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Control strategies for harmonic mitigation and power factor correction using shunt active filter under various source voltage conditions

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ABSTRACT

This paper gives a new insight into the concept of load compensation using shunt active filter (SAF) under ideal and non-ideal source voltage conditions. A novel approach based on an improved instantaneous active and reactive current component method is proposed. The performance of the proposed control strategy has been compared with instantaneous reactive power theory, symmetrical component theory and dq theory. SAF has been realized by three-phase voltage source converter. Reference currents generated by control strategies has been tracked by a SAF in a hysteresis band control scheme. The performance of the proposed scheme is evaluated in terms of reactive power compensation, reduction in magnitude of source currents, compensator currents, and harmonic compensation as per IEEE-519 standard. To ascertain the viability of the proposed control algorithm, the performance is evaluated under different source voltage conditions with the IEEE Standard-1459 power definitions. Variation in magnitude as well as harmonic content of source voltage has been considered. Under balanced sinusoidal source voltage condition, all control strategies congregate to similar results. Under unbalanced sinusoidal source voltage condition, dq theory and proposed theory have shown similar performance. However, under distorted source voltage conditions, an improved instantaneous active and reactive current component theory presents superior performance. A three-phase, three-wire distribution system supplying non-linear load is considered for simulation study. Simulation results from a complete model of SAF are presented to validate and compare the control strategies.

1. Introduction

With the increase in the number of sensitive loads, power quality issues are gaining significant attention. Nowadays, the power quality in the distribution system is polluted due to high reactive power burden, harmonically contaminated and unbalance load currents [1–3]. It results in the distorted voltages at the supply point of the utility due to non-linear voltage drop across the feeder [4]. Hence harmonic mitigation and reactive power compensation under various source voltage conditions are important issues in modern power system. The power quality indices are governed by various standard regulations and recommendations, such as IEEE-519 [5].

Traditionally, harmonic mitigation is achieved by passive filters. The possibility of resonance and filter overloading has become more prominent with passive filter when supply waveforms are non-ideal [6]. SAF is a active filter which is connected in shunt with the load. SAF can regulate current injection into the system very efficiently by the power electronics based control in it. It can be used for power factor correction, harmonic compensation and reactive power compensation, etc. [7]. The system configuration with shunt active filter is shown in Fig. 1. In this scheme, three-phase voltage source converter is used as shunt active filter. This voltage source converter injects appropriate currents into system such that undesirable components of load current responsible for harmonic pollution and poor power factor are eliminated.

Selection of control strategy for SAF plays an important role to get desired compensation characteristics. To serve this purpose, many control algorithms have been presented by various researchers. These algorithms are based on instantaneous reactive power theory (pq), synchronous reference frame theory (SRF), symmetrical component theory (sc), instantaneous active and reactive current component theory (dq theory), unity power factor compensation strategy, perfect harmonic compensation strategy, etc. [2,8–22].

Any attempt to make perfect sinusoidal source currents leads to a poor power factor (PF) when source voltages are non-sinusoidal. Moreover, efforts to achieve unity power factor on source side has resulted in distorted source current waveform. Thus, there is a trade off between the requirements of high source PF and low total harmonic distortion (THD) [9–11]. The best key to this trade off is

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Nomenclature

$V_{sa/b/c}$	source voltage of phase-a, phase-b and phase-c respectively
$i_{sa/b/c}$	source current of phase-a, phase-b and phase-c respectively
$i_{la/b/c}$	load current of phase-a, phase-b and phase-c respectively
$i_{ca/b/c}$	compensator current of phase-a, phase-b and phase-c respectively
P_{load}	instantaneous active power of load
P_s	instantaneous active power of source
P_c	instantaneous active power of compensator
q_{load}	instantaneous reactive power of load
q_s	instantaneous reactive power of source
q_c	instantaneous reactive power of compensator
$\sim$	over the letter: variable part
$-$	over the letter: average value

Subscript

d	d component in *odq* coordinates system
q	q *component* in *odq* coordinates system
α	α component in $0\alpha\beta$ coordinates system
αF	α component in $0\alpha\beta$ coordinates system after filtration.
β	β component in $0\alpha\beta$ coordinates system
βF	β component in $0\alpha\beta$ coordinates system after filtration
$1h$	fundamental component
nh	nth harmonic component

Superscript

+	positive sequence component
$-$	negative sequence component

the reference current generation technique should be such that both PF and THD requirements are satisfied. Hence the source current should be shaped in such a manner that source power factor is improved and at the same time, THD of source current is restricted as per IEEE-519 standard.

