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A NOVAL ALGORITHM FOR FIVE LEVEL FIVE PHASE VOLTAGE SOURCE INVERTER USING TWO LEVEL FIVE PHASE SVPWM

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Abstract-- Multilevel voltage-fed inverters with space vector pulse width modulation strategy are gained importance in high power high performance industrial drive applications. Multi-phase machines and drives is a topic of growing relevance in recent years, and it presents many challenging issues that still need further research. Multilevel multiphase technology combines the benefits of both technologies. This paper proposes a new simplified space vector PWM method for a five-level five phase voltage source inverter. The five- level inverter has a large number of switching states compared to a two-level inverter. In the proposed scheme, five-level space vector PWM inverter is easily implemented using algorithm based on a displacement plus a two-level multiphase SVPWM modulator. Therefore, the proposed method can also be applied to multilevel inverters. In this paper, a five-level five phase inverter using space vector modulation strategy has been modeled and simulated. Simulation results are presented for operation conditions using R-L load.

Key words—Decomposition, Multilevel Inverter, Multi Phase Machine, Svpwm

I.INTRODUCTION:

Multilevel converter technology is based on the synthesis of a Voltage waveform from several dc voltage levels. As the number of levels increases, the synthesized output voltage gets more Steps and produces a waveform which approaches the reference More accurately. The major advantages of using multi level Inverters are:

1) high voltage capability with voltage limited devices;

2) low harmonic distortion;

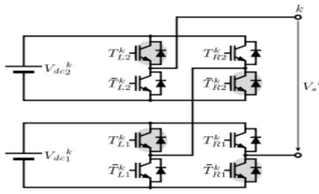
3) reduced switching losses;

4) increased efficiency;

5) good electromagnetic compatibility.

The interest in multi-phase motor drives has increased in recent years due to several advantages when compared to three-phase drives [1-2]. Some of these advantages are known from the early days of the multi-phase drives [3], although they have recently considered with high-level analysis [4]. These advantages are inherent to the own structure of the machine, and include less torque ripple, less acoustic noise and losses, reduced current per phase, greater efficiency and increased reliability due to the additional number of phases [1-4]. These advantages make multi-phase drives suitable for high power/current applications such as EV/HEVs traction or electric ship propulsion.

II.CASCADED FULL BRIDGE INVERTER:



Early uses of the topology were devoted to single-phase applications . Later, this approach was extended to include three-phase systems. The cascaded full-bridge converter consists of series full-bridge cells. Since each cell can provide three voltage levels (zero, positive dc voltage, and negative dc voltage), the cells are themselves multilevel converters. A phase of a two-cell series full-bridge inverter is shown in Figure.

Table: Five-level cascaded full-bridge converter relationships.

T^k_{L1}	T^k_{L2}	T^k_{R1}	T^k_{R2}	$V_s{}^k$	$V_s{}^k$ (if $V_{dc_i}^k = V_{dc}$)	$v_s{}^k$
0	0	1	1	$-V_{dc_2}^k - V_{dc_1}^k$	$-2V_{dc}$	-2
1	0	1	1	$-V_{dc_2}^k$	$-V_{dc}$	-1
0	1	1	1	$-V_{dc_1}^k$	$-V_{dc}$	-1
0	0	0	1	$-V_{dc_2}^k$	$-V_{dc}$	-1
0	0	1	0	$-V_{dc_1}^k$	$-V_{dc}$	-1
1	1	1	1	0	0	0
1	0	0	1	$V_{dc_1}^k - V_{dc_2}^k$	0	0
1	0	1	0	0	0	0
0	1	0	1	0	0	0
0	1	1	0	$V_{dc_2}^k - V_{dc_1}^k$	0	0
0	0	0	0	0	0	0
1	1	0	1	$V_{dc_1}^k$	V_{dc}	1
1	1	1	0	$V_{dc_2}^k$	V_{dc}	1
1	0	0	0	$V_{dc_1}^k$	V_{dc}	1
0	1	0	0	$V_{dc_2}^k$	V_{dc}	1
1	1	0	0	$V_{dc_2}^k + V_{dc_1}^k$	$2V_{dc}$	2

