SPACE VECTOR CONTROL OF THREE PHASE INVERTER

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ABSTRACT:

A three phase inverter with a neutral leg is represented in this paper. With additional neutral leg, space vector modulation is used. Space vector modulation control of inverter and its design considerations are described. The analysis is performed with respect to switching losses and total harmonic distortion under both balanced and unbalanced load. Three phase inverter is designed considering the power handling capability, operating speed and efficiency considerations of the load. Inverter consists of IGBT hex bridge as switch and EPROM is used to generate the switching sequence which is determined using the switching sequence schemes.

Space Vector Modulation is more advanced switching algorithm which overcomes the drawbacks of the SINE PWM algorithm and increases overall efficiency. Here SVM is implemented digitally which increases the ease of VF control. The results of the experiment of the hardware and software implementation of inverter are observed. EPROM control makes the inverter more efficient, fast and reliable and Space Vector Modulation makes the circuit to eliminate the drawbacks of the sine PWM implementation.

Key words: Space vector modulation (SVM), pulse width modulation (PWM), Sinusoidal pulse width modulation (SPWM), voltage source inverter (VSI), Total Harmonic Distortion (THD), Uninterrupted Power Supply (UPS).

INTRODUCTION:

DC to AC converter is known as inverter. The function of inverter is to convert a DC input voltage into symmetrical AC output voltage of desired magnitude and frequency. A variable output voltage can be obtained by two ways. Either by varying input voltage and maintaining gain of the inverter constant or by keeping the input voltage constant and varying the gain of the inverter.

The wave shape of the inverter should be sinusoidal. However practical inverter gain output voltages are non-sinusoidal and contain harmonics. The wave shape of output voltage are square wave, quasi square wave or distorted sinusoidal. Using Space Vector Modulation technique number of harmonics can be effectively reduced also distortion can be minimised upto greater extent.

Inverters used in low and medium power applications normally give square or quasi square wave output. But inverter required for high power application requires sinusoidal waveform as output. Three phase inverters are normally used for high power applications. Space Vector Modulation is most efficient way to control inverter parameters.

There is an increased interest in four-leg inverters for their use under unbalanced load conditions especially in UPS and power systems applications. A high-power standalone power supply is needed to provide a continuous and high quality energy flow to critical loads, such as Medical Equipment, Military equipment, Satellite Earth Stations, Broadcasting Systems, Large Space Computer Systems, for rural areas where utility lines cannot reach[1]. In combining an engine generator set and a three phase power inverter, a rotary standalone three phase AC power supply is proposed which has merits of unlimited ampere hour capability, fast dynamic regulation and high performance.

METHODS:

TWO DIMENSIONAL SPACE VECTOR

In a conventional three phase inverter, where an assumption of $Xa + Xb + Xc = 0$ is made, variables in a-b-c coordinates Xabc can be transformed into variables in an α-β orthogonal coordinates Xαβ. A conventional three phase inverter has 8 total possible switch combinations representing 8 possible three phase bridge voltages transforming the 8 three phase bridge voltages into α-β coordinates results in 8 switching vectors distributed in a plane.

THREE DIMENSIONAL SPACE VECTOR:

When a neutral leg is added to a conventional three-phase inverter to deal with the zero-sequence load current, the assumption of $Xa+Xb+Xc = 0$ is no longer valid. The three phase variables Xabc truly become three independent variables, which can be transformed into three-dimensional orthogonal coordinates Xαβγ by applying the equation given below.

$$\begin{matrix} X\alpha \\ X\beta \\ X\gamma \end{matrix} = 2/3 \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{matrix} Xa \\ Xb \\ Xc \end{matrix}$$

BLOCK DIAGRAM:

