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Simulation and real time implementation of predictive direct power control for three phase shunt active power filter using robust phase-locked loop

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ABSTRACT

This paper proposes a predictive direct power control for shunt active power filters. The main goal of the proposed active filtering system is to eliminate the unwanted harmonics and compensate fundamental reactive power drawn from the non-linear loads. The proposed control is characterized by a high transient dynamic, which makes it an interesting alternative for classic direct power control. In order to improve the efficiency of the proposed control, different simulation and experimental tests were carried out with real time implementation on dSPACE 1104 card in steady and transient states. The obtained results indicate closeness between simulation and experimental tests, which prove and verify the effectiveness of the proposed control strategy.

1. Introduction

Harmonic pollution is a major problem that degrades the quality of electric energy in distribution systems. These harmonics are presented in the electrical grids from the use of non-linear loads which are subjected to a sinusoidal voltage and absorb a non-sinusoidal current. In many cases, these loads act as sources of harmonic currents [1,2]. Many solutions have been developed to desensitize industrial facilities and grid by considering harmonic pollution. The most common solution implemented is the passive harmonic filtering. It uses a capacitor in series with an inductor in order to obtain an agreement on a given harmonic frequency, nevertheless, they present several disadvantages such as: the inability to compensate for random frequency variations in the current, the deterioration of the filtering performance due to changes in the parameters, problems of adjustment, and the parallel resonance [3], so another compensation system is investigated that can adapt quickly to the harmonic spectrums. This quoted passive solution was not expected and a new powerful way of compensation appeared. Active power filter (APF) is the most popular solution used to eliminate the undesired current harmonics [4], it is divided into two types: parallel and series [5]. In this paper, the first type is taken into consideration [6]. The shunt active power filter compensator injects a current that opposes the harmonic current emitted by the load. The entire load/filter appears on the grid as a load which absorbs sinusoidal current.

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Nomenclature

AC	alternative current
DC	direct current
PI	proportional-integral controller
Kp	proportional gain
Ki	integral gain
Ts	sample time
DB	diode bridge
APF	active power filtering
SAPF	shunt active power filtering
DTC	direct torque control
DPC	direct power control
P-DPC	predictive direct power control
THD	total harmonic distortion coefficient
PLL	phase locked loop
PWM	pulse width modulation
MVF	multi-variable filter
ω_n	natural frequency
θ	angle phase
IEEE	Institute of Electrical and Electronics Engineers
$e_{s\ 1,2,3}$	grid voltages (V)
$Is_{\ 1,2,3}$	grid currents (A)
$I_{\alpha\beta}$	grid currents in $\alpha\beta$ reference frame (A)
$e_{\alpha\beta}$	grid voltages in $\alpha\beta$ reference frame (V)
$V_{a,b,c}$	inverter output voltages (V)
V_{dc}, $V_{dc\ ref}$	actual and reference
P_{ref}	reference active power (W)
Q_{ref}	reference reactive power (Var)
$L_{S1,2,3}$	source inductance (H)
$R_{S1,2,3}$	source resistance (Ω)
$L_{f1,2,3}$	output filter inductance (H)
$L_{C1,2,3}$	input DB inductance (H)
L_L	load inductance (H)
R_L	load resistance (Ω)
C	DC bus capacitor
ξ	damping coefficient
Sa,Sb,Sc	switching state
ε	error
F	cost function

In the literature, several control strategies were presented to control the APF such as: hysteresis current control [7] and direct power control [8]. All these methods have one goal: to reduce the impact of harmonic currents and improve the power factor, but it differs in the principle.

Over recent years, researchers have focused on direct power control (DPC) due to its characteristics which are essentially: no internal current loops, good dynamic and performance. Its principle was inspired from the DTC [9] applied on the electric machines.

The important element of this command is the switching table, that is responsible for the selection of the converter switching states, it was applied to the three-phase PWM rectifier [10] and on active filter [11]. It requires a high sampling rate for efficient and precise control of active and reactive powers [12]. However, this configuration of the DPC has a major drawback associated with the periodicity of switch control signals, which cannot be controlled [13].

Predictive direct power control (P-DPC) has become widely used [14]. It has many applications in control of DC/AC converters [15] and AC/DC converters [16]. It is characterized by a constant switching frequency and a high transient dynamic in choosing the optimum voltage vector, which reduces the error between the actual active, reactive power and their references [17]. These advantages make the P-DPC control an interesting alternative for classic direct power control DPC [18]. It can also cover its greater disadvantages, which are related mainly to the periodicity of switch control signals, that cannot be controlled contrary to what is available in P-DPC [19].

In this paper, a simulation and an experimental validation of predictive direct power control of a shunt active power filter is presented, allowing a proper regulation of active and reactive power, and a compensation of undesirable current