III.ALGORITHM FORMULATION:

Since the switching states of any power converter topology Stay at discrete states, the SVPWM issued to approximate Reference voltage vector Vr by means of a sequence of space vectors $S_1 = \{Vs_1, Vs_2, \ldots, Vs_l\}$ during each modulation cycle. To achieve a proper synthesis of the reference vector ,each switching vector Vsj must be applied during an interval Tj in accordance with the following modulation law:

$$\mathbf{V}_r = \frac{1}{T}\sum_{j=1}^{l} \mathbf{V}_{sj} T_j \qquad (1)$$

$$\sum_{j=1}^{l} T_j = T. \qquad (2)$$

Where the sum of the intervals T_j must be equal tothe modulation period T. The reference vector summarizes the voltage reference for each Phase of the system, whereas each switching vector summarizes. The switching state of each phase of the converter

$$\mathbf{V}_r = \left[V_r^1, V_r^2, \ldots, V_r^P\right]^T \in \mathbb{R}^P \qquad (3)$$

$$\mathbf{V}_{sj} = \left[V_{sj}^1, V_{sj}^2, \ldots, V_{sj}^P\right]^T \in \mathbb{R}^P. \qquad (4)$$

Therefore ,the reference vector and the switching vectors belong to the multidimensional space R^p ,where P is the number of phases of the converter. In most common multilevel topologies such as flying capacitor, diode-clamped, cascaded full-bridge or hybrid converters, the output level of every phase Vs is an integer multiple of a fixed voltage step Vdc [5],[7]

$$V_s = nV_{dc}, \qquad n \in \mathbb{Z}. \qquad (5)$$

therefore, vectors and switching times can be normalized by using the voltage step and the switching period ,respectively to non dimensionalize (1)and(2)

$$\mathbf{v}_r = \frac{\mathbf{V}_r}{V_{dc}} \in \mathbb{R}^P \qquad (6)$$

$$\mathbf{v}_{sj} = \frac{\mathbf{V}_{sj}}{V_{dc}} \in \mathbb{Z}^P \qquad (7)$$

$$t_j = \frac{T_j}{T}. \qquad (8)$$

It is important to remark that new normalized switching vectors v_{sj} now belong to the multidimensional space of integer numbers Z^P.If the above expressions are substituted in(1)and(2) ,the modulation law can be rewritten interms of the new Normalized variables as

$$\mathbf{v}_r = \sum_{j=1}^{l} \mathbf{v}_{sj} t_j \qquad (9)$$

$$\sum_{j=1}^{l} t_j = 1. \qquad (10)$$

If the reference and the switching normalized vectors are Expressed as follows:

$$\mathbf{v}_r = \left[v_r{}^1, v_r{}^2, \ldots, v_r{}^P\right]^T \qquad (11)$$

$$\mathbf{v}_{sj} = \left[v_{sj}{}^1, v_{sj}{}^2, \ldots, v_{sj}{}^P\right]^T \qquad (12)$$

$$\begin{bmatrix} 1 \\ v_r{}^1 \\ v_r{}^2 \\ \vdots \\ v_r{}^P \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ v_{s1}^1 & v_{s2}^1 & \cdots & v_{sl}^1 \\ v_{s1}^2 & v_{s2}^2 & \cdots & v_{sl}^2 \\ \vdots & \vdots & \ddots & \vdots \\ v_{s1}^P & v_{s2}^P & \cdots & v_{sl}^P \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_l \end{bmatrix}. \qquad (13)$$

The above system of linear equations constitutes the modulation law, which must be solved by the multilevel multiphase SVPWM algorithm. The problem solving includes three main steps:

1) searching a set of integer coefficients for the matrix that Permits solving the linear system;
2) solving the system of linear equations to calculate the Switching times;
3) extracting the switching vector sequence from the coefficient matrix.

