectors are equally distributed, with T_z /2 at the beginning and T_z /2 at the end[3].

SVM-based controllers have high performance, including lower out-put voltage/current harmonics and switching loss, [9].

G. Limitation of above methods

- SPWM combines three independent single-phase sinusoidal controllers. Here power loss is high as all six switches are operated at switching frequency, and three sets of controllers are needed due to the independent control of each phase[4].
- In SVM, a coordinate transformation, a high speed DSP, a high sampling rate A/D converter is necessary. These increase both the cost and design complexity of SVM based controllers. In addition a high performance voltage regulator is to be combined with the modulator to complete the control task.
- In SPWM and SVM, for every switching time, the switching occurs in all the three phases of the inverter. This increases the switching losses.

II. LITERATURE SURVEY

In [1] A general pulse-width modulation (PWM) method for control of four-switch three-phase inverters is presented. The proposed vector PWM offers a simple method to select three or four vectors that effectively synthesize the desired output voltage, even in presence of voltage oscillations across the two dc-link capacitors. The method utilizes the so-called space vector modulation, and includes its scalar version. Different vector combinations are compared. The effect of Wye and delta motor winding connections over the pulse width modulator is also considered. The common mode voltage generated by the four-switch three-phase converter is evaluated and compared to that provided by the standard six-switch three-phase inverter.

In [2] The inherent relations between sine-triangle and space-vector pulse width modulation schemes for three-level voltage-source inverters is discussed. It is shown that the two schemes can function equivalently through proper selection of common-mode injections in the case of sine-triangle modulation, or dwell times in equivalent redundant switching states in the case of space-vector modulation.

In [3] the equivalence between the PD Carrier and Space Vector Modulation Strategies applied to Diode Clamped, Cascaded N-level or Hybrid multilevel inverters are presented. By analysis of the time integral trajectory of the converter voltage, the paper shows that the optimal harmonic profile for a Space Vector Modulator occurs when the two middle Space Vectors are centered in each switching cycle. The required zero sequence offset to achieve this centering for an equivalent carrier based modulator is then determined. The results can be applied to any multilevel converter topology without differentiation. Discontinuous behavior is also examined, with the Space Vector and Carrier based modulation methods shown to similarly produce identical performance.

In [4] the relationship between regular-sampled pulse width modulation (PWM) and space-vector modulation is defined, and it is shown that, under certain circumstances, the two approaches are equivalent. The various possibilities of adding a zero-sequence component to the regular-sampled sinusoidal modulating wave are explored, and these effects are quantified

In [5] it is discussed that the advancements in power electronics technology allowed the wide investigation of multilevel converters that provide high safety voltages with less harmonic components compared to the two-level structures. Employed for converter's gating signals generation, the space-vector pulse width modulation (SVPWM) strategy reduces the switching losses by limiting the switching to the two thirds of the pulse duty cycle.

In [6] The Significance of Zero Space Vector Placements for Carrier-Based PWM is discussed. Pulse-width modulation has been one of the most intensively investigated areas of power electronics for many years now, and the number and combination of permutations seem to be endless. However, a general hierarchal consensus appears to have emerged from this work, which ranks space vector modulation techniques, regular sampled modulation, and sine-triangle modulation strategies in decreasing order of merit based on harmonic performance. However, what has not been clearly identified is why space vector modulation should lead to a reduced harmonic current ripple compared to regular sampled modulation, especially since it is straightforward to show that they produce identical low-frequency fundamental components. This paper addresses this issue by showing how it is the placement of the zero space vector components within the carrier interval that determines the harmonic performance of the modulation strategy, rather than any intrinsic differences between the various methods of calculating the switching instances.

III. PROPOSED WORK

This work aims to implement PWM for a three-phase inverter with considerable reduction in switching frequency, still maintaining the same PWM frequency. The novelty of the work is in the observation to generate PWM for a three-phase inverter by only switching two legs of the inverter without distorting the output[5].

This paper offers a new analog controller, which has a fixed switching frequency as well as combined modulation and regulation. It employs a circuit-level decoupling method similar to those in and can be implemented by simple logic and an analog circuit. With the proposed controller, the three-phase inverter is proven to possess the ability to maintain good regulation of output voltages over 0%–100% rated linear or nonlinear loads, reject source voltage noise, follow abrupt reference changes, and withstand extreme load transients[6]. The inverter under this control has low switching loss, as two of its six switches in the power converter are not operated at switching frequency at any instant.

