Electrical Power and Energy Systems 61 (2014) 629–646

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Hybrid direct power/current control using feedback linearization of three-level four-leg voltage source shunt active power filter

M. Bouzidi [a,b,*], A. Benaissa [b], S. Barkat [c]

[a] Département de l'Electronique et des Communications, Faculté des Nouvelles Technologies d'Information et Communication, Université Kasdi Merbah, Ouargla 30000, Algeria
[b] Département d'Electrotechnique, Faculté des Sciences de l'Ingénieur, Université Djillali Liabes de Sidi Bel Abbes, Sidi Bel Abbes 22000, Algeria
[c] Département d'Electrotechnique, Faculté de Technologies, Université de M'sila, M'sila 28000, Algeria

ARTICLE INFO

Article history:
Received 3 January 2013
Received in revised form 27 March 2014
Accepted 28 March 2014
Available online 3 May 2014

Keywords:
Three-level four-leg shunt active filter
Hybrid direct power/current control
Feedback linearization
Three dimensional space vector modulation

ABSTRACT

This paper proposes a hybrid direct power/current control-three dimensional space vector modulation combined with feedback linearization control for three-phase three-level four-leg shunt active power filter (SAPF). The four-leg SAPF ensures full compensation of harmonic phase currents, harmonic neutral current, reactive power and unbalanced nonlinear load currents. It also regulates its self-sustaining DC bus voltage. The voltage-balancing control of two split DC capacitors of the three-level four-leg SAPF is achieved using three-level three dimensional space vector modulation with balancing strategy based on the effective use of the redundant switching states of the inverter voltage vectors. Complete simulation of the resultant active filtering system validates the efficiency of the proposed nonlinear control method. Compared to the traditional control, the use of feedback linearization control allows to exhibit excellent transient response during balanced and unbalanced load, and grid voltage.

© 2014 Elsevier Ltd. All rights reserved.

Introduction

The excessive use of power electronic equipments, which represent nonlinear loads, in a distribution network has caused many disturbances in the quality of power such as harmonic pollutions, unbalanced load currents, and reactive power problems. As a result poor power factor, weakening efficiency, overheating of motors and transformers, malfunction of sensitive devices etc. are encountered [1–3].

Conventionally, a passive power filter which consists of passive elements is used to provide harmonic filtering as an economical and effective filtering device. However it has shortcomings such as fixed compensation performance, bulk in size and resonance troubles [4–7]. Important kinds of passive power filters and their configurations are discussed in [4]. To overcome the shortcomings of passive power filters and to mitigate the power pollution in networks caused by the nonlinear loads, an active power filter (APF) was established in around 1970s [8–10]. APFs are previously not implemented in power networks, because of unavailability of high speed power switching devices. Recently the power electronic development spurred the interest in IGBTs, MOSFETs, etc. [8] and then APFs are developed incorporating power electronics technology to support the needs of industry. Shunt, series, and hybrid configuration are the three main types of three-phase, three-wire active power filters and their merits and demerits are discussed in [4].

For medium to high power applications the multilevel converters are the most attractive technology. Indeed, multilevel converters have shown some significant advantages over traditional two-level converters [9–12]. The main advantages of the multilevel converter are a smaller output voltage step, lower harmonic components, a better electromagnetic compatibility, and lower switching losses [9–12]. In the recent time, the use of multilevel inverters is prevailing in medium-voltage active power filters without using a coupling transformer [13–17].

In several areas, power is distributed through three-phase four-wire system and traditional APF is inadequate for harmonics compensation and power factor correction. To overcome this shortage, a three-phase four-wire SAPF has been introduced in the 1980s [18–22].

Basically there are two main kinds of three-phase, four-wire SAPF depending on their connection to the neutral wire. In the first kind the neutral wire is connected to the midpoint of the DC-link capacitors. In [23,24], this approach was studied where the inverter was operating as an active power filter. However, although it is simple in terms of topology, this approach is not suitable for SAPF

---

* Corresponding author at: Département de l'Electronique et des Communications, Faculté des Nouvelles Technologies d'Information et Communication, Université Kasdi Merbah, Ouargla 30000, Algeria. Tel.: +213 661352139.