The multilevel multiphase SVPWM problem can be simplified if it is decomposed into the sum of a displacement plus a two-level SVPWM problem with the same number of phases.

*A. **Algorithm Decomposition***

The reference vector can be decomposed into the sum of its Integer and fractional parts

$$\mathbf{v}_r = \mathbf{v}_i + \mathbf{v}_f, \qquad \mathbf{v}_i = \text{integ}(\mathbf{v}_r) \in \mathbb{Z}^P. \qquad (14)$$

Components of the new vector v_i are integer numbers, and Therefore it belongs to the same space Z^P of the switching Vectors and it could be directly synthesized with one of them. The fractional part v_r still belongs to the space R^P and it cannot be directly synthesized by means of a single switching vector. It has to be approximated with a sequence of switching vectors. Besides , a new set of switching vectors is obtained by displacing all switching vectors the distance given by vi

$$\mathbf{v}_{dj} = \mathbf{v}_{sj} - \mathbf{v}_i. \qquad (15)$$

If those vectors are expressed as

$$\mathbf{v}_i = [v_i{}^1, v_i{}^2, \ldots, v_i{}^P]^T \qquad (16)$$

$$\mathbf{v}_f = [v_f{}^1, v_f{}^2, \ldots, v_f{}^P]^T \qquad (17)$$

$$\mathbf{v}_{dj} = [v_{dj}^1, v_{dj}^2, \ldots, v_{dj}^P]^T \qquad (18)$$

And if(15)is substituted in(13),the new expression for the modulation law is obtained

$$\begin{bmatrix} 1 \\ v_r{}^1 \\ v_r{}^2 \\ \vdots \\ v_r{}^P \end{bmatrix} = \begin{bmatrix} 0 \\ v_i{}^1 \\ v_i{}^2 \\ \vdots \\ v_i{}^P \end{bmatrix} + \begin{bmatrix} 1 & 1 & \ldots & 1 \\ v_{d1}^1 & v_{d2}^1 & \ldots & v_{dl}^1 \\ v_{d1}^2 & v_{d2}^2 & \ldots & v_{dl}^2 \\ \vdots & \vdots & \ddots & \vdots \\ v_{d1}^P & v_{d2}^P & \ldots & v_{dl}^P \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_l \end{bmatrix}. \qquad (19)$$

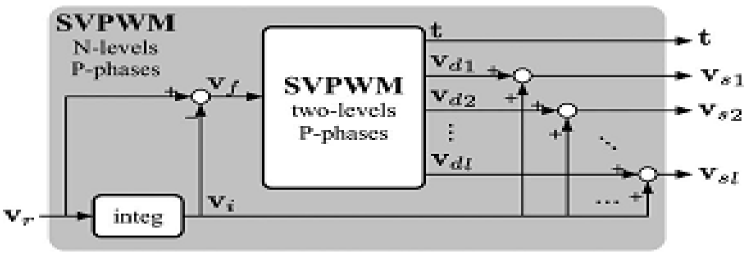
Finally, if (14) is written as

$$\begin{bmatrix} 1 \\ v_r{}^1 \\ v_r{}^2 \\ \vdots \\ v_r{}^P \end{bmatrix} = \begin{bmatrix} 0 \\ v_i{}^1 \\ v_i{}^2 \\ \vdots \\ v_i{}^P \end{bmatrix} + \begin{bmatrix} 1 \\ v_f{}^1 \\ v_f{}^2 \\ \vdots \\ v_f{}^P \end{bmatrix} \quad (20)$$

And if (19) and (20) are compared, the following relationship between the fractional part of the reference and the displaced Switching vectors is obtained:

$$\begin{bmatrix} 1 \\ v_f{}^1 \\ v_f{}^2 \\ \vdots \\ v_f{}^P \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ v_{d_1}^1 & v_{d_2}^1 & \cdots & v_{d_l}^1 \\ v_{d_1}^2 & v_{d_2}^2 & \cdots & v_{d_l}^2 \\ \vdots & \vdots & \ddots & \vdots \\ v_{d_1}^P & v_{d_2}^P & \cdots & v_{d_l}^P \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_l \end{bmatrix}. \quad (21)$$

