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Analytical Model and Investigation of a Four-Switch Space-Vector Modulated Hybrid Power Filter with Six-Fold Switching Symmetry

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1. Introduction

In this paper a new topology introduced in [1] is analytically investigated. The system configuration is shown in Fig.1. We propose in this paper the same switching symmetry (six-fold) as in a normal (B6) inverter for a four-switch converter shown in Fig.1.

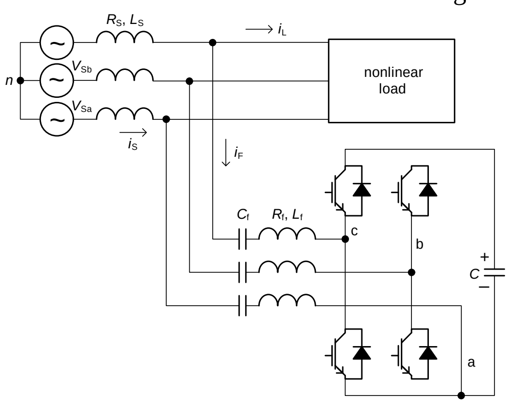

Fig.1 Configuration of the proposed topology

2. Space Vector Modulation for B4 connection with Six-Fold Symmetry

As in B4 configuration, we have four switching states. We can also find four possible voltage space vectors **V**1, **V**2, **V**3 and **V**4 in the complex αβ plane as shown in Fig.2.
For this connection with only four switches we want to have the same switching symmetry as in normal B6 inverter. To form six-fold symmetry we must use some vectors for the whole output period twice

$$\mathbf{V}_1(Z00),\ \mathbf{V}_1(Z00),\ \mathbf{V}_2(Z10) \\ \mathbf{V}_3(Z11),\ \mathbf{V}_3(Z11),\ \mathbf{V}_4(Z01) \tag{1}$$

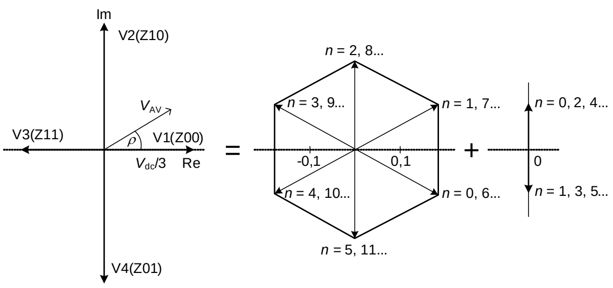

Fig.2 Voltage space vector decomposition

The unsymmetrical vector sequence (1) can be decomposed into two symmetrical ones. The first sequence has symmetry π/3 as in the conventional B6 inverter.

The second symmetrical sequence is laying in the imaginary axis and it has amplitude lowered by two times compared with the first sequence. Because of its period, this sequence will form the third order voltage harmonics in the output cycle period.

As a nonlinear load we assume the full bridge rectifier whose current is shown in Fig.3.

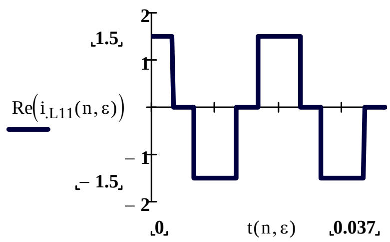

Fig.3 Nonlinear load current

The utility current can be determined by using a mixed p-z approach in analytical closed-form.

The trajectories of the utility current are shown in Fig.4 for the following parameters:

$$V_S = 120\sqrt{2}\ \text{V}, V_{dc} = 700\ \text{V}, I_S = 1.5\ \text{A}, R_S = 1.0\ \Omega,$$
$$L_S = 0.1\ \text{H}, R_F = 2.0\ \Omega, L_F = 0.005\ \text{H},$$
$$C_F = 0.000041\ \text{F}$$

