Selective Harmonics Elimination for Five Level Inverters with Unequal DC Sources

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Abstract - *In virtue of the use of a set of independent dc sources, multilevel inverters (MLI) are capable to operate at higher voltage levels and at lower switching frequencies than conventional inverters In order to limit losses and to increase converter efficiency, very low frequency modulation techniques should be adopted, such as selective harmonic elimination (SHE) at fundamental frequency operation. This paper proposes a modulation technique based on a harmonic elimination method developed for five level inverters with unequal dc link voltages. The approach is based on the analytical solution of nonlinear equations associated with the inverter. After a description of the method, an analysis on the computed switching angles and on their impact on total harmonic distortion is reported with the support of simulation result.*

Key Words: **Selective Harmonic Elimination (SHE), 5-level cascaded inverter, Unequal dc sources, Total Harmonic Distortion(THD).**

1. INTRODUCTION

In firmness of purpose for the use of independent DC sources, multilevel inverters (MLI), can be capable to operate at higher voltage levels and at lower switching frequencies than conventional inverters and similarly, to synthesize staircase output voltage waveforms ensuring better harmonic content and reduced electromagnetic interferences (EMI). For such reasons, nowadays, they are considered a very appealing solution for medium and high voltage power applications [1]. Very low frequency modulation techniques should be adopted In order to limit losses and to increase converter efficiency, one of which is selective harmonic elimination (SHE). In [2] the theory of symmetric polynomials has been applied. By increasing the number of levels, the polynomials degree tends to be high; hence the mathematical complexity of the SHE problem reaches a high level. The non-linear equations describing the problem can be solved using some iterative techniques such as the Newton-Raphson method, but they need a proper initial guess. Heuristic algorithms, such as genetic algorithm (GA) and particle swarm optimization (PSO) are very interesting because, for the range space where there is no analytical solution, they will find the nearest solution providing a smooth data set [3]. However, they present the disadvantage of computationally intensive and time-consuming equations. Therefore, switching angles are calculated offline. In [4] the Bee algorithm (BA) is applied to a 5-level inverter for solving the equations and the superiority.

2. Analytical Procedure for Switching Angle Computation

A five-level cascaded inverter fed by two separate unequal dc sources $V1$ and $V2$ is shown in Fig. 1. For such an inverter the switching angles α1 and α2 .0 < α1 < α2 <π .that eliminates a harmonic from the output voltage waveform can solving the following system:

$$u_1 \cos(k\alpha_1) + u_2 \cos(k\alpha_2) = 0$$
$$u_1 \cos(\alpha_1) + u_2 \cos(\alpha_2) - m_1 = 0 \text{.......(1)}$$

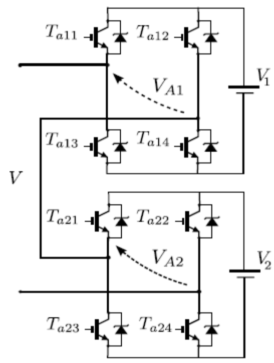

Fig.1: Single-phase cascaded H-Bridge five level inverter with unequal dc sources.

Where, k = 3,5,7 and m_1 is modulation index.

a) By Eliminating 3rd Harmonics :

By introducing Chebyshev polynomials:

$T_1(x_i) = x_i = \cos(\alpha_1)$ (2)

And $T_3(xi) = 4xi^3 - 3x_i = \cos(3\alpha_1)$ (3)

I = 1,2 by transforming polynomial system

$$\begin{cases} v_1 T_3(x_1) + v_2 T_3(x_2) = 0 \\ v_1 T_1(x_1) + v_2 T_1(x_2) - m_1 = 0. \end{cases} \quad (4)$$

The following final system can be obtained:

$a_3 x^3{}_1 + a_2 x^2{}_1 + a_1 x_1 + a_0 = 0$

$x_2 = -b_1x_1 + b_0$ (5)

The solutions of the system (5) are three, belonging to C2 but only one solution ($x1$, $x2$) is valid because it has to satisfy the following two conditions:

- Each component of the solution should belong to the interval [0, 1],and
- $x1>x2$.

