

Control of Series Active Power Filter by State Feedback

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1. Brief introduction

The active power filters in series connection or series APF, are static compensation systems based on an electronic converter PWM (Pulse Width Modulation). The systematic use of series APFs in the power systems allows the elimination of the harmonics caused by specific loads named voltage source harmonic loads. To obtain this compensation objective, several strategies have been proposed up now. Nevertheless, each strategy development has been based on the equivalent electrical circuit and on the results obtained in simulation and/or experimental tests. Generally, the control structure formal analysis is not carried out. In this work, the whole system state model has been obtained. Besides, the system behavior has been analyzed from the state equations for each compensation strategy. As a consequence, the analysis has allowed the establishment of design rules respect to the resultant control strategy. Finally, a practical case is presented, whose results illustrate the proposed method.

Key words: Harmonics, series active power filter, state space.

2. Series Active Filters. Compensation Strategies

The series active filters control has been carried out by means of three different compensation strategies:

- Control strategy which measures the load voltage to make that the APF generates a voltage with that same harmonic content and the opposite sign. The measurement of the load voltage harmonic generally depends on the instrumentation sensibility k_v . So, the voltage supplied by the APF applying this strategy can be expressed as follows:

$$v_{CH} = -k_v v_{LH} \quad (1)$$

According to this expression, the voltage in the point of common coupling is, for a specific harmonic $h \in H$:

$$V_{CCh} = V_{Lh}(1 - k_v) \quad (2)$$

- Control strategy based on the source current measurement. It consists of supplying a voltage proportional to the source current harmonics. It is:

$$v_{CH} = k i_{SH} \quad (3)$$

Where k is proportionality constant. The active filter behaves as a resistance whose value corresponding to the fundamental frequency is zero. Its value, corresponding to the different net frequencies, is k ohms. The voltage in the point of common coupling corresponding to the h order harmonic is:

$$V_{CCh} = \frac{Z_{Sh}}{(Z_{Sh} + k)} V_{Lh} \quad (4)$$

- Hybrid strategy where the APF supplies a voltage that combines the previous two strategies:

$$v_{CH} = k i_{SH} - k_v v_{LH} \quad (5)$$

The voltage in the point of the common coupling is the next:

$$V_{CCh} = \frac{Z_S(1 - k_v)}{(Z_S + k)} V_{LH} \quad (6)$$

The simultaneous action of the factor $(1 - k_v)$ in the numerator and the $(Z_S + k)$ in the denominator, decrease the influence of the mistake in the load harmonic voltages measurement. On the other hand, the simultaneous effect allows the utilization of a smaller k value.

3. Analysis Based on State Variables

To represent the system by means of state variables, the circuit shown in figure 1 is used.

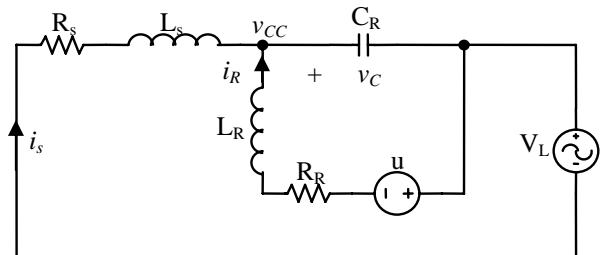


Fig 1. Circuit single-phase model

For the values presented in table 1 and when the control signal u is null, the system has a low frequency gain of -6 dB, with three poles and three zeros, placed as shown in

figure 2. Figure 3 shows the poles and zeros map obtained applying the first control strategy.