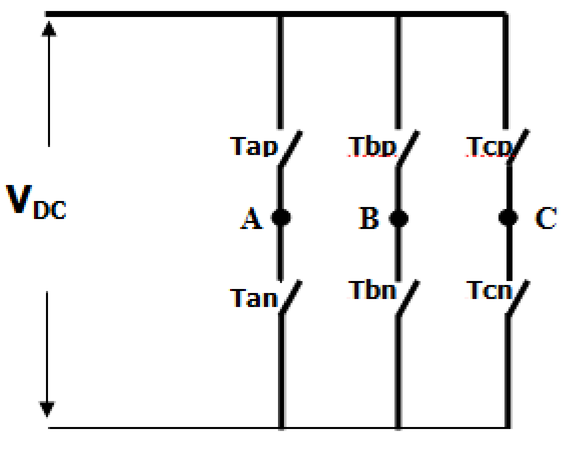

Figure 6 Three-phase three-legged VSI.

The Figure 6 shows a three-phase three-wire VSI that is commonly used for three-phase voltage generation. It consists of six switches *T*ap –*T*cn. The VSI can generate three-phase ac voltages (*V*AO, *V*BO, and *V*CO), as shown in Fig 4.2, by operating the switches according to the gate-trigger signals from a controller that determines the duty ratio of the switches. A line period is divided into six regions, as shown in Fig. 7 By inspecting the three-phase voltage waveforms in each region, one common fact is found that two phase voltages are always positive and the other is negative in regions 0◦–60◦, 120◦–180◦,and 240◦–300◦,whereas the opposite can be found in regions 60◦–120◦, 180◦–240◦,and 300◦–360◦. This fact leads to the thought of pulse width modulating the switches in the phase of the same signs while keeping the switches in the other phase steady state for the entire region. In regions 0◦–60◦, 120◦–180◦,and 240◦–300◦,the voltage waveforms in Fig. 3 have the same pattern, i.e., two phases are higher than one phase. The following modulation method is used[7].

1) The switch *T*in (*i* = *a*,*b*,*c*) for the phase with lower voltage is always turned on, and the corresponding *T*ip for this phase is always turned off.

2) The switches *T*in and *T*ip for the other two phases are driven complementary, where the duty ratio of one *T*ip is defined by *dp*; the duty ratio of the other *T*ip is defined by *dn*.

While in regions 60◦–120◦, 180◦–240◦,and 300◦–360◦,the voltage waveforms in Fig. 3 have the same pattern, i.e., two phases are lower than one phase. The following modulation method is used[4].

1) The switch *T*ip (*i*= *a*,*b*,*c*) for the phase with the highest voltage is always turned on, and the corresponding *T*in for this phase is always turned off.

2) The switches *T*ip and *T*in for the other two phases are driven complementary, where the duty ratio of one *T*in is defined by *dp*; the duty ratio of the other *T*in is defined by *dn*.