The switching angles are computed as _1 = arccos (x1) and a_2 = arecos (x_2) fig 2 shows curve for k =3. With two functions denoted by dash curve and continuous line.

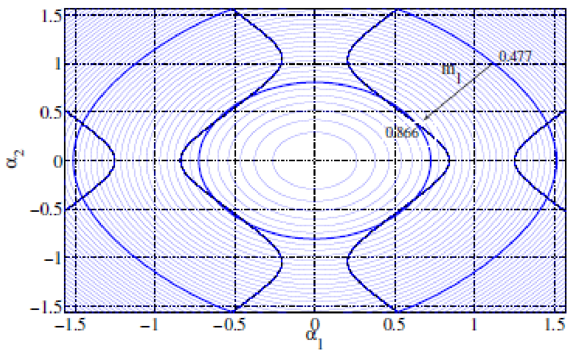

Fig 2: Curves in implicit form of the system (1) for k = 3.

b) By Eliminating 5th Harmonics:

By considering the term,

$T_5(x_i) = 16x^5i - 20x^3i + 5xi = \cos(5\,\boldsymbol{\alpha_1})$ i = 1; 2, in addition to T1 (xi) and T3 (xi), the following polynomial system can be obtained:

$$v_1T_5(x_1) + v_2T_5(x_2) = 0$$

$$v_1T_1(x_1) + v_2T_1(x_2) - m1 = 0 \qquad (6)$$

Algebraic manipulations lead to the following system:

$$c_5x^5{}_1 + c_4x^4{}_1 + c_3x^3{}_1 + c_2x^2{}_1 + c_1x_1 + c_0 = 0$$

$$x_2 = -b_1x_1 + b_0 \qquad (7)$$

Where, $c_5= 16v_1(1-b_1^4)$, $c_4 =80m_1b_1^4$, $c_3= 20v_1[b_1^2(1-8b^2{}_0) - 1]$, $c_2 = 20m_1b^2{}_1(8b^2{}_0 - 3)$, $c_1 = 20m_1b_0b_1(3 - 4b^2{}_0)$, $c_0 =m_1[5 + 4b^2{}_0(4b^2{}_0 - 5)]$, Among the five solutions of the system (7) in C2 two at most valid. Figure 3 shows, for k = 5,

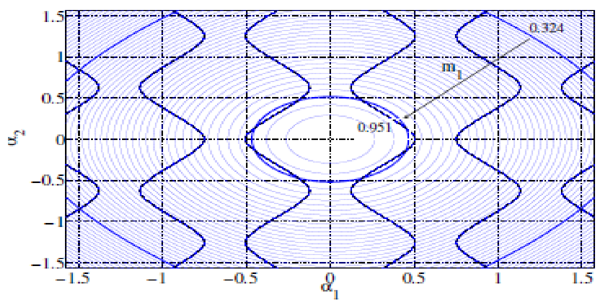

Fig 3: Curves in implicit form of the system (1) for k = 5.

3. Application

A five-level cascaded inverter characterized by v1 = 0:55 and v2 = 0:45 has been considered and the proposed procedure has been applied for computation of the switching angles in two distinct cases:

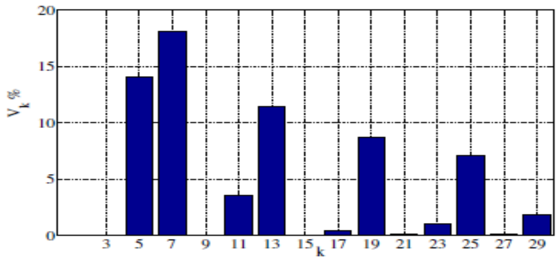

Fig 4: Vk % obtained eliminating the third harmonic for $m1$ = 0.5 and $\alpha1$ = 0.49465 rad, $\alpha2$ = 1.53540 rad.