TABLE I. Passive elements values

L_s	R_s	L_R	R_R	C_R
0.1 mH	1 Ω	5 mH	1 Ω	50 μ F

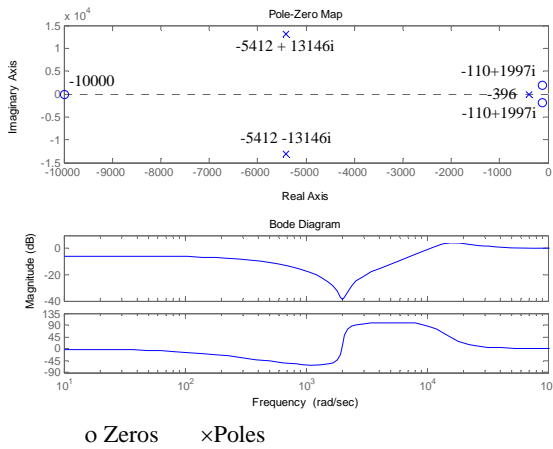


Figure 2. Poles and zeros map and Bode diagram, when control sign is null

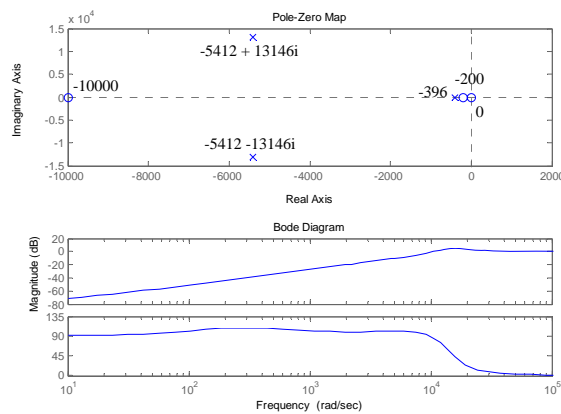


Figure 3. Poles and zeros map and Bode diagram, when $u = -v_L$

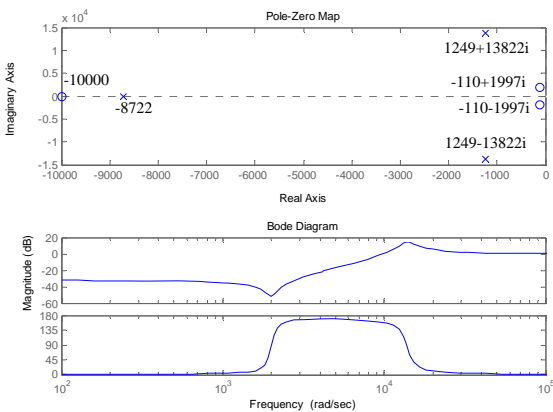


Figure 4. Poles and zeros map and Bode diagram, when $u = 40 i_s$

Applying the hybrid strategy, the zeros will fit in with the first strategy ones and the poles with the second strategy ones.

With $k=40$ the system is stable, and the low frequencies gain is about -32 dB. This gain will go to -25 dB at 3500

rad/s, figure 4. It is possible to attain the objective of gain -40 dB applying the second strategy. Nevertheless, this k value will destabilize the system.

4. Conclusion

The electrical analysis demonstrated the superiority of the hybrid control approach with respect to the two previous strategies. Nevertheless, this type of approach does not allow the knowledge of the system stability and it does not establish any criterion for the election of the design parameters. Here, the state model of a compensated system has been found by means of a series active filter. From it, the three types of compensation strategies have been analyzed. In the state space, the terms of the hybrid control have been analyzed. Then, the system dynamic behavior and the design parameters election have been studied. Finally, the results of a practical case have allowed the verification of the proposed scheme validity.

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References

- [1] H. Akagi, "Active harmonic filters," *Proceedings of the IEEE* Volume 93, Issue 12, Dec. 2005 Page(s):2128 – 2141.
- [2] A. Ghosh, A. K. Jindal, A. Joshi, "Design of a capacitor-supported dynamic voltage restorer (DVR) for unbalanced and distorted loads," *IEEE Trans. Power delivery*. Vo, 19, no.1, January 2004, pp. 405-413.
- [3] Y. S. Kim, J. S. Kim and S. H. Ko, "Three-Phase Three-Wire Series Active Power Filter, which Compensates for Harmonics and Reactive Power", *IEE Proc. Electr. Power Appl.*, Vol, 151, no. 3, May 2004, pp. 276-282.
- [4] S. P. Litrán, P. Salmerón, J. R. Vázquez and R. S. Herrera, "Different control strategies applied to series active filters", in Proc. *ICREPO*, May, 2007.
- [5] F. Z. Peng and D. J. Adams, "Harmonics sources and filtering approaches," in Proc. *Industry Applications Conference*, October 1999, Vol, 1, pp. 448-455.
- [6] F. Z. Peng, H. Akagi, A. Nabae, "A novel harmonic power filter," in Proc. *IEEE/PESC*, April, 1988, pp. 1151-1159.
- [7] F. Z. Peng, H. Akagi, A. Nabae, "A new approach to harmonic compensation in power systems-a combined system of shunt passive and series active filters," *IEEE Trans. Industry Applications*. Vol, 26, no. 6, Nov/Dec 1990, pp. 983-990.
- [8] Z. Wang, Q. Wang, W. Yao and J. Liu, "A series active power filter adopting hybrid control approach," *IEEE Trans. Power Electronics*, vol. 16, no. 3, May 2001, pp. 301-310.