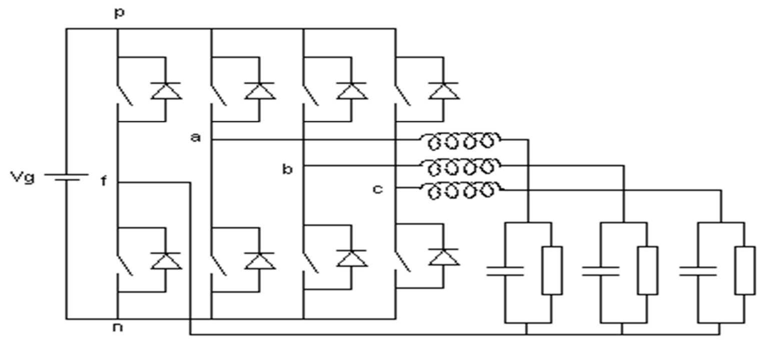
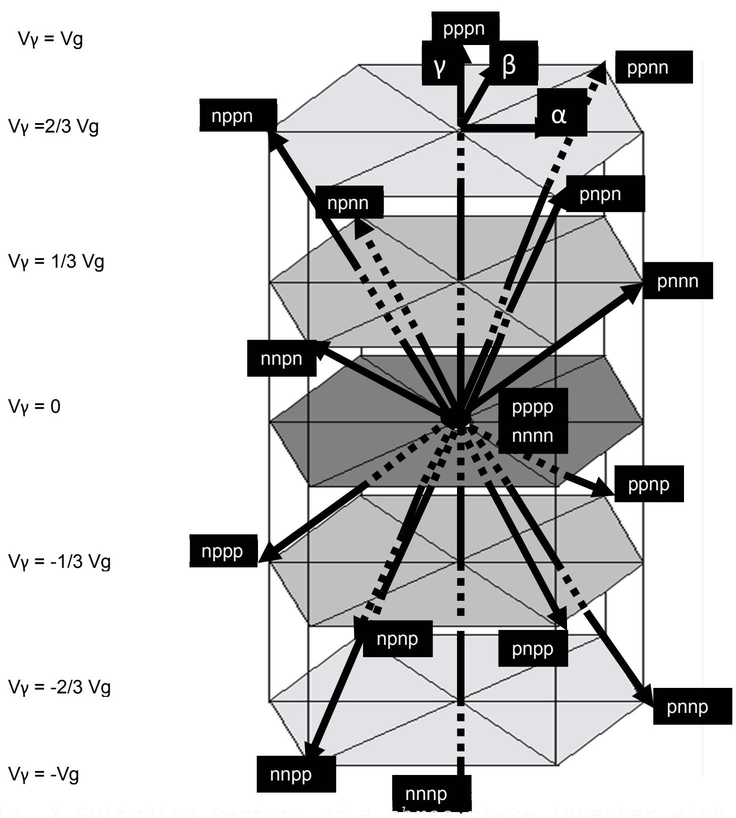


Fig.1 Three phase inverter with a neutral leg

Fig.1 shows three phase inverter using neutral leg where the neutral leg is used in the unbalanced load condition [5].

In four leg inverter there are 16 switching states vector (SSV).Where there are 14 non-zero vectors, and 2 zero vectors, which is shown in Fig.2



Out of these 16 SSV's, 14 of them produce a non-zero output voltage and remaining two topologies produce

Fig 2. Switching Vectors of a three-phase inverter with a neutral leg [5]

	pppp	nnnp	pnnp	ppnp	npnp	nppp	nnpp	pnpp
Vaf	0	-Vg	0	0	-Vg	-Vg	-Vg	0
Vbf	0	-Vg	-Vg	0	0	0	-Vg	-Vg
Vcf	0	-Vg	-Vg	-Vg	-Vg	0	0	0
	pppn	nnnn	pnnn	ppnn	npnn	nppn	nnpn	pnpn
Vaf	Vg	0	Vg	Vg	0	0	0	Vg
Vbf	Vg	0	0	Vg	Vg	Vg	0	0
Vcf	Vg	0	0	0	0	Vg	Vg	Vg