E-mail addresses: bouzidi.m.28@gmail.com (M. Bouzidi), aek_benaissa@yahoo.fr (A. Benaissa), sa_barkati@yahoo.fr (S. Barkat).

http://dx.doi.org/10.1016/j.ijepes.2014.03.071
0142-0615/© 2014 Elsevier Ltd. All rights reserved.

application, for the following reasons [25,26]: (1) insufficient DC-link utilization, (2) high ripple on DC-link capacitors, (3) problem of DC-link capacitor voltages balance. In the second type the neutral wire is connected to the additional fourth leg, this topology has been shown to be a solution for inverters operating in three-phase four-wire systems and it offers full utilization of the DC-link voltage and lower stress on the DC-link capacitors [26].

Various control strategies have been proposed to control grid-connected DC/AC converters, a classic control usually based on grid voltage [27,28] or virtual-flux [29] oriented vector control (VOC or VFOC) scheme. This scheme decomposes the AC current into active and reactive power components in the synchronously rotating reference frame. Decoupled control of instantaneous active and reactive powers is then achieved by regulating the decomposed converter currents using proportional integral (PI) controllers. One main drawback for this control method is that the performance highly relies on the completeness of current decoupling, the accurate tuning of PI parameters, and the connected grid voltage conditions.

Based on the principles of the well-known direct torque control (DTC) [30,31] of AC machines, an alternative control approach, namely, direct power control (DPC) was developed for the control of grid-connected voltage-sourced converters [32,33]. Similar to the traditional DTC, lookup table direct power control (DPC-LUT), as the name indicates, selects the proper converter switching signals directly from an optimal switching table on the basis of the instantaneous errors of active and reactive powers, and the angular position of converter grid voltage [33] or the virtual flux vector. This later result from the integration of converter grid voltage measured with voltage transducers [34] or estimated based on the DC-link and the converter switch states [34]. The main disadvantage of DPC-LUT is the variation of switching frequency, which generates an undesired broadband harmonic spectrum range and makes it pretty hard to design a line filter.

These disadvantages can be effectively overcome by using space vector modulation (SVM) algorithm to replace the traditional switching table. The combination of SVM and traditional DPC forms the space vector modulation direct power control (SVM–DPC) [35].

Indeed the traditional two dimensional SVM algorithms only can be used to control converter connected to power system with balanced voltage/current where the homopolar component in Concordia transformation is equal to zero. In the four-wire system distribution, the case of unbalanced voltage is taken in consideration; therefore, the homopolar component is not equal to zero. Thus, three dimensional space vector modulation (3DSVM) algorithms must be taken into account in order to generate the desired signal.

In [25,26], 3DSVM schemes are analyzed for a four-leg two-level voltage source inverter. Authors in [23,24] have presented a modulation scheme for a three-level inverter as an active power filter in three-phase four-wire systems where hysteresis modulation was designed in a three-dimensional domain. However, 3DSVM for a four-leg three-level inverter has not yet been studied in stationary reference frame. A novel algorithm of space vector modulation for a four-leg three-level inverter is proposed in this paper. The effectiveness of the proposed modulation algorithm, and the advantages of the proposed topology over conventional ones, are discussed and verified with simulation results with SAPF system.

Commonly, the abovementioned control techniques are based on traditional PI control. In order to improve the performance of three-phase four-leg SAPF, various nonlinear control strategies have been reported in the literature. The proposed control strategies include among others sliding mode control [36], passivity control [37], nonlinear optimal predictive control [38] and H_∞ control [39].

In this paper, a nonlinear control strategy based on the feedback linearization associated to hybrid direct power/current control with 3DSVM (DP/CC-3DSVM) is applied to three-phase three-level four-leg SAPF in order to improve its performances. It is well known that feedback linearization technique is a control method which aims to eliminate the nonlinearity of the system by using the inverse dynamics [40]. It has been applied successfully to control the three-level neutral point clamped (NPC) boost converter [41], three-phase AC/DC PWM converters [42] and three-level three-phase shunt active power filter [43]. As a result, good performances have been reported and the nonlinear control law was able to reduce the influence of parametric variations, utility disturbances, and DC load shedding [41].

