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Ripple analysis for three-phase four-leg active power filters

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An important feature of power electronic circuits working in switching scheme is a ripple effect. Switching frequency errors are undesirable effects always accompanying these techniques [1]. The magnitude of current ripples can be computed by simulation of a specific PWM realisation. More general information can be obtained from analytical formulae. Such formulae can be derived when an average model of PWM inverter is employed. Average models simplify analysis and speed up simulation.

The main components of active power filters are voltage source inverters. Three-phase voltage source inverters normally have two ways of improving a neutral connection for three-phase four-wire systems: using split dc link capacitors and using a four-leg inverter topology. From comparative study it is found that the three-phase four-leg topology is best suited for unbalanced and nonlinear load compensation in three-phase four-wire systems [2]. This topology is illustrated in Fig. 1. A properly switched circuit should generate such phase currents that are as close to reference signal as possible.

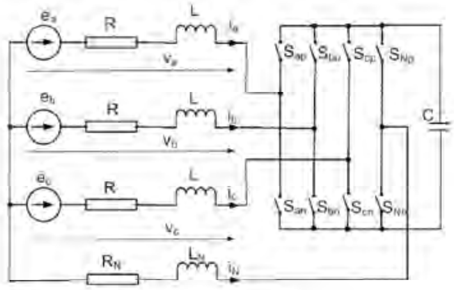

Fig. 1. Three-phase four-leg active filter

The deviation level of real generated current waveform from the smooth average waveform can be easy estimated for power active filters working with fixed switching frequency. Within single switching period T_s there are four switching. Switching period T_s is small in comparison with the periods of the harmonics to be generated by active filters, and the averaging operator within the moving interval $(t-T_s,t)$

$$\xi_{av}(t)=\frac{1}{T_s}\int_{t-T_s}^{t}\xi(\tau)d\tau \tag{1}$$

can be applied [3].

It means that variations of state variables $x(t)$ within interval $(t-T_s,t)$ is small and the following approximation is acceptable

$$\frac{1}{T_s}\int_{t-T_s}^{t}s(\tau)x(\tau)d\tau=s_{av}(t)x_{av}(t) \tag{2}$$

where $x(t)$ state variable, $s(t)$ discontinuous switching function, $x_{av}(t)$ average state variable and $s_{av}(t)$ average switching function

Actual current waveform $i(t)$ differs from smooth averaged current $i_{av}(t)$, it contains ripples caused by switching. The approximated piece wise linear waveforms of averaged current $i_{av}(t)$ and actual rippled current $i(t)$ of chosen phase a within single switching period T_s are shown in Fig.2.

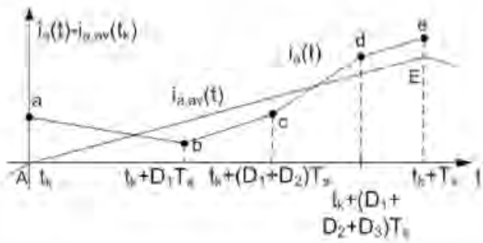

Fig. 2. Piece wise linear approximation of average and actual current within one switching period

The analytical formulae for ripple magnitude can be derived basing on the approximated waveforms shown in Fig. 2. These formulae enable one to compute ripples for any specific realization of power active filter

$$\begin{aligned}\Delta i_n(t_k)=\frac{V_C T_s}{3L}[&(s_n-s_{av})(D_n^2+2D_nD_{n+1}+\\&2D_nD_{n+2}+2D_nD_{n+3})+(s_{n+1}-s_{av})(D_{n+1}^2+\\&2D_{n+1}D_{n+2}+2D_{n+1}D_{n+3})+(s_{n+2}-s_{av})(D_{n+2}^2+\\&2D_{n+2}D_{n+3})+(s_{n+3}-s_{av})D_{n+3}^2]\end{aligned} \tag{3}$$

where $n=1,2,3,4$ is the segment number of the piece-wise waveform shown in Fig. 2 and $D_5=D_1, D_6=D_2, D_7=D_3$.

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