Table 1. Switch combinations and independent bridge voltages

	pppp	nnnp	pnnp	Ppnp	npnp	nppp	Nnpp	pnpp
Vα	0	0	⅔Vg	⅓Vg	-⅓Vg	-⅔Vg	-⅓Vg	⅓Vg
Vβ	0	0	0	1/√3Vg	1/√3Vg	0	-1/√3Vg	-1/√3Vg
Vγ	0	-Vg	-⅔Vg	-1/√3Vg	-⅔Vg	-1/√3Vg	-⅔Vg	-1/√3Vg
	pppn	nnnn	pnnn	Ppnn	npnn	nppn	Nnpn	pnpn
Vα	0	0	⅔Vg	⅓Vg	-⅓Vg	-⅔Vg	-⅓Vg	⅓Vg
Vβ	0	0	0	1/√3Vg	1/√3Vg	0	-1/√3Vg	-1/√3Vg
Vγ	Vg	0	⅓Vg	⅔Vg	-⅓Vg	⅔Vg	⅓Vg	⅔Vg

Table 2. Switch combinations and inverter voltages in α-β-γ

VOLTAGE SPACE VECTORS:

Space vector modulation (SVM) for three-leg VSI is based on the representation of the three phase quantities as vectors in a two-dimensional (a,b) plane[3]. This is shownin table 2 and illustrated here for the sake of completeness. Considering topology 1 of Fig. 3(a),we see that the line voltages *Vab*, *Vbc*, and *Vca* are given by

$$Vab = Vg$$

$$Vbc = 0$$

$$Vca = -Vg$$

This can be represented in the α,β plane as shown in Fig.3(b), where voltages *Vab*, *Vbc*, and *Vca* are three line voltage vectors displaced 120° in space. The effective voltage vector generated by this topology is represented as V1(pnn) in Fig.3(b). Here the notation 'pnn' refers to the three legs/phases a,b,c being either connected to the positive dc rail (p) or to the negative dc rail (n). Thus 'pnn' corresponds to 'phase a' being connected to the positive dc rail and phases b and c being connected to the negative dc rail.

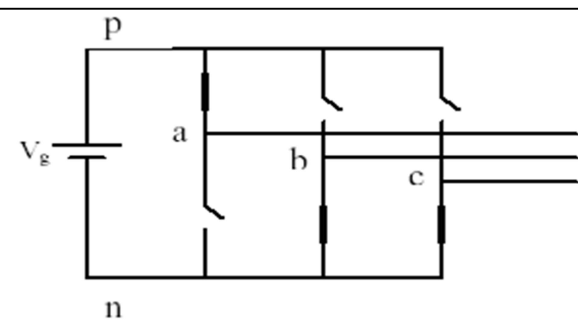


Fig 3(a). Topology 1-V1(pnn) of a voltage source inverter.

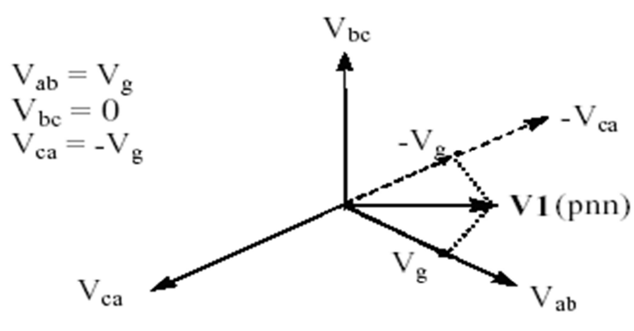


Fig. 3(b). Representation of topology 1 in the α, β plane.

SPACE VECTOR MODULATION:

The desired three phase voltages at the output of the inverter could be represented by an equivalent vector **V** rotating in the counter clock wise direction as shown in Fig. 4(a). The magnitude of this vector is related to the magnitude of the output voltage and the time this vector takes to complete one revolution is the same as the fundamental time period of the output voltage.