This new system of line are quations presents the same form As the general modulation law (13). However, in this case, the Components of vector v_f are bounded in the interval [0, 1). Therefore, only the subset of displaced vectors with compoNents zero or one is enough to carry out the reference approximation. Consequently, this new equation represents a two-level modulator where the reference vector is vf and the array of switching vectors are the displaced set of switching vectors vdj .Switching times are the same in the multilevel and the two-level modulators. Fig.1shows a 2-D example of the decomposition where vector v_i coincides with a switching vector and the subset {[0, 0], [1, 0], [0, 1], [1, 1]} of displaced vectors is enough to synthesize the fractional part of the reference vf .



In summary,(19)demonstrates that a multilevel multiphase Modulator can be realized from a displacement plus a two-level Modulator with the same number of phases.Fig.2shows a Block diagram of the proposed technique.

B. Two-Level Multiphase SVPWM Algorithm

Once the multilevel problem has been decomposed, the two-Level modulation law (21) has to be solved. To obtain an exactly determined system of linear equations, the coefficient matrix of that modulation law must be a square matrix. Hence, the length of the switching vector sequence l must be

$$l = P + 1 \quad (22)$$

and the particular linear system, which has to be solved ,is

$$\begin{bmatrix} 1 \\ v_f^{1} \\ v_f^{2} \\ \vdots \\ v_f^{P} \end{bmatrix} = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ v_{d1}^{1} & v_{d2}^{1} & \cdots & v_{d\,P+1}^{1} \\ v_{d1}^{2} & v_{d2}^{2} & \cdots & v_{d\,P+1}^{2} \\ \vdots & \vdots & \ddots & \vdots \\ v_{d1}^{P} & v_{d2}^{P} & \cdots & v_{d\,P+1}^{P} \end{bmatrix} \begin{bmatrix} t_1 \\ t_2 \\ \vdots \\ t_{P+1} \end{bmatrix}. \qquad (23)$$

The objective of the two-level modulation algorithm is to find a Switching vector sequence ,that is ,the coefficient matrix of the System (23)should be filled with zeros and ones, thus allowing A subsequent system solution.Moreover,the coefficient selection must be carried out taking into account that the switching Times must be always positive after the system solution.

There are many different possibilities to fill the coefficient matrix. Nevertheless, the whole power system performance depends on the method employed for calculating the coefficient matrix. In this way, switching losses are minimized if coefficients are selected in such a way that consecutive switching vectors of the switching sequence are adjacent. In other words, only one coefficient is different in two consecutive matrix columns. One possible method for calculating such a matrix is detailed below.

Equation (23)can be written in a shorter form as

$$\begin{bmatrix} 1 \\ \mathbf{v}_f \end{bmatrix} = \mathbf{D}\mathbf{t}. \qquad (24)$$

Finding a permutation matrix P that puts the elements of the Reference vector vf in descending order

$$\mathbf{P}\begin{bmatrix} 1 \\ \mathbf{v}_f \end{bmatrix} = \begin{bmatrix} 1 \\ \hat{\mathbf{v}}_f \end{bmatrix} \qquad (25)$$

Where

$$1 > \hat{v}_f^{1} \geq \cdots \geq \hat{v}_f^{k-1} \geq \hat{v}_f^{k} \geq \cdots \geq \hat{v}_f^{P} \geq 0 \qquad (26)$$