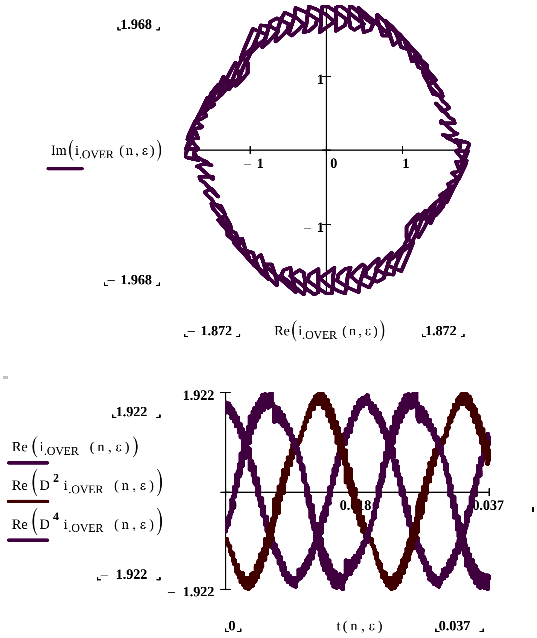

Fig.4 Utility space-vector current (top) and phase waveforms (bottom)

3. Experimental results

We verified the proposed method through experiments. The experimental system consists of a three-phase inverter, R_f, L_f , and C_f passive filter (tuned to the 7th harmonic) and a nonlinear load (a three-phase uncontrolled rectifier). The setup contains also digital control unit. The inverter is an integrated power module MITSUBISHI PS12038 (1200 V, 25 A, 15 kHz at maximum). The digital control unit, based on the dSPACE control system DS 1103, generates firing signals for the PWM rectifier.

Fig. 5 shows the proposed control scheme of the HPF. In order to control the magnitude of the DC voltage u_{dc}, an additional control loop is inserted into the q_1 axis path in the feedback control part. Also into the d_1 axis part another control loop is inserted, whose aim is to adjust the non-active power delivered from the source to its demanded value.

Fig. 6 shows the trajectories of load and utility phase currents. The control loop of the non-active power has not been activated here, so a phase shift between the load and source current is seen due to the capacitor of the passive part of the HPF.

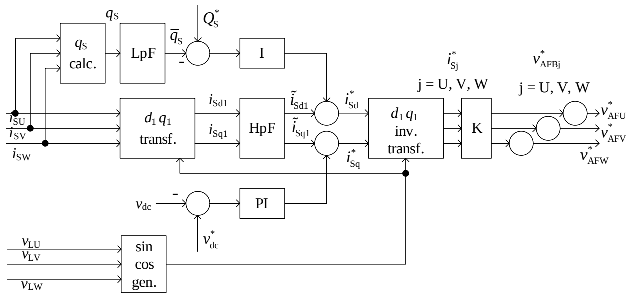

Fig.5 Control strategy of HPH

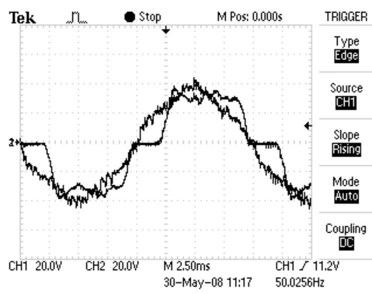

Fig.6 Trajectories of load and utility phase currents (1A/div)

4. Conclusion

In this paper we proposed the analytical model and the original space-vector modulation strategy for a new circuit configuration of a hybrid power filter with only four switches and not utilizing the center point of the dc bus voltage. This configuration removes the problems with pulsation of the dc bus voltage known from the bus clamped converters. An original closed-form solution of steady-state line currents, based on the mixed p-z approach is introduced. The analytical results and experiment tests on the component minimized three-phase PWM HPF are shown as well to demonstrate the validity and effectiveness of the proposed control scheme.

References

[1] Wu J. Jou, H. Feng, Y. Hsu, W. Huang, W. Hou, "Novel Circuit Topology for Three-Phase Active Power Filter". IEEE Transactions on PD-22, No. 1, 2007, pp. 44–449.

[2] J. Klima, "Mixed p-z approach for time-domain analysis of voltage source inverters with periodic pulse width modulation." IEEE Transactions on Circuits and Systems II. 2004, No. 10, October, pp. 529–536