Fig.4(a)

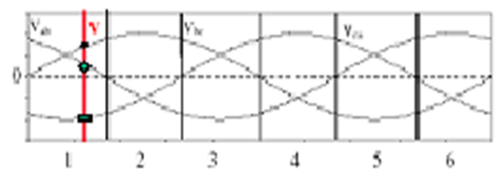


Fig.4(b) Output voltage vector and output line voltage in time domain

Let us consider the situation when the desired line-to-line output voltage vector **V** is in sector 1 as shown in Fig.4 (a).This vector could be synthesized by the pulse-width modulation (PWM) of the two adjacent SSV's **V1** (pnn) and **V2** (ppn), the duty cycle of each being d1 and d2, respectively, and the zero vector (**V7**(nnn) / **V8**(ppp)) of duty cycle d0

$$\boldsymbol{d_1 V_1 + d_2 V_2 = V = m V_g\, e^{je}} \qquad (1)$$

$$\boldsymbol{d_1 + d_2 + d_0 = 1} \qquad (2)$$

Where, 0≤m≤ 0.866, is the modulation index. This would correspond to a maximum line-to-line voltage of 1.0Vg, which is 15% more than conventional sinusoidal PWM [4]. Three SVM algorithms are considered which are described below. Symmetric Sequence (SCM1)
The sequence of vectors applied in this scheme has been shown in the following figure.5

- This scheme has the lowest THD because of the symmetry in the switching waveforms.
- The number of commutations in one sampling period is eight.
- Since this scheme has the same number of switching with three switch turn-ons and three switch turn-offs, their switching losses are expected to be similar.

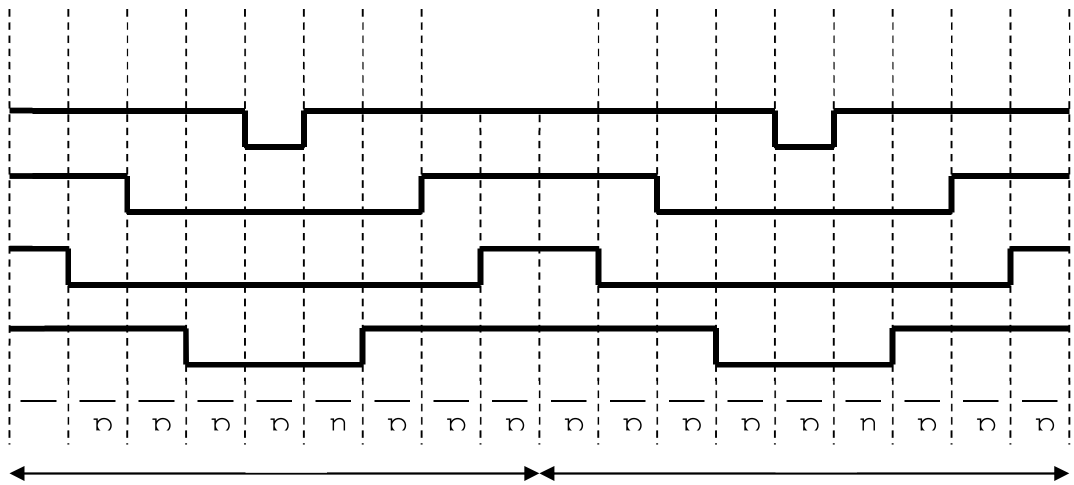


Fig.5 Scheme 1

Alternating Zero Vector Sequence (SCM2)tgf3

- In this scheme, the zero vectors (pppp) and (nnnn) are used alternatively in adjacent cycles so that the effective switching frequency is halved, as shown in Fig.6
- The sampling period is Ts, same as in the other schemes.
- The switching losses for this scheme are expected to be ideally 50% as compared to those of the other two schemes.
- THD is significantly higher due to the existence of the harmonics at half of the sampling frequency. Which is shown in fig 9 .