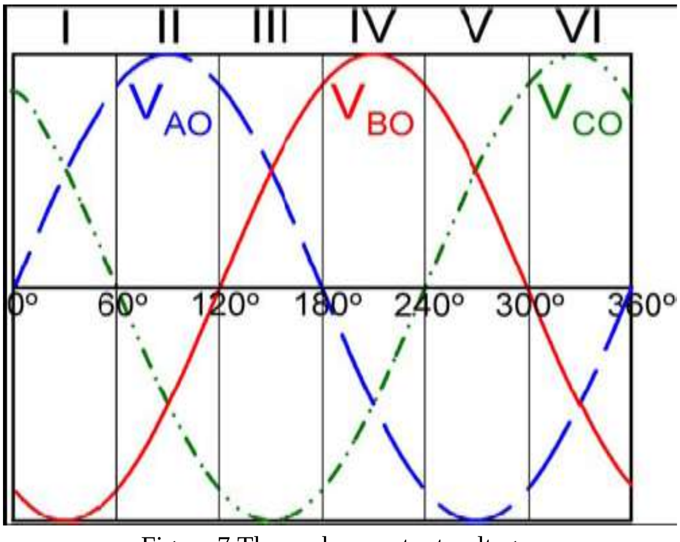

Figure 7 Three-phase output voltages

IV. ANALYSIS OF PROPOSED CONTROLLER

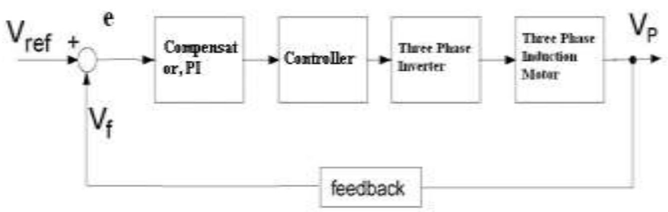

Figure 8 System Block Diagram

Fig.8 shows the generalized block diagram of the controlled inverter in every 60° Region, where PI represents the compensator transfer function. The desired speed is represented as V_{ref} and the feedback speed o actual speed of the induction motor is represented as V_f. Comparing V_{ref} and V_f, which is fed to the compensator block, produces an error signal 'e'. The compensator produces three sinusoidal reference signals V_A ,V_B ,V_C, which are 120° phase shifted by each other. The controller accepts three sinusoidal inputs and it selects the regions and generates the PWM signals by comparing these sinusoidal inputs and a triangular carrier signal. According to the region selected and the PWM signals, the controller generates gating signals for the appropriate switches for the inverter. The three-phase output of the inverter is fed to the three-phase induction motor. The actual speed of the induction motor is sensed by a speed sensor and is fed back; to be compared with the desired speed.

A three-phase induction motor is connected to the output of the thee-phase inverter. Feedback path is used to feed back the output of the induction motor (V_f) and compare with reference voltage (*Vref)* and produce an error signal, which is fed to the PI compensator[5].

The logics for region selection and gate signal distribution are shown in Table 2.

Table 2- Logics Of Proposed Controller

Outputs of Region Selector	Logic for Control Signal Selector		Logic for Gate Signal Distributor		
Regions	CON_p	CON_n	d_p	d_n	$d_f=1$
I: 0°~60°	$V_{F\text{-}AB}$	$V_{F\text{-}CB}$	T_{ap}	T_{cp}	T_{bn}
II: 60°~120°	$V_{F\text{-}AB}$	$V_{F\text{-}AC}$	T_{bn}	T_{cn}	T_{ap}
III: 120°~180°	$V_{F\text{-}BC}$	$V_{F\text{-}AC}$	T_{bp}	T_{ap}	T_{cn}
IV: 180°~240°	$V_{F\text{-}BC}$	$V_{F\text{-}BA}$	T_{cn}	T_{an}	T_{bp}
V: 240°~300°	$V_{F\text{-}CA}$	$V_{F\text{-}BA}$	T_{cp}	T_{bp}	T_{an}
VI: 300°~360°	$V_{F\text{-}CA}$	$V_{F\text{-}CB}$	T_{an}	T_{bn}	T_{cp}

V.ADVANTAGES OF PROPOSED CONTROLLER

The proposed controller for three-phase three-wire inverter has the following advantages.

1. Generalization and implementation flexibility—Control core can be carried out by all dc–dc control methods; the feedback signal processor has four ways of realization. The combination of any can generate one way of implementation of the proposed controller[6].

2. Application flexibility—the proposed controller is used for the control of the voltage generation inverter. When such an inverter is incorporated in UPS systems where electrical isolation is needed for critical load, the proposed controller can be applied to control the power converter with either transformer isolation at the output or dc/dc converter isolation at the dc bus input the same way as it is applied to three-legged VSI shown in Fig. 6. In addition, when the voltage generation inverter experiences a failure or is overloaded, the controller can facilitate an immediate transfer of power from inverter to incoming utility power by synchronizing its voltage reference with the power line frequency.

3. Simplicity—No DSP, microprocessor, or software is required, which simplifies the design and reduces the implementation cycle.

4. Fast response—it can quickly respond to reference change and load variation.

5. Low switching loss—by not switching the phases that have the highest voltage, the switching action is reduced by 1/3 and the switching loss is significantly reduced. When the controlled inverter is powering loads with a unity power factor, the saving can reach 50%. A compromise has to be made between the reduction of switching loss and the reduction of harmonic contents. Due to the huge savings on switching loss, any controller that can reduce switching actions is a more popular choice, particularly at high-power applications. With the proposed controller, the measured efficiency of the inverter is 96% at full load[7].

VI. CONCLUSION AND FUTURE WORK

This paper introduces a new controller for three-phase three-legged Voltage source inverter, with a control goal of generating expected three-phase output voltages. The proposed controller has lot of advantages when compared with the existing ones. The efficiency of the inverter is 96% at full load, also it can quickly respond to reference change and load variation.The implementation of the controller in according to the strategy, which has been already described, shall be the future work.

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