Hybrid Active Power Filter: Design Criteria

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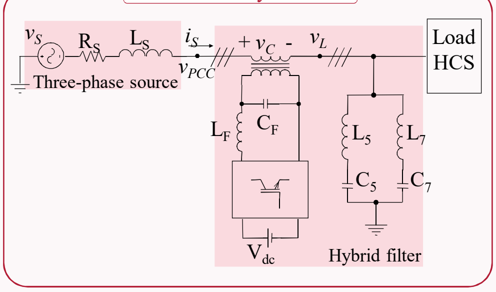
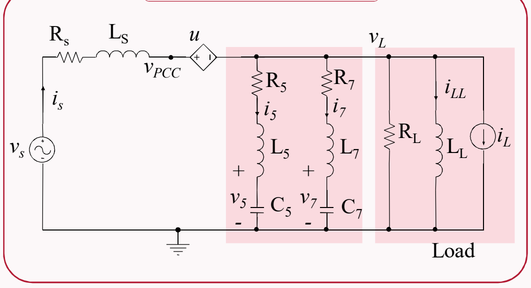
ABSTRACT. The configuration of a series active power filter (APF) and a parallel passive filter (PPF) has been proved that it is an efficient system for nonlinear load compensation. For this topology, different compensation strategies have been proposed to control the series APF. The most effective strategy determines the APF reference voltage as a proportion of the source current harmonics. The proportionality constant in the control algorithm implementation is related to the APF gain and the system dynamics. In this paper, the system state model has been obtained for three control strategies of series APF: voltage proportional to source current harmonics, voltage opposite to the load voltage harmonics and a hybrid strategy which combines both previous. The resulting model analyses provide the information needed to establish design criteria for each strategy, both in terms of harmonic filtering and the system stability. The three strategies were compared in two different situations: sinusoidal supply voltages and distorted supply voltages. Finally, results of an experimental prototype developed for this purpose allowed the proposed analysis to be verified.

Scheme of a hybrid filter



Single-phase model



Model state

$$\dot{\mathbf{x}} = \mathbf{A}\,\mathbf{x} + \mathbf{B}_1\,\mathbf{u} + \mathbf{B}_2\,\mathbf{v}$$
$$\mathbf{y} = \mathbf{C}\,\mathbf{x} + \mathbf{D}_1\,\mathbf{u} + \mathbf{D}_2\,\mathbf{v}$$

SCD Strategy $u = k\,i_S$

LVD Strategy $u = -k_v\,v_L$

CVD Strategy $u = k\,i_S - k_v\,v_L$

$$\mathbf{x} = \begin{bmatrix} i_S & i_5 & i_7 & i_{LL} & v_5 & v_7 \end{bmatrix}^T \quad \mathbf{v} = \begin{bmatrix} v_S & i_L \end{bmatrix}^T$$

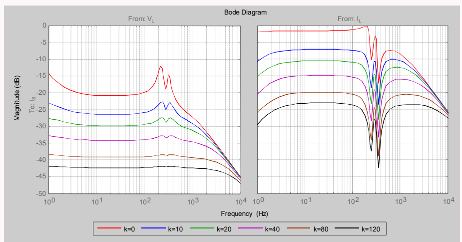
$$\mathbf{A}' = (\mathbf{A} + \mathbf{B}_1\mathbf{K}_1) = \begin{bmatrix} -\frac{(R_S + R_L(1-k_v)+k)}{L_S} & \frac{R_L(1-k_v)}{L_S} & \frac{R_L(1-k_v)}{L_S} & \frac{R_L(1-k_v)}{L_S} & 0 & 0 \\ \frac{R_L}{L_5} & -\frac{(R_L+R_5)}{L_5} & -\frac{R_L}{L_5} & -\frac{R_L}{L_5} & -\frac{1}{L_5} & 0 \\ \frac{R_L}{L_7} & -\frac{R_L}{L_7} & -\frac{(R_L+R_7)}{L_7} & -\frac{R_L}{L_7} & 0 & -\frac{1}{L_7} \\ \frac{R_L}{L_L} & -\frac{R_L}{L_L} & -\frac{R_L}{L_L} & -\frac{R_L}{L_L} & 0 & 0 \\ 0 & \frac{1}{C_5} & 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{C_7} & 0 & 0 & 0 \end{bmatrix}$$

$$\mathbf{B}_1 = \begin{bmatrix} -\frac{1}{L_S} & 0 & 0 & 0 & 0 & 0 \end{bmatrix}^T$$

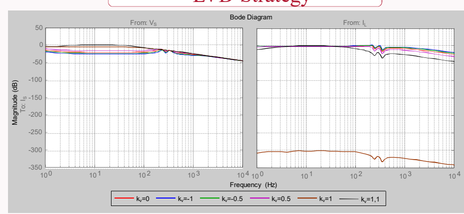
$$\mathbf{B}_2 = \begin{bmatrix} \frac{1}{L_S} & 0 & 0 & 0 & 0 & 0 \\ \frac{R_L}{L_S} & -\frac{R_L}{L_5} & -\frac{R_L}{L_7} & -\frac{R_L}{L_L} & 0 & 0 \end{bmatrix}^T$$

