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UPQC implemented with Cascade Asymmetric Multilevel Converters

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ABSTRACT

The power quality (PQ) in distribution systems is affected by the pollution introduced by the customers. The Unified Power Quality Controller (UPQC) custom power device is the most integral actuator to improve the quality of the systems. Today, several manufacturers offer solutions using multilevel inverters in medium voltage applications with different control methods. In particular, the Cascaded Asymmetric Multilevel Converter (CAMC) is a novel alternative among the 5-level converters for back-to-back application. In this paper an UPQC with two CAMC in back-to-back connection is proposed. The hybrid modulation technique used in the CAMC made easier the implementation of the control objectives. Those are, regulating the voltage on sensitive load and control of its reactive power and harmonics current. They are carried out managing the active and reactive power into the UPQC. The model and the control strategy are discussed in d–q coordinates and the performance of the proposed UPQC is evaluated with SPICE simulations.

1. Introduction

The PQ in distribution systems has been significantly degraded because of different disturbances introduced in the electrical grid. The start-up of electric motors, the connection and disconnection of large loads, the presence of non-linear loads and the short circuits which take place in sub-transmission systems [1–3] are the most common examples which cause disturbances. The effects of these are displayed through voltage distortion, unbalance voltages sag/swells, voltages flicker, etc. When a sensitive load is connected to a system with poor PQ then a custom power device should be used to mitigate this deficit [1,4]. The UPQC is one of the custom power devices which have the capability to solve most of problems related to the low quality of the power system, in an integrated form. Actually, the applications of the UPQC can be extended to compensate PQ problems in systems with interconnection of distributed renewable energy sources or microgrids [5–7]. The UPQC is a combined action between a series and shunt compensators to enhance the voltage on a particularly point of connection. The UPQC has been classified in different groups depending of the supply systems and the control strategies [8,9]. The structure of the UPQC in power distribution networks most widely studied, it is implemented with two voltage source inverters (VSI) in back-to-back connection [8,10]. The classical two levels VSI topology in medium voltage level (MV) applications has limited implementations because the low reverse blocking voltage of the switches and low frequency switching [11]. One solution of the UPQC in MV level was presented in [12]. Here, the numerous mono-phase-VSI in series connection with voltage transformers are used, both the series compensator and the shunt compensator. The major drawback of this solution is the complex strategy to control the amplitude and phase of each inverter. Other possible solution can seen in [13] where the 5 levels diode-clamped multilevel inverter is used. In this case the control is easier because each multilevel voltage source inverter (MVSI) syntheses only one voltage. The UPQC come in a more compact structure from the point of view of the control strategy of the device. In general the MVSI by different topologies allow to spread the voltage and to reduce individual device switching frequency without the use of the voltages transformers. The most modern solution in MV can be found in [14]. Here, the modular multi-level converter (MMC) is used. This solution has the virtue of the MVSI but a great number of switches are necessary and consequently, they require mayor attention to synchronize the control of the switches.

The MVSI have developed important advances in the range of medium voltage and high power [15–17]. Different custom power applications such as, transformer less shunt compensator [18–20] and series compensator [21,22] have been carried out. The MVSI topologies as diode clamping (DC) or flying capacitors (FC) present practical limitations when a high number of levels of voltages are pretended, namely, (a) it increase the number of switches more than proportional with respect to the number of voltages levels,

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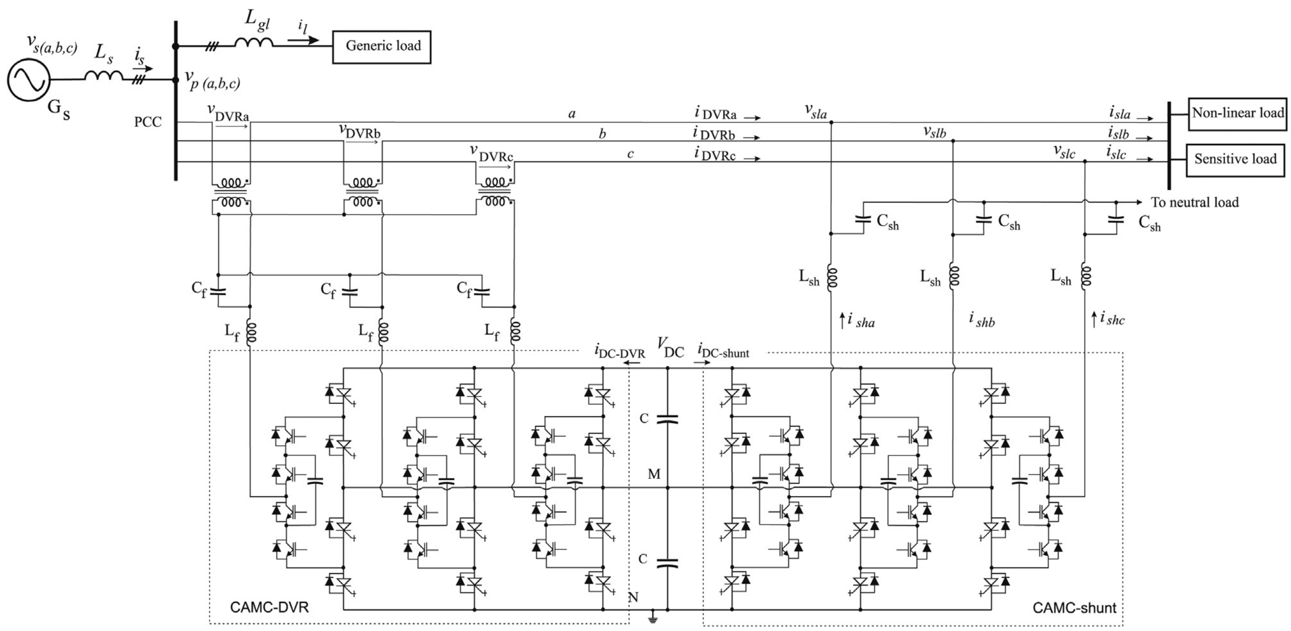