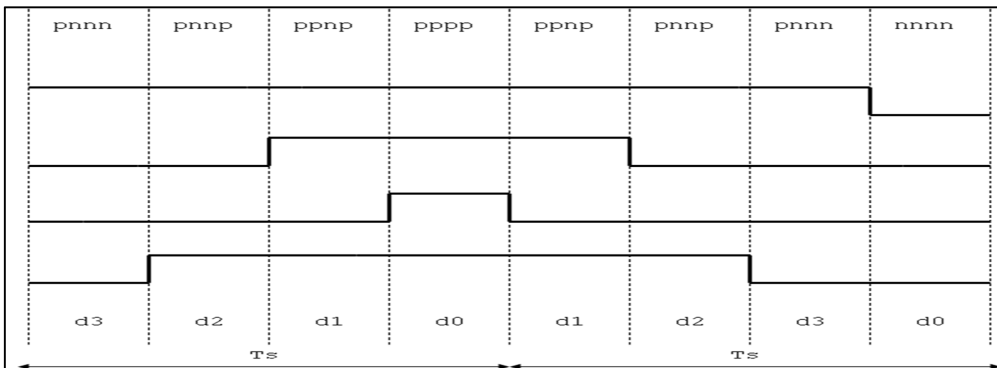


Fig.6 Scheme 2 (Alternating Zero Vector)

Highest Current Not-Switched Sequence (SCM3)

In this scheme switching losses are approximately proportional to the magnitude of the current being switched and hence it would be advantageous to avoid switching the inverter leg carrying the highest instantaneous current.[2] This is possible in most cases, because all adjacent SSV's differ in the state of switches in only one leg. Hence, by using only one zero vector, (pppp) or (nnnn) within a given sector one of the legs does not have to be switched at all, as shown in Fig.7

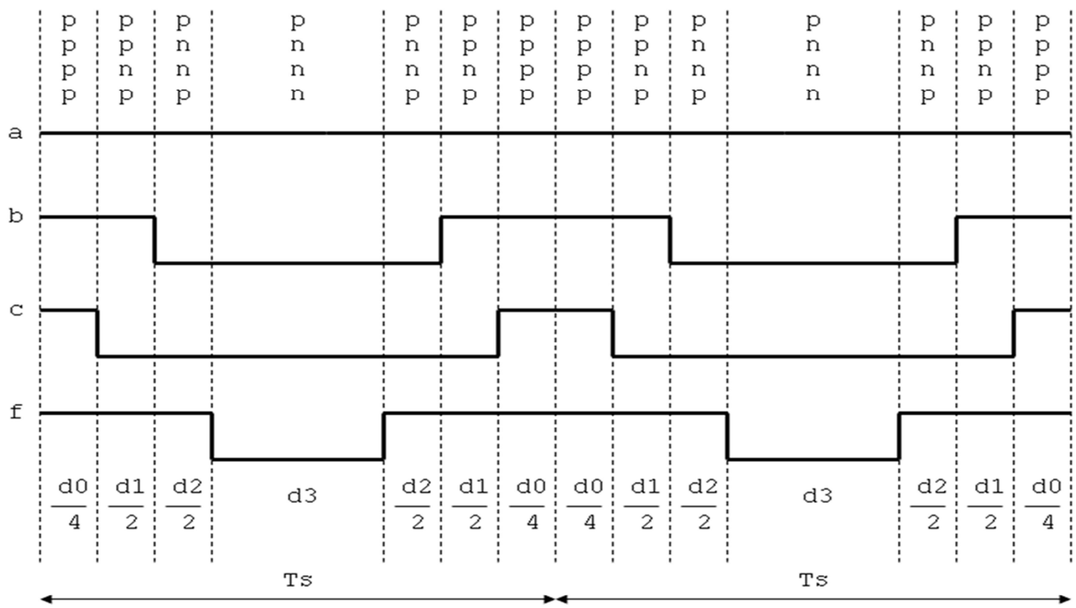


Fig.7 Scheme 3 (Highest Current not Switched)