An instantaneous active and reactive current component theory had been proposed by Soares et al. for harmonic mitigation using shunt active filter in three-phase, three-wire distribution system under unbalance sinusoidal source voltage condition and balanced distorted source voltage conditions [17]. In this paper, an improved instantaneous active and reactive current component theory (idq) has been proposed such that both requirements of unity power factor on source side and restriction of THD of source current as per IEEE-519 standard are fulfilled simultaneously. The performance of the proposed control strategy has been evaluated under ideal, unbalance sinusoidal, balanced distorted and unbalance distorted source voltage conditions.

It is essential to evaluate the performance of SAF under various source voltage conditions with non-linear load and ascertain the most appropriate control strategy to achieve desirable current compensation. In this paper, the performance of proposed control strategy is compared with pq theory [2], sc theory [18] and dq theory [17] under various source voltage conditions.

In this paper, the performance of various control strategies for SAF is evaluated on the basis of following objectives:

- To eradicate the effect of poor load power factor such that it results in almost unity power factor on supply side.
- To restrict harmonic mitigation as per IEEE-519 standard in such a way that source currents are sinusoidal irrespective of harmonic content in distorted source voltage and non-linear load.
- To decrease apparent power supplied from source for given source voltage conditions.

2. Control algorithms

2.1. pq Theory, sc theory and dq theory

Detailed description of pq theory, sc theory and dq theory are found in [2], [18] and [17], respectively.

2.2. Improved instantaneous active and reactive current component method

Fig. 2 shows the basic block diagram of the proposed method. The transformation angle is obtained with the voltages of the ac

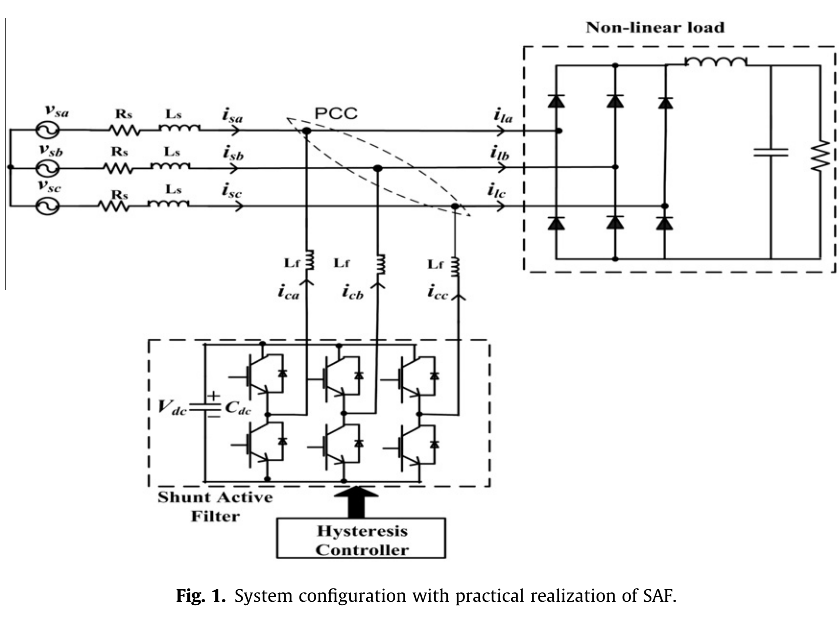

Fig. 1. System configuration with practical realization of SAF.