Electric Power Systems Research 80 (2010) 1543–1551

Contents lists available at ScienceDirect

Electric Power Systems Research

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

# Active power filter for medium voltage networks with predictive current control

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ARTICLE INFO

*Article history:*
Received 19 April 2010
Received in revised form 28 June 2010
Accepted 29 June 2010
Available online 9 August 2010

*Keywords:*
Active power filters
Current control
Multilevel converters
Predictive control

ABSTRACT

A transformer less Shunt Active Power Filter (SAPF) for medium voltage distribution networks based on Multilevel Diode Clamped Inverter is presented in this paper. Converter current control is based on a Model Predictive strategy, which gives very fast current response. Also, the algorithm includes voltage balancing capability which is essential for proper converter operation. The presented current control algorithm is naturally applicable to converters with an arbitrary number of levels with reduced computational effort by virtue of the incorporation of switching restrictions which are necessary for reliable converter operation. The performance of the proposed algorithm is evaluated by means of computer simulations.



## 1. Introduction

Proliferation of electronic drives and power supplies in industrial and residential installations has led to extensive power system quality degradation. High levels of current harmonics and voltage wave shape distortion results in system components overheating and premature failure among other undesirable effects. This has increased the concern about power quality issues leading to new concepts and technologies for the mitigation and reduction of these problems [1].

Although several converter topologies are being taken into account as implementation alternatives for AC/DC power supplies [2], present installations need external custom solutions for the accomplishment of the new power quality standards [3]. In this sense, traditional solutions based on inductors, capacitors and/or resistors, and the more complex FACTS-based devices form a set of choices to address this problem. According to the particular necessity, solutions may vary from standard passive filters, to converter-based filters and more complete solutions as Universal Power Quality Conditioners for critical processes.

Regarding harmonics filtering, Active Power Filters have advantages regarding versatility and adaptability to changing operating conditions. Also, controllers are completely programmable depending on the control goals, with the same power electronic platform. Regarding harmonic filter controllers, there are lots of new control strategies to determine the harmonic currents to be compensated. Several approaches were developed and analyzed such as rotating integrators, wavelets assisted methods, PQ theory and intelligent algorithms [4].

Also, new achievements in the development of high power and high voltage electronic switches have pushed forward the applications to higher voltage levels jointly with new converter structures and topologies [5,6]. In this sense, depending on the selected converter topology, each one has their own control problems. In particular, the Diode Clamped Multilevel Inverter (DCMI) with more than three levels has problems with the DC link voltage balance, thus an implementation of a robust voltage balancing algorithm is mandatory [7]. Then, a whole control approach can be implemented for the search of converter switching states that leads to the better set of controlled output variables but also its inner variables, the DC capacitors voltages. This suggests that an optimization strategy is adequate to reach an acceptable global performance of the controlled variables. In this sense, the Model Predictive Control (MPC) approach is a promising alternative because their advantages rise when the control problem consists in the control of a set of variables that are linked together and to the control action. Regarding MPC application to power converters control, this technique has the additional advantage of the discrete nature of switching converters. This inherently limits the control action to a finite set of possibilities.

In fact, MPC has proven to be a very successful approach for power converters control [8]. Several works deal with MPC of two level inverters both in front-end and load applications. In these cases, current control is achieved through the evaluation of a cost function that measures the error between reference and predicted currents. Also, three level DCMI's were controlled successfully [9,10], taking into account current control and ripple minimiza-

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0378-7796/$ – see front matter 
doi:10.1016/j.epsr.2010.06.019

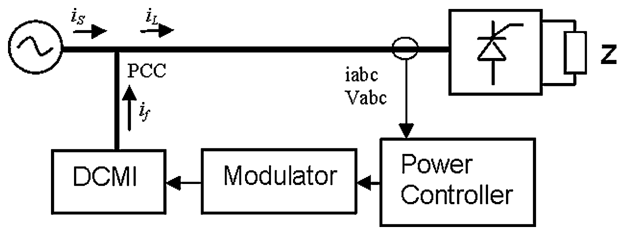


**Fig. 1.** Block diagram.

tion of the DC bus middle point. Finally, in [14] a control algorithm addresses the current control and the DC bus voltage balance of a four level converter using all the switching states. However, it is worth mentioning that as converter levels increase ($N$), the available switching states also increases as $N^3$, which rises to an overwhelming computational effort.