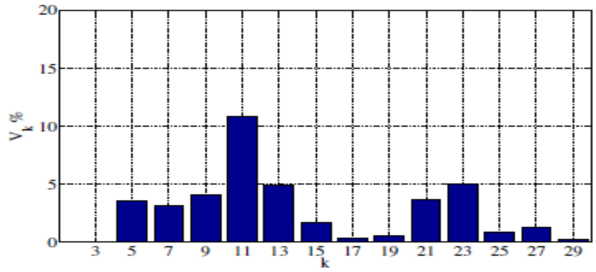

Fig 5: Vk % obtained eliminating the third harmonic for $m1$ = 0.83 for $\alpha1$ = 0.28436 rad, $\alpha2$ = 0.83483 rad

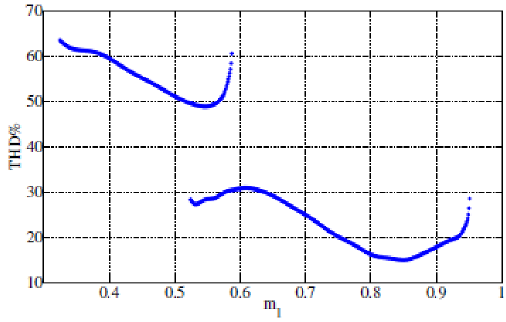

Fig 6: THD% obtained eliminating the fifth harmonic.

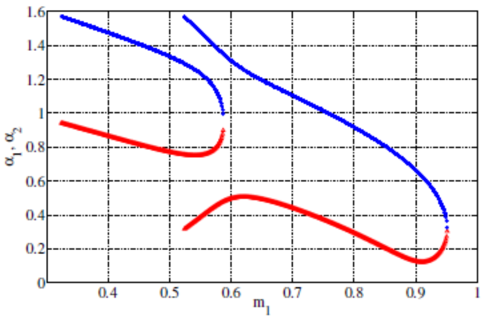

Fig 7: Computed switching angles for fifth harmonic elimination.

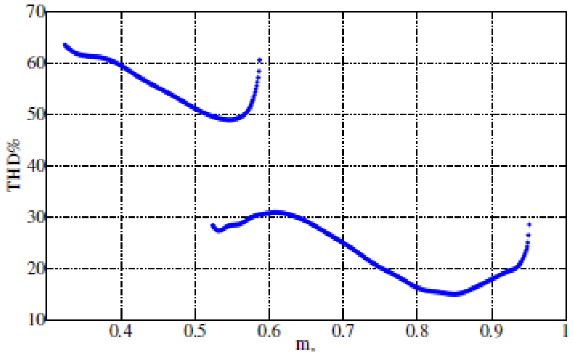

Fig 8: THD% obtained eliminating the fifth harmonic.

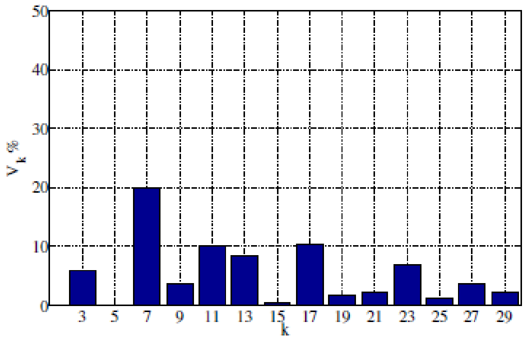

Fig 9: % obtained eliminating the fifth harmonic for $m1$ = 0.55, $\alpha1$ = 0.38753 rad, $\alpha2$ = 1.48004 rad

Considering the unbalanced cases, for third harmonic elimination there are two intervals of the modulation index, in [0; 1], where the solution exists. They become smaller if v2 grows. In this case, the first interval moves to left. For fifth harmonic elimination, for unbalancing, there are three intervals of the modulation index in [0; 1], where one or two solutions do exist. Also in this case, these intervals become smaller when v2 grows. As shown in Fig. 20, for modulation index values variable between about 0:35 and 0:5, the unbalancing gives better THD values.

4. Conclusion

In this paper a modulation technique based on the selective harmonic elimination method applied to multilevel converters with unequal dc link voltages has been presented. The analytical solution of the nonlinear equations corresponding to the mathematical model of the problem has been obtained in terms of switching angles and THD%. Unbalancing, characterized by v1 < v2 and by v2 < v1 have been considered for either third or difference between v1and v2 increases.

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