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# Suppression of parallel resonance and mitigation of harmonic distortion through shunt active power compensation

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ABSTRACT

In this contribution a solution to the parallel resonance problem that can be present in practical applications of shunt Active Power Filter (APF) compensation is proposed. The proposed solution involves turning the shunt APF scheme of compensation into a Shunt Hybrid Filter (SHF) configuration. A Linear Quadratic Regulator (LQR)-based switching controller was specifically designed for this hybrid scheme of compensation, maintaining stringent performance requirements on the tracking of filtering currents and the draining of the harmonic ripple currents. Results obtained with Matlab/Simulink® illustrate an effective and sound system of compensation which also reduces the necessary KVA rating of the APF.


## Introduction

With the continuous increase in the incorporation of nonlinear loads in the power network, the harmonic distortion of voltage and current waveforms, among other power quality problems, has become a great concern. This paper focuses on the use of shunt filtering techniques such as shunt Active Power Filter (APF) and shunt hybrid filter (SHF), to mitigate harmonic distortion and to compensate reactive power. In particular, the shunt APF has been demonstrated to be an appropriated tool for the mitigation of harmonic currents and reactive power compensation [1–10].

The shunt APF can be modeled as a controlled current source that supplies a compensation current in parallel with the nonlinear load. The main components of a shunt APF are: a reference current generator, a switching current controller based on a pulse-width modulation (PWM) technique, a power electronic converter (usually a voltage-source-type PWM inverter), and a dc voltage controller (PI controller). These components make possible the injection of the desired filtering currents into the electric system. Usually, the modulation technique used when modeling the shunt APF is the hysteresis-band current controller, due to its fast dynamic response and its easy implementation [5,11–13], whereas this switching technique maintains a variable modulation frequency [11,12]. A relevant characteristic, due to the nonlinear nature of the inverter and the PWM modulation techniques, is that the current injected by the APF into the electric network includes an undesired ripple current, i.e., a high frequency current with relatively low amplitude. For the case of the hysteresis band current controller, there is a presence of variable high frequency modulation harmonics [11,12]. In some cases this ripple current could lead to some undesirable effects in the electric system, such as harmonic ripple contamination to the load voltages, due to the feeder impedance voltage drop at the point of common coupling (PCC), and/or even more, eventually, this ripple current could trigger possible resonances, being parallel resonances of particular consideration due to their severity. These phenomena are described with detail in Section 'Shunt filtering performance in non-stiff systems'. It is known that a path should be provided to drain this high frequency ripple current; this goal could be achieved with a LC ripple-filter [14] or a compensator-passive filter structure designed for this particular purpose [15]. The necessity of adequate development an application of techniques to solve potential problems of resonance and harmonic distortion in diverse electrical networks has been stressed in more recent contributions [16–18]. In [16] application of techniques for harmonic mitigation in networks with integration of wind power plants are analyzed through simulation for certain types of wind turbines; considering resonance

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and non-resonance operation conditions. Details of the techniques applied are however not given. In [17] frequency scan and modal analysis methods are applied for harmonic distortion and system resonances identification in wave power plant applications, so that appropriate correction measures can be timely undertaken. A distributed series/hybrid-shunt compensation technique is proposed in [18] for harmonic mitigation in industrial/commercial facilities.

The main aim of this paper is to provide a strong and high quality scheme of compensation, e.g., shunt filtering, when applied to non-stiff systems. The proposed control is good enough to provide the following goals: (1) To provide a sound solution to the parallel resonance problem that can be present in shunt APF compensation, (2) To allow the correct shunt filtering compensation, (3) To avoid the propagation of the harmonic ripple current into the electric network, (4) To reduce, as much as possible, the KVA rating of the APF.

During the development of the proposed control methodology it is necessary to transform the shunt APF scheme of compensation into a SHF compensation scheme; this is achieved by incorporating a shunt capacitor bank. Due to the inclusion of the shunt capacitor bank, which compensates the reactive power, the proposed solution has the advantage of significantly reducing the KVA rating of the shunt APF converter. Under this *new* SHF configuration; the shunt APF (active element) performs harmonic current mitigation, and the shunt capacitor (passive element) is placed to compensate reactive power and to provide the path for draining out the harmonic ripple current. In order to properly achieve these goals with the SHF; a Linear Quadratic Regulator (LQR) switching current controller, based on that proposed in [15], is specifically designed for this SHF configuration.