In this work we present a Shunt Active Power Filter for medium voltage distribution networks which avoids the use of a coupling transformer. This is achievable through the utilization of a Multilevel Diode Clamped Inverter as the power electronic interface. The converter control is performed by means of a predictive control algorithm that optimizes the DC bus voltage balance and also performs the line current control with no need for converter averaged models. This leads to excellent dynamic behavior in comparison with traditional linear nested current control loops. Also, the necessary restrictions on switching state transition for suitable blocking voltage clamping of the electronic switches reduces computational effort, through the limitation of the possible switching combinations from $N^3$ to $3^3$. Also, given to the independence of this switching restriction respect to the number of levels considered, the strategy can be applied to a converter of an arbitrary number of levels with almost constant computational effort.

## 2. System description

Fig. 1 shows a block diagram of a Shunt Active Power Filter for the compensation of harmonics and reactive currents generated by a nonlinear load.

The nonlinear load draws a current $i_L$ that is composed of fundamental active and reactive currents but also harmonics. The power filter supplies the reactive and harmonic components in the point of common coupling (PCC) so that the utility only provides sinusoidal current with high power factor.

The power controller is based on the definition of instantaneous power variables (a review of this theory and its application to power filtering is presented in [1]):

$$\begin{aligned} p &= v_\alpha i_\alpha + v_\beta i_\beta = \bar{p} + \tilde{p} \\ q &= v_\beta i_\alpha - v_\alpha i_\beta = \bar{q} + \tilde{q} \end{aligned} \tag{1}$$

$$\begin{bmatrix} f_0 \\ f_\alpha \\ f_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix}$$

$f_a, f_b, f_c$ : phase variables

Eq. (1) expresses the real and imaginary power drawn by the nonlinear load. Power controller generates the SAPF current references for the modulator to compensate the reactive and harmonic real power. This is, active power $\bar{p}$ is supplied by the utility and fundamental reactive power $\bar{q}$ and also harmonic terms $\tilde{p} + \tilde{q}$ are supplied by the power filter at the PCC, so that the utility only provides sinusoidal in-phase current. Fig. 2 shows power controller calculation, where a power loss component $\bar{p}_{loss}$ is added to stabilize the DC bus voltage.

The schematics of the filter connection is presented in Fig. 3, where an $N$ level DCMI is used as the power interface. This type of converter can be directly connected to the medium voltage distribution network without the use of a coupling transformer, which represents a significant decrease in system cost and complexity.

The figure includes the coupling inductor with impedance $Z_f$, the line inductance $L_S$ and the load to be compensated. The rated DC bus voltage is $(N-1)V_c$, and the maximum peak line voltage that can be synthesized by the converter is $(N-1)V_c$.

Given that the system is three wired without neutral conductor, the filter currents are determined by line voltages $e_{ab}$, $e_{bc}$, $V_{ab}$ and $V_{bc}$ where the last two can only assume values which are multiples of $V_c$ from $-(N-1)V_c$ to $(N-1)V_c$. Then, a representation in terms of line voltages can be used, independently of the load connection.

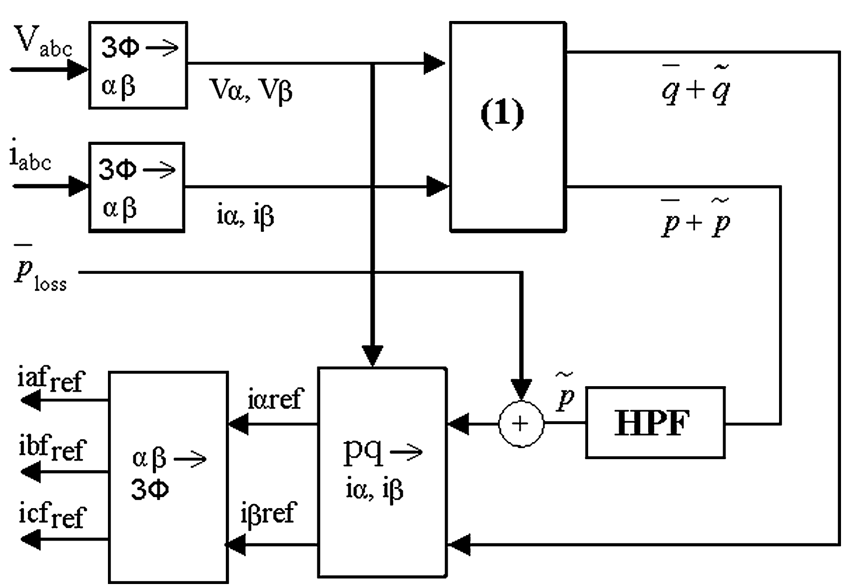


**Fig. 2.** Power controller.