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \qquad \mathbf{D}_1 = \mathbf{D}_2 = [0]$$

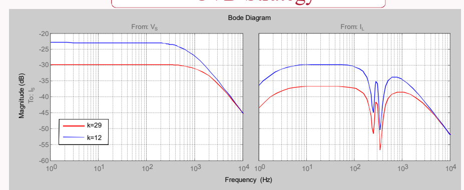
SCD Strategy



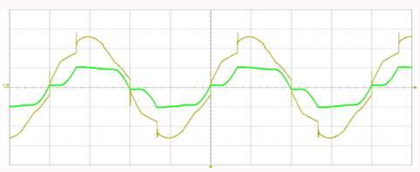
LVD Strategy



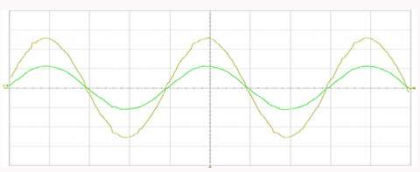
CVD Strategy



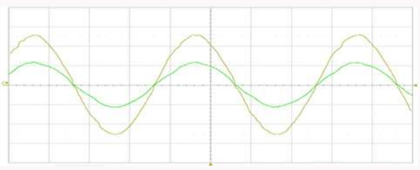
Without comp.



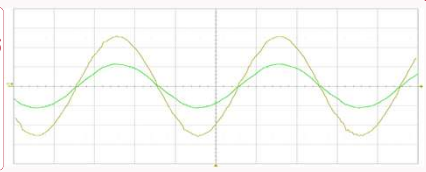
SCD Strategy



LVD Strategy



CVD Strategy



Sinusoidal source

			THD (%)	RMS	H1	H3	H5	H7	H9	H11	H13	P (kW)	Q (kvar)	S (kVA)	PF
	W F	V	9.6	86.8	86.4	0.1	6.2	4.4	0.0	1.6	1.4	0.78	0.25	0.82	0.95 Ind.
		I	17.2	7.8	7.7	0.0	1.2	0.6	0.1	0.3	0.2				
k=25	SCD	V	2.0	87.6	87.5	0.2	0.8	0.3	0.1	0.8	0.7	0.69	0.03	0.70	0.99 Cap.
		I	2.3	7.9	7.9	0.0	0.1	0.0	0.0	0.1	0.1				
	LVD	V	2.1	87.6	87.6	0.3	1.1	0.3	0.1	0.8	0.6	0.70	0.04	0.70	0.99 Cap.
		I	3.5	8.0	8.0	0.1	0.2	0.0	0.0	0.1	0.0				
k=12	CVD	V	2.0	87.6	87.5	0.2	0.8	0.3	0.1	0.8	0.7	0.69	0.03	0.70	0.99 Cap.
		I	2.3	7.9	7.9	0.0	0.1	0.0	0.0	0.1	0.0				

Non Sinusoidal source

			THD (%)	RMS	H1	H3	H5	H7	H9	H11	H13	P (kW)	Q (kvar)	S (kVA)	PF
	WF	V	19,1	87,1	85,5	0,2	15,4	3,2	0,1	2,4	2,1	0,63	0,20	0,66	0,95 Ind.
		I	13,3	7,6	7,5	0,0	0,8	0,5	0,0	0,2	0,2				
k=50	SCD	V	13,4	87,5	86,6	0,2	11,5	0,2	0,1	0,8	0,7	0,68	0,09	0,68	0,99 Cap
		I	2,5	7,8	7,8	0,0	0,2	0,0	0,0	0,1	0,1				
	LVD	V	9,0	87,0	86,6	0,3	7,7	0,2	0,1	0,5	0,4	0,68	0,06	0,68	0,99 Ind.
		I	10,3	7,8	7,8	0,1	0,8	0,0	0,0	0,0	0,0				
k=29	CVD	V	13,4	87,5	86,7	0,2	11,5	0,2	0,1	0,8	0,7	0,68	0,09	0,68	0,99 Ind.
		I	2,5	7,8	7,8	0,0	0,2	0,0	0,0	0,1	0,1				

CONCLUSIONS

A system dynamic analysis has been carried out by means of the state equations. It has allowed the design guidelines for the APF control to be established. Specifically, using the CVD compensation strategy, the APF voltage is obtained by a combination of a term proportional to the source current harmonics and another term in opposite to the load voltage harmonics. This requires the specification of the proportionality constant in the first term and the sensitivity of the instrumentation in the second term. In this paper, the analysis has allowed the values of these parameters to be chosen from a reduction in harmonic distortion of source current specified by design.

Finally, the proposed methodology has been applied to an experimental SAPPF using each of the three mentioned compensation strategies. The voltage and current waveforms and the measured results in terms of distortion and power before and after compensation have been presented

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