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Modified 3DSVM with Discontinues PWM for Three Phase Four Leg Inverters to Reduce CMV

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Abstract:
This paper describes the three dimensional space vector modulation technique (3DSVM) modified with DPWM for a three phase four leg inverter. The distributed generation and its resulted unbalances in the three-phase system demands 3D space vector modulation for the inverter switching. The 3D coordinate system with the application of DPWMfor four leg inverters with enhancement in CMV reduction is explained in this paper. Past researchers in this field developed a number of alternate coordinate methods to improve the system with primary focus to reduce computational complexity, common mode voltage as well as switching loss. This paper shows that the application of discontinuous PWM on 3DSVM reduces switching loss and common mode voltage.

Keywords —3DSVM, Inverters, Space Vector Modulation, CMV, Three phase system, Modulation, Power Quality, switching loss, DPWM.

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I. INTRODUCTION

The population of distributed generation affects quality of power in standalone and grid power system. Past researchers contributed a constant development with three dimensional space vector modulation [17][1]. The unbalanced system is due to the asymmetry in load distribution and real time variation in the load. Harmonics, reactive power and neutral current are the forms of power quality degradation contributed by non-linear loads [17]. Sensitive loads such as communication equipments, and medical equipment demands reliable power with quality [18]. Polluted energy sources results in power loss, excessive heating in neutral line and in rotary machines, electromagnetic interference, low power factor and failure of devices. For a balanced three phase system, three leg inverter without a neutral connection is sufficient (Fig.1). But in practical systems, the load will be unbalanced and systems required wire from load side to inverter as forth wire to deal neutral current. This forth wires enable the inverter to deal with with unbalanced and non-linear loads. They are the common cause for excessive neutral currents in a three-phase system. There are two four wire topologies – three leg or four leg, with an extra connection from the neutral point of the load side to the inverter to provide current path for neutral currents[17][18].

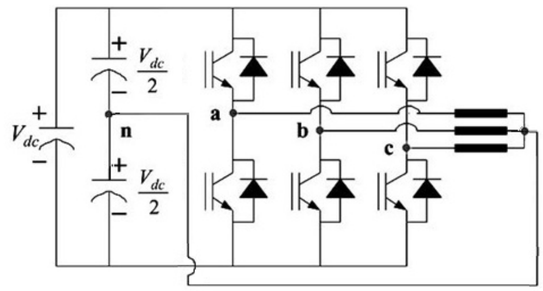
In unbalanced systems, the sum of phase voltages is non-zero, and hence to control the zero sequence current three dimensional space vector modulation is essential[17].

II. FOUR WIRE INVERTER TOPOLOGIES

To control the neutral current, a four wire topology is required [6]. The two popular configurations of converters that provides a neutral connection are[17],

(a) Split DC link capacitor type [1][17].

(b) Four leg inverter topology[7][18].



g. 1 Split DC link capacitor topology

(a) Split DC Link capacitor type

It is theconventional approach to handle neutral current by linking neutral point to the centre point of DC link capacitors, so that the neutral current can flow through the capacitors [1], as shown in Fig.1. Six switches in this topology and thereby reduced cost of installation and switching loss. The neutral current flows through the upper and lower capacitors, variations in DC link voltages may result.

This method have (i) high value capacitors requirement for DC link voltage regulation and (ii) poor utilization of DC link voltage[4][6][8].

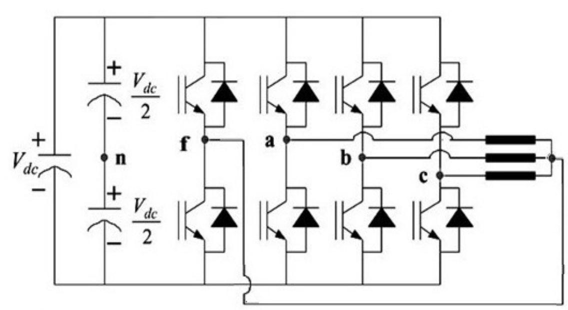


Fig. 2 Four leg inverter topology

(b) Four leg inverter topology

This is an advanced configuration to handle neutral current due to unbalanced load. The drawbacks of split DC link capacitor system is solved using neutral link and fourth leg. A four-leg inverter provides good compensation for zero sequence harmonics and gives best utilization for DC link voltage[4]. Small capacitance requirement, low EMI and reduction in common mode voltage (CMV) [8] are the advantages. A four legged converter requires 3DSVM with sixteen switching vectors[9]. The switching vector controllability of this topology is better than split capacitor topology[6]. Complexity in modulation schemes and number of semiconductor switching devices required are the disadvantages of this topology.

III. 3DSVM

3DSVM is used for four wire inverters, and is applicable to both three-leg and four-leg four-wire topologies[1][17]. The three phase variables X_{abc} can be transformed into any convenient coordinate system to represent the space vectors in three-dimensional space[2][17][18].$X_a + X_b + X_c \neq 0$ in unbalanced system, X_{abc} become three independent variables. The most commonly used 3D coordinate systems are αβγ and abc coordinate systems[18].