And multiplying both sides of (24)by this permutation matrix P, we obtain the following equation:

$$\begin{bmatrix} 1 \\ \hat{\mathbf{v}}_f \end{bmatrix} = \hat{\mathbf{D}}\mathbf{t} \qquad (27)$$

where

$$\hat{\mathbf{D}} = \mathbf{PD}. \qquad (28)$$

One coefficient matrix ˆ D with adjacent consecutive columns That makes this new system of linear equations exactly determined is the following upper triangular matrix:

$$\hat{\mathbf{D}} = \begin{bmatrix} 1 & 1 & 1 & \dots & 1 \\ & 1 & 1 & \dots & 1 \\ & & \ddots & \ddots & \vdots \\ & & & \ddots & 1 \\ 0 & & & & 1 \end{bmatrix}. \qquad (29)$$

As it will be shown below, the switching times obtained with This coefficient matrix are always positive. A permutation matrix is an orthogonal matrix so P is invertable and Therefore, the coefficient matrix D of the two-level modulation Law can be obtained by solving (28) as

$$\mathbf{P}^{-1} = \mathbf{P}^{\mathrm{T}}. \qquad (30)$$

$$\mathbf{D} = \mathbf{P}^{\mathrm{T}}\hat{\mathbf{D}}. \qquad (31)$$

The permutation matrix P applies a set of elementary row Switching transformations to the column vector v_f . In the same manner, the inverse set of elementary row-switching transfor mations is applied to the matrix ˆ D by the matrix P^T and, consequently, the number of ones and zeros in each column does not change. Hence, the switching number is minimized because consecutive vectors of the sequence are still adjacent after the transformation.

Due to the fact that the solution t is the same for both linear systems,(24)and(27),it can be calculated by using either of them. The second option seems the best choice because, in this case, the solution is trivial as shown below

$$t_j = \begin{cases} 1 - \hat{v}_f^{\,1}, & \text{if } j = 1 \\ \hat{v}_f^{\,j-1} - \hat{v}_f^{\,j}, & \text{if } 2 \le j \le P \\ \hat{v}_f^{\,P}, & \text{if } j = P + 1. \end{cases} \qquad (32)$$

All equations calculated by means of the above expression will Always be positive numbers because the coordinates of the vector ˆ v_f obey(26). In summary, matrix D permits solving the two-level modulation law getting positive switching times and minimizing Switching number. The two-level switching sequence can be Directly extracted from the columns of that matrix.

IV.SIMULATION RESULTS:

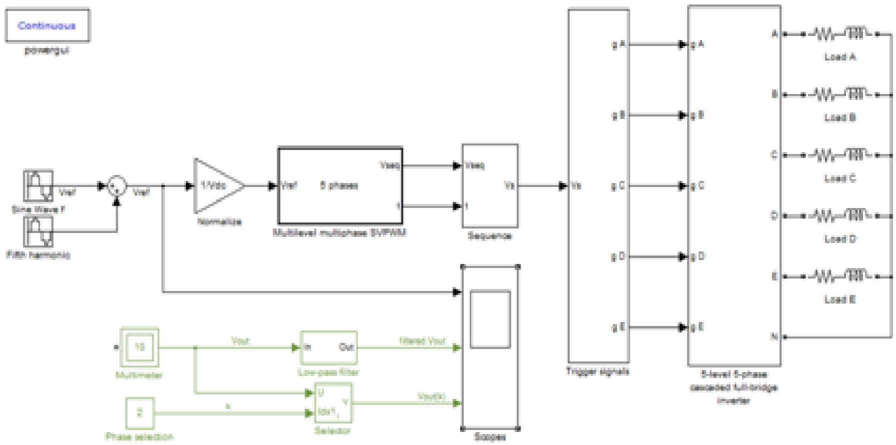
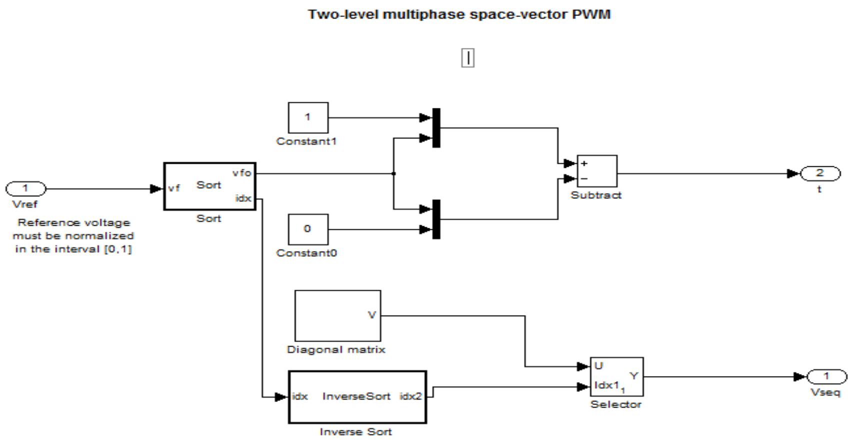