This contribution is organized as follows: in Section 'Shunt filtering performance in non-stiff systems' the performance of the shunt filtering techniques, shunt APF and shunt SHF, are tested in a non-stiff three-phase four-wire electric system and the obtained results are observed and analyzed. The electric system for the test is the same used throughout the paper. Section 'Shunt hybrid filter control' details the development of the control design for the proposed SHF compensation scheme; simulation results obtained with Matlab/Simulink® are compared against those obtained in Section 'Shunt filtering performance in non-stiff systems'; the main conclusions drawn from this investigation are given in Section 'Conclusions'.

## Shunt filtering performance in non-stiff systems

This section details how the performance of the shunt APF and the SHF compensation schemes are widely and potentially affected, sometimes leading to miss functioning or even failure, when these shunt filtering techniques are applied for compensation of non-stiff electric systems where the source impedance is considered, in some literature also referred as weak systems. Through Matlab/Simulink® simulations the shunt APF and the SHF compensation performance and their non-desirable associated effects are observed and analyzed. First; the shunt APF compensation scheme is applied and the propagation of the harmonic ripple current to the load voltages will be shown. Second; the SHF compensation scheme is applied using the same test system, and the associated parallel resonance phenomenon which can be potentially present will be shown. In both cases it is important to notice that the wrong compensation performance does not depend on the reference current generator used by the shunt APF. In fact, these problems will be triggered by the high frequency ripple current inherent to the injected shunt APF currents.

### *Shunt active power filter – harmonic ripple contamination of load voltages*

The shunt APF scheme of compensation in a three-phase four-wire electric system is illustrated in Fig. 1. In this system an unbalanced linear load in parallel with a nonlinear load are supplied by a balanced voltage source.

The nonlinear load is a 9.41 KVA, 6-pulse diode rectifier and the linear load is a series resistance–inductance branch per phase. Table 1 gives the system parameters. The reference current generator to be used by the APF is implemented according with [5], and is given by,

$$i^*_{fa}(t) = i_{la}(t) - \frac{2(P_T + P_{loss})}{U_T}\sin(\omega t + \phi_{a1}) \tag{1}$$

$$i^*_{fb}(t) = i_{lb}(t) - \frac{2(P_T + P_{loss})}{U_T}\sin(\omega t + \phi_{a1} - 2\pi/3) \tag{2}$$

$$i^*_{fc}(t) = i_{lc}(t) - \frac{2(P_T + P_{loss})}{U_T}\sin(\omega t + \phi_{a1} + 2\pi/3) \tag{3}$$

where $i^*_{fk}(t)$ is the reference filtering current of phase $k$, $i_{lk}(t)$ is the line current of phase $k$, e.g. in this example it corresponds to the load current drawn by the combination of the linear unbalanced load current and the rectifier load current; the subscript $k$ represents the phases $a$, $b$ or $c$, respectively. $P_T$ is the total active power delivered to the load, $U_T$ is the sum of the peak value of the source voltages $u_k$, $\phi_{a1}$ is the phase angle of the fundamental component of the load voltage at phase $a$, and $\omega$ is the angular speed at fundamental frequency $f$ of 60 Hz.

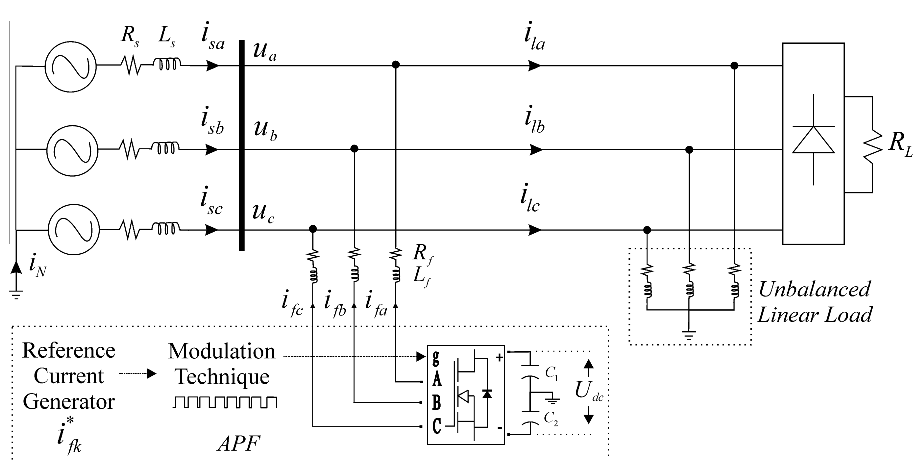


**Fig. 1.** Shunt active power filter compensation scheme in a 3F4W system.