Fig. 1. A UPQC implemented with two back-to-back CAMCs.

(b) major amount of capacitors are necessary, (c) they required complex assembly and (d) they use sophisticated modulation strategies to keep the voltages balance on the capacitors. So, UPQCs implemented with DC-MVSI or FC-MVSI have been limited to three or four voltage levels [15]. Other topologies like hybrid multilevel converters (HMC) offer the possibility to increase the number of voltage levels without a proportional increment of the number of components [23]. But this topology cannot be used in a back-to-back connection.

In this paper two 5-levels Cascaded Asymmetric Multilevel Converters (CAMC) are proposed to implement a UPQC. The CAMC has the properties of the hybrid multilevel converter and in addition it can be used in back-to-back connection. This converter, which is built as the cascade of two different topologies together with a hybrid modulation strategy, allows to obtain five voltage levels with a reduce number of components and reduce control complexity [24]. This proposal is a good alternative to develop a MVSI-UPQC because it generates 5-levels phase voltages with a simple modulation scheme.

The CAMC has already been applied as DSTATCOM custom power [25] and dynamic voltage restorer (DVR) application [26]. The behavior of the CAMC-UPQC to protect a sensitive and non-linear load in front of disturbances introduced on a grid weak will be analyzed in this paper. In order to obtain good results, the CAMC-UPQC should manage different amounts of energy depending on the control strategies [9,27,28]. The most effective strategy to mitigate disturbance is exchanging active and reactive power [8,29]. In this way, it is possible to obtain with the CAMC-UPQC high dynamic range in amplitude as well as in phase, to compensate any sag and swell disturbances. On the other hand the control designed is adjusted completely with the hybrid modulation schemes of either CAMC converters. Therefore any control strategy described in the literature [8,30,31] can be used in this topology. So in this paper a control strategy dealing with both active a reactive power exchange is used.

The paper is organized as follows. The distribution power system under study and the control objectives are described in Section 2. In Section 3 a brief description of the CAMC and the dynamic model of the CAMC in a synchronous reference frame to be employed in the design of the series and shunt controllers are presented. The current control loops for the CAMC-shunt and CAMC-DVR in synchronous frame are designed in Section 4. The UPQC and its control are tested and discussed in Section 5. Finally, the conclusions are presented in Section 6.

2. Power system and UPQC

2.1. System description

The power system at 13.8 kV under consideration to study the CAMC-UPQC is shown in Fig. 1. The MV weak grid is depicted by a source generator (G_S) associated with an inductance (L_S). Two loads are connected at the point of common coupling (PCC), one of these is a generic load which causes voltage disturbances, and the second one is a sensitive load composed by a linear load and a non linear load.

The CAMC connected to left is CAMC-DVR through a coupling voltage transformer, while the CAMC connected to right is a CAMC-shunt. Both low-pass filters are implemented on the output of each CAMC to reduce the high frequency voltage ripple. The inductor L_{sh} is designed to control the amplitudes of the reactive and harmonic currents, handled by the CAMC-shunt [11].

In order to analyze the control objective of the UPQC, the power system can be simplified in a single-line representation as presented in Fig. 2. The CAMC-DVR is represented by a voltage generator (v'_C) in series with the inductance L'_C and the resistance R'_C. L'_C equals the transformer leakage inductance plus L_f and R'_C represents the losses of the coupling and the CAMC-DVR, both parameters are reflected at the primary side of the transformer. On the other hand, the CAMC-shunt is represented by a sinusoidal voltage generator (v_{sh}) coupled to the line through L_{sh}. The losses of this converter are neglected at this stage to simplify the analysis.

2.2. The control objectives of the UPQC

According to Fig. 2 the v_{DVR} is the difference between the load voltage (v_{sl}) and the voltage at the PCC (v_p),

$$v_{DVR} = v_{sl} - v_p \quad (1)$$