The input to the 3DSVM algorithm is the three phase quantity X_{abc}, X may be either voltage or current. This quantity represents a rotating space vector, it can be converted into coordinate systems like αβγ, abc, KL0 or ghγ. For example in αβγ coordinate system, the conversion from three phase quantity into space vector is using Clarke's transformation [10] (1).

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_\gamma \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

The table 1 shows the switching vectors and corresponding vectors in αβγ coordinates as per the conversion formula (1). Where 'p' indicates the upper switch of inverter is 'ON' and 'n' indicates lower switch is 'ON'. The sixteen vectors V_0 to V_{15} are distributed in 3D space as shown in fig. 3[17].

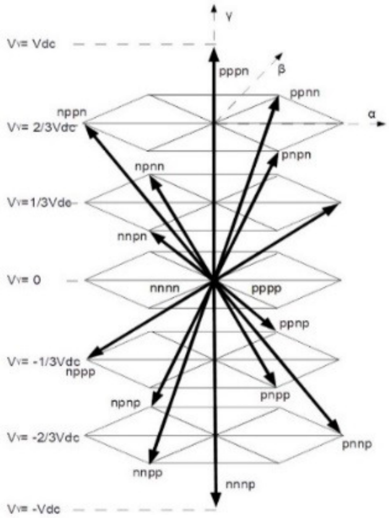


Fig. 3 Distribution of vectors in 3D space in αβγ coordinate system

The ghγ coordinate system

The ccomputational complexity reduction of αβγ coordinate system results into ghγ coordinate system in [12] with 60^0 and 90^0 coordinates[17]. This coordinate system is derived from αβγ coordinate system with modification on second axes β, that is 60^0 from first axis. The projection of switching vectors of a four leg inverter in 3DSVM is a regular hexagon similar to 2DSVM. This makes 60^0 coordinate system feasible for unbalanced system. Instead of β axis, the second axis is defined in 60^0 counter clockwise withrespect to first axis *g*, which is equivanent to α axis. The third axis γ is same as that in αβγ coordinate system to represent zero sequence component.

$$\begin{bmatrix} V_g \\ V_h \\ V_\gamma \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -1 & 0 \\ 0 & 1 & -1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_{af} \\ V_{bf} \\ V_{cf} \end{bmatrix} \quad (2)$$

The reference vector in abc coordinate can be transformed into ghγ coordinate as given in (2).

Switching Vector	V_{af}	V_{bf}	V_{cf}	α	β	γ	Vector
nnnn	0	0	0	0	0	0	V_0
nnnp	$-V_{dc}$	$-V_{dc}$	V_{dc}	0	0	$-V_{dc}$	V_1
nnpn	0	0	V_{dc}	$-{}^{1}/_{3}V$ dc	$-{}^{1}/_{\sqrt{3}}$vd c	${}^{1}/_{3}$ Vdc	V_2
nnpp	$-V_{dc}$	$-V_{dc}$	0	$-{}^{1}/_{3}$ Vdc	$-{}^{1}/_{\sqrt{3}}$Vd c	$-{}^{2}/_{3}$ Vdc	V_3
npnn	0	$-V_{dc}$	0	$-{}^{1}/_{3}$ Vdc	${}^{1}/_{\sqrt{3}}$Vdc	${}^{1}/_{3}$ Vdc	V_4
npnp	$-V_{dc}$	0	$-V_{dc}$	$-{}^{1}/_{3}$ Vdc	${}^{1}/_{\sqrt{3}}$Vdc	$-{}^{2}/_{3}$ Vdc	V_5
nppn	0	V_{dc}	V_{dc}	$-{}^{2}/_{3}$ Vdc	0	${}^{2}/_{3}$ Vdc	V_6
nppp	$-V_{dc}$	0	0	$-{}^{2}/_{3}$ Vdc	0	$-{}^{1}/_{3}$ Vdc	V_7
pnnn	V_{dc}	0	0	${}^{2}/_{3}$ Vdc	0	${}^{1}/_{3}$ Vdc	V_8
pnnp	0	$-V_{dc}$	$-V_{dc}$	${}^{2}/_{3}$ Vdc	0	$-{}^{2}/_{3}$ Vdc	V_9
pnpn	V_{dc}	0	V_{dc}	${}^{1}/_{3}$ Vdc	$-{}^{1}/_{\sqrt{3}}$Vd c	${}^{2}/_{3}$ Vdc	V_{10}
pnpp	0	$-V_{dc}$	0	${}^{1}/_{3}$ Vdc	$-{}^{1}/_{\sqrt{3}}$Vd c	$-{}^{1}/_{3}$ Vdc	V_{11}
ppnn	V_{dc}	V_{dc}	0	${}^{1}/_{3}$ Vdc	${}^{1}/_{\sqrt{3}}$Vdc	${}^{2}/_{3}$ Vdc	V_{12}
ppnp	0	0	$-V_{dc}$	${}^{1}/_{3}$ Vdc	${}^{1}/_{\sqrt{3}}$Vdc	$-{}^{1}/_{3}$ Vdc	V_{13}
pppn	V_{dc}	V_{dc}	V_{dc}	0	0	V_{dc}	V_{14}
pppp	0	0	0	0	0	0	V_{15}

Table-1 Switching Vectors in $\alpha\beta\gamma$ system

The three phase quantity X_{abc} can be transformed into ghγ coordinate as given in (4). The table II shows the switching vectors and corresponding vectors in ghγ coordinate system. The orientation of switching vectors in 3D space as per ghγ coordinate system is shown in Fig. 5. The orientation of vectors are same as that in αβγ coordinate system. The difference is only in the orientation of second coordinate 'h', which is 60^0 with respect to the first coordinate 'g'.