Hardware Block Diagram Description

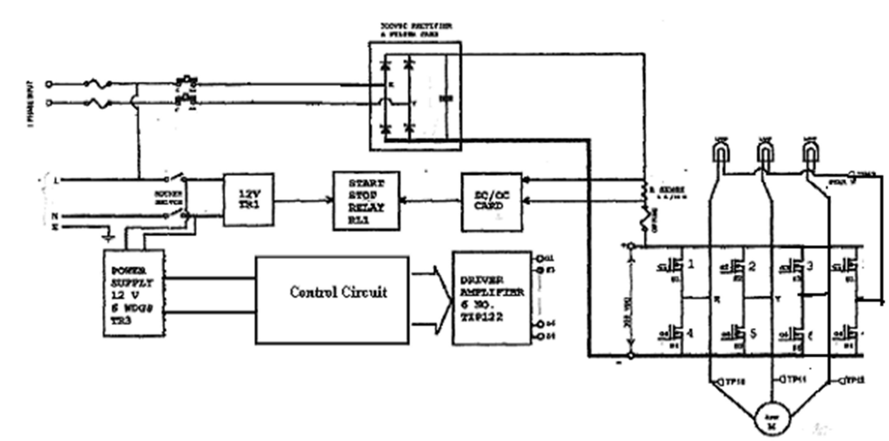


Fig.8 *POWER CIRCUIT FOR THREE PHASE INVERTER*

The schematic diagram of a four-leg inverter is shown in Fig. 8. This topology is known to produce balanced output voltages even under unbalanced load conditions. Due to the additional leg, a four-leg inverter can assume sixteen topologies which is twice. RECTIFIER : The main function of this block is to convert input ac supply to dc. This is given to power drive. SC/OC CARD: This card is used to protect power circuit from over current and short circuit. CONTROL CIRCUIT: This circuit is used with the advanced and latest technology space vector modulation (SVM). Where EEPROM is used to produce pulses DRIVER CARD : This block provides isolation between power card and control circuit (SVM) POWER CARD : This block is having four leg inverter . The sequential switching of devices provides ac at output.