This paper is organized as follows. In Section 'Four-leg shunt active power filter', the configuration of four-leg SAPF is presented and the system model is developed. In Section 'Control of three-level four-leg compensator', the feedback linearization associated to the DP/CC-3DSVM is investigated. The nonlinear controllers are synthesized and the three-level 3DSVM with balancing capability are presented also in this section. In Section 'Simulation results', the performances of controlled system are verified by simulation results. Finally, in Section 'Conclusion' some conclusions are established.

Four-leg shunt active power filter

System description

The basic compensation principle of the four-leg SAPF is shown in Fig. 1. The main task of the four-leg SAPF is to reduce harmonic currents and to ensure reactive power compensation. Ideally, the four-leg SAPF needs to generate just enough reactive and harmonic current to compensate the nonlinear load harmonic in the line. The resulting total current drawn from the AC main is sinusoidal and balanced. The compensated neutral current is provided through a fourth leg allowing a better controllability than the three-leg with split-capacitor configuration. The main advantage of the four-leg configuration is the ability to suppress the neutral current from the source without any drawback in the filtering performance.

Mathematical model of the three-level four-leg SAPF

The switching functions are defined as F_{ij} where $i \in \{a, b, c, n\}$ is the phase and $j \in \{0, 1, 2\}$is the voltage level. F_{ij} takes value "1" if *i*-phase is connected to voltage level j and "0" otherwise; these switching functions can be expressed as:

$$\begin{aligned} F_{x2} &= S_{x2}S_{x1} \\ F_{x1} &= S_{x2}\bar{S}_{x1} \qquad x = a, b, c \text{ or } n \\ F_{x0} &= \bar{S}_{x2}\bar{S}_{x1} \end{aligned} \tag{1}$$

The instantaneous AC converter phase to neutral voltages v_{Fa}, v_{Fb} and v_{Fc} can be expressed in terms of switching functions and DC-link voltages capacitors as given by:

$$\begin{bmatrix} v_{Fa} \\ v_{Fb} \\ v_{Fc} \end{bmatrix} = \begin{bmatrix} F_{a2} - F_{n2} & F_{a1} - F_{n1} & F_{a0} - F_{n0} \\ F_{b2} - F_{n2} & F_{b1} - F_{n1} & F_{c0} - F_{n0} \\ F_{c2} - F_{n2} & F_{c1} - F_{n1} & F_{c0} - F_{n0} \end{bmatrix} \begin{bmatrix} v_{C2} + v_{C1} \\ v_{C1} \\ 0 \end{bmatrix} \tag{2}$$

The mathematical equations which govern the behavior of the AC-side of SAPF are:

$$\begin{aligned} \frac{di_{Fa}}{dt} &= \frac{1}{L_F}(v_{Fa} - v_a - R_F i_{Fa}) \\ \frac{di_{Fb}}{dt} &= \frac{1}{L_F}(v_{Fb} - v_b - R_F i_{Fb}) \\ \frac{di_{Fc}}{dt} &= \frac{1}{L_F}(v_{Fc} - v_c - R_F i_{Fc}) \end{aligned} \tag{3}$$

دریافت فوری ← متن کامل مقاله

ISIArticles
مرجع مقالات تخصصی ایران

- ✓ امکان دانلود نسخه تمام متن مقالات انگلیسی
- ✓ امکان دانلود نسخه ترجمه شده مقالات
- ✓ پذیرش سفارش ترجمه تخصصی
- ✓ امکان جستجو در آرشیو جامعی از صدها موضوع و هزاران مقاله
- ✓ امکان دانلود رایگان ۲ صفحه اول هر مقاله
- ✓ امکان پرداخت اینترنتی با کلیه کارت های عضو شتاب
- ✓ دانلود فوری مقاله پس از پرداخت آنلاین
- ✓ پشتیبانی کامل خرید با بهره مندی از سیستم هوشمند رهگیری سفارشات