Switching Vect	V_{af}/V_{dc}	V_{bf}/V_{dc}	V_{cf}/V_{dc}	$V_g/\frac{1}{3}V_{dc}$	$V_h/\frac{1}{3}V_{dc}$	$V_\gamma/\frac{1}{3}V_{dc}$	Vector Name
nnnn	0	0	0	0	0	0	V_0
nnnp	-1	-1	-1	0	0	-3	V_1

nnpn	0	0	1	0	-2	1	V_2
nnpp	-1	-1	0	0	-2	-2	V_3
npnn	0	1	0	-2	2	1	V_4
npnp	-1	0	-1	-2	2	-2	V_5
nppn	0	1	1	-2	0	2	V_6
nppp	-1	0	0	-2	0	-1	V_7
pnnn	1	0	0	2	0	1	V_8
pnnp	0	-1	-1	2	0	-2	V_9
pnpn	1	0	1	2	-2	2	V_{10}
pnpp	0	-1	0	2	-2	-1	V_{11}
ppnn	1	1	0	0	2	2	V_{12}
ppnp	0	0	-1	0	2	-1	V_{13}
pppn	1	1	1	0	0	3	V_{14}
pppp	0	0	0	0	0	0	V_{15}

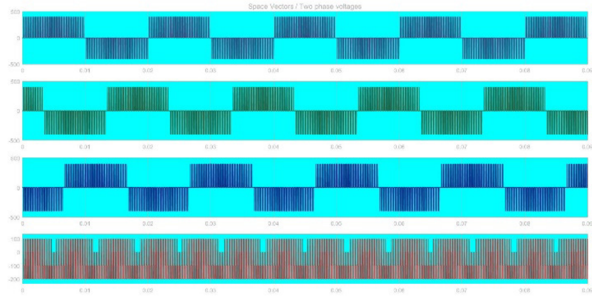
Table II Switching Vectors in $gh\gamma$ system

DPWM in 3DSVM

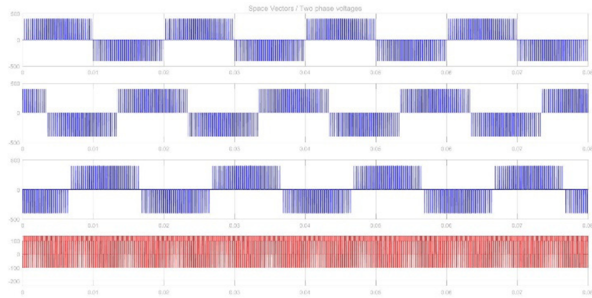
Discontinuous PWM (DPWM) schemes are discussed in [13] for four leg inverters.DPWMreduces switching loss and common mode voltage [14]. In 3DSVM with two vectors V_0 and V_{15} are ZVs among the sixteen vectors [15]. The harmonic properties and switching loss can improve by using only one zero vector in switching sequence [16]. Avoiding V_0 results into DPWMMAX [13] and avoiding V_{15} results into DPWMMIN[13]. In this paper the DPWMMIN and DPWMMAX are applied to the 3DSVM method based on $gh\gamma$ coordinate system[17].

Simulation results

The improvements obtained in $gh\gamma$ system by incorporating the DPWM schemes is verified by simulation. Here DPWMMIN and DPWMMAX are simulated and compared with conventional $\alpha\beta\gamma$ coordinate system.



(a) Phase to phase voltages and CMV in DPWMMIN



(b) Phase to phase voltages and CMV in DPWMMAX

Fig 4. Simulation of DPWM implemented in ghγ coordinates system

Comparison of parameters

	Phase to phase voltage Total Harmonic Distortion	Common Mode Voltage level (Maximum)
Space Vector PWM (3Leg)	0.97	Vdc
αβγ system (4 leg)	1.37	Vdc
ghγ system (4 leg)	1.16	Vdc
ghγ system with DPWMMIN	6.82	¾ Vdc
ghγ system with DPWMMAX	1.07	¾ Vdc

Conclusions

The common mode voltage reduction techniques in 2DSVM are well proved by many researchers in the past decades, but its 3D versions are not popular [17]. Due to more increased population of unbalanced three phase distribution systems, research area of 3D space vector modulation has a lot of research gaps to be filled.DPWM with 3DSVM can reduce common mode voltage. In 3DSVM new computationally efficient coordinate systems like $gh\gamma$ coordinate system can do more betterments on further refinement.

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