Total Harmonic Distortion

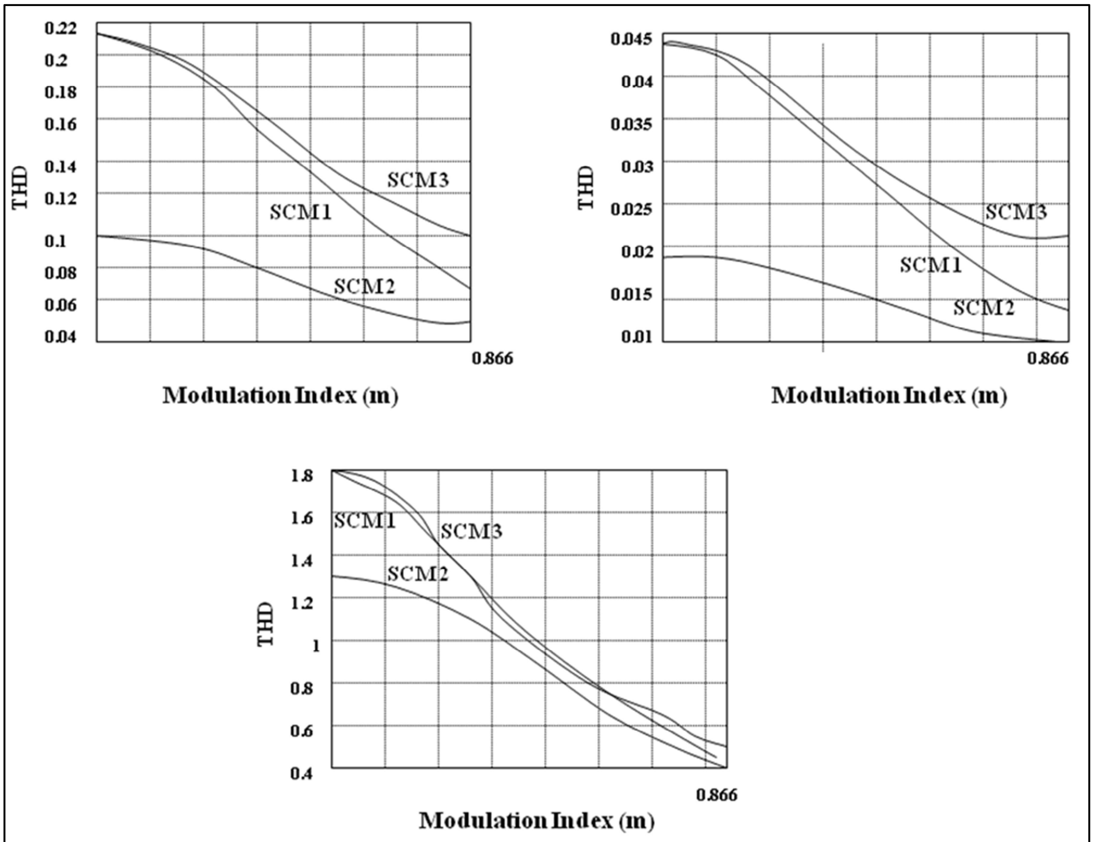


fig. 9

Fig. 9 shows the variation of THD (of phase voltage and phase current) with modulation index for all the schemes. The results are similar to the three-leg inverter.

SWITCHING LOSSES:

Fig. 10 shows the relative variation of switching losses with load power factor for the three schemes.

Under balanced load conditions the neutral leg carries only the high frequency ripple. Hence the switching losses are

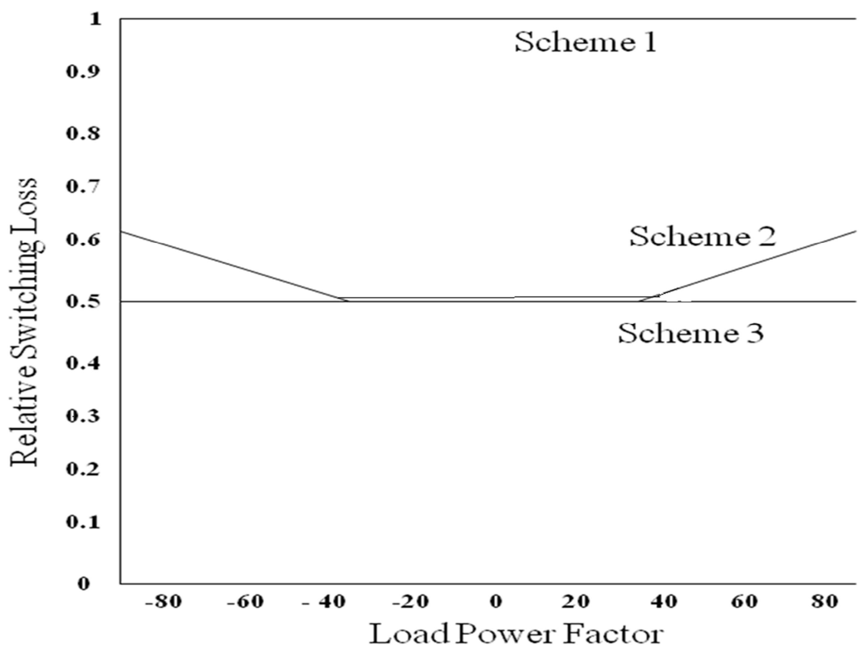


Fig 10 Relative switching losses as a function of load power factor

expected to be similar to the three leg inverters. Losses for schemes 1 and 3 are independent of the load whereas for scheme 2 the losses depend on the load power factor.

CONCLUSION:

This analysis analyses the most important modulation schemes for a four leg inverter. The analysis was performed over the entire range of modulation index and load power factor. The Harmonic Distortion and Switching losses for all three switching schemes are studied and plotted. We can conclude that third switching scheme is more effective as it reduces switching losses.The analysis clearly brings out the tradeoff's to be observed between the THD and switching loses. Thus SVM is a balanced method that gives 15% more efficiency and less THD.

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