Figure. Simulink model for 5level 5 phase svpwm inverter



Here all five phases output voltages,currents are shown. If the modulation index is high, then modulation algorithm takes advantage of all five levels of the inverter. Nevertheless, if the modulation index is low then output voltage is a three-level waveform .with purely sinusoidal output when the modulation index is high ,the low-order harmonics are negligible and the total harmonic distortion (THD) is3.8%.If the modulation index is low, then the low-order harmonics grow because of the three-level output and the THD increases up to 6.4%.

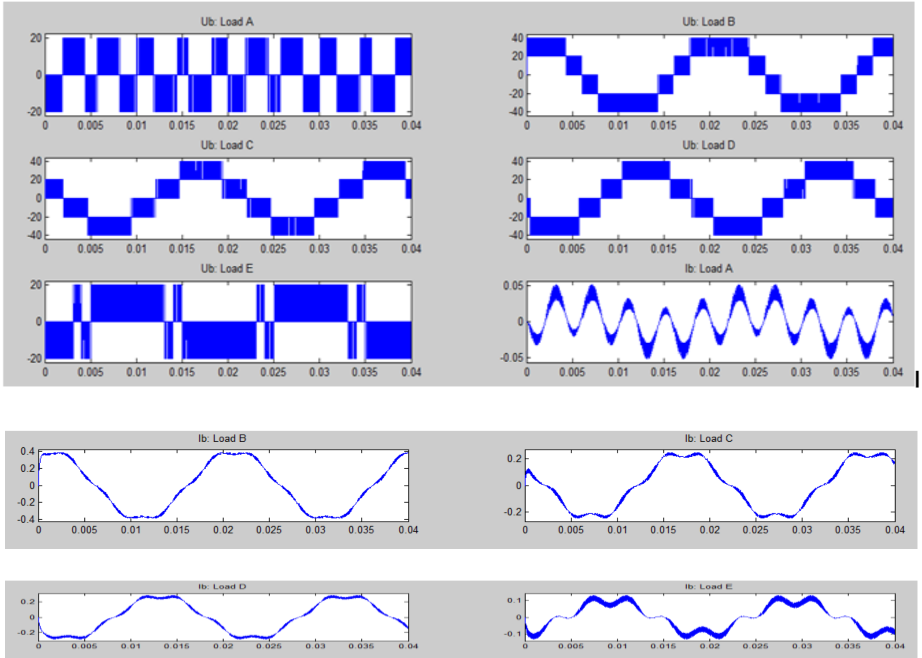


Fig : five level five phases voltages, currents

V.CONCLUSION:

A novel formulation of the modulation problem in multilevel multiphase converters has been presented in this paper, as a part of investigation work done on the topologies of multi level inverters. This new formulation that was carried out in a multidimensional space, from the analysis has proved to be simple and very useful to study the modulation process. By using this new formulation the multilevel multiphase SVPWM problem has been solved for converters, without switching state redundancy. In this case, it was demonstrated that a multilevel modulator can be realized by means of a two- level modulator.

The new modulation technique handles all switching states of the converter and it provides a sorted switching vector sequence that minimizes the number of switchings. It is obviously found that the proposed PWM offers lower THD compared to conventional PWM one, thus the superiority.

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