Electric Power Systems Research 80 (2010) 1413–1420

Contents lists available at ScienceDirect

Electric Power Systems Research

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

Compensation of voltage disturbances in distribution systems using single-phase dynamic voltage restorer

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A R T I C L E   I N F O

Article history:
Received 31 October 2009
Received in revised form 11 April 2010
Accepted 6 June 2010
Available online 3 July 2010

Keywords:
DVR
Voltage sags
Voltage swells
Harmonics elimination
Flicker
Single-phase direct converter

A B S T R A C T

In this paper, a new topology is proposed for a single-phase dynamic voltage restorer (DVR) using direct ac/ac converter. This topology does not require dc-link energy storage elements. The proposed topology has a simple structure and can compensate several types of voltage disturbances such as voltage sags, swells, harmonics and flickers. This topology will not face any problem in long time compensation due to the fact that it provides the required energy directly through grid. The proposed topology can be easily extended to *n*-phase systems such as three-phase based on the same principle of the operation. In *n*-phase systems, the voltage sags and swells can be properly compensated regardless of the balanced or unbalanced operation. A new control method is also proposed for direct ac/ac converter in the proposed topology. The simulation and experimental results verify the effectiveness of the proposed topology and its control method in voltage restoration.

1. Introduction

Recently, an increased number of sensitive loads have been integrated in electrical power systems. Consequently, the demand for high power quality and voltage stability has been increased significantly [1]. DVR is a series custom power device intended to protect sensitive loads from the effects of voltage disturbances such as voltage sags and swells at the point of common coupling (PCC). A typical location in a distribution system and the principle operation of DVR is shown in Fig. 1 [2]. As Fig. 1 shows, DVR essentially consists of a series-connected injection transformer, a voltage source inverter, inverter output filter and an energy storage device connected to the dc-link.

The basic operation of DVR is to inject a voltage of the required magnitude, phase angle and frequency in series with distribution feeder to maintain the desired amplitude and waveform for load voltage even when the voltage is unbalanced or distorted [3–6].

Many topologies and control methods have been presented for DVRs. The presented topologies are categorized into two main groups. The first group of the presented topologies uses ac/dc/ac conversion. In these topologies, the required dc voltage is provided through a transformer from the grid (source side or load side) via a rectifier. In the second group of the presented topologies for DVRs, the required energy for compensation of voltage is taken from the dc capacitor or another energy storage element such as double-layer capacitor, super conducting magnet or lead-acid battery via an inverter [7]. In both groups of topologies, it is necessary to embed a large capacitor in dc-link. The cost of this dc-link capacitor is high and it results in high cost and limited applications of DVRs [1]. There has been less attention to topologies of DVR that do not require any energy storage element. In [8], a zero energy sag corrector topology has been presented which is able to compensate both balanced and unbalanced voltage sags without using a capacitor. This given topology is not able to compensate voltage swells and its ability of harmonics mitigation has not been investigated. In [9], a topology for single-phase DVR has been presented which uses direct ac/ac converter and as a result, it does not require any dc-link. In this topology, the compensation ranges are restricted to 25% and 50% for voltage sags and swells, respectively. In [10], a voltage regulator which uses direct ac/ac conversion and can compensate voltage sags has been presented. The control method of this topology is based on measuring and calculating of the RMS value. According to the fact that RMS calculation requires at least half of cycle time interval. So, at least in the first and in the last half of cycles of the duration of disturbance, the compensator cannot have a proper operation. In [11], a topology for a three-phase DVR has been presented which uses indirect matrix converter. This topology possesses flywheel energy storage. But, the ability of this topology in compensation of harmonics, voltage swells and unbal-

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doi:10.1016/j.epsr.2010.06.003

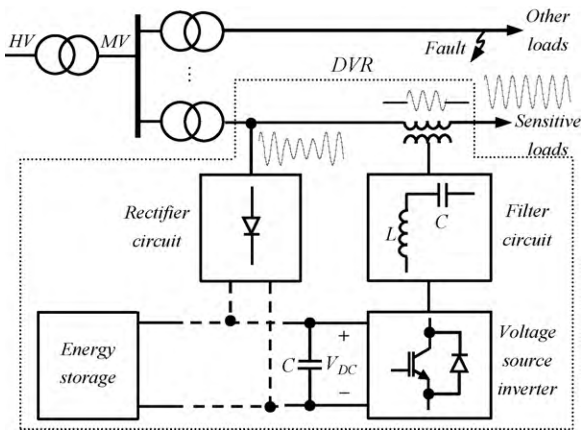

Fig. 1. A typical location and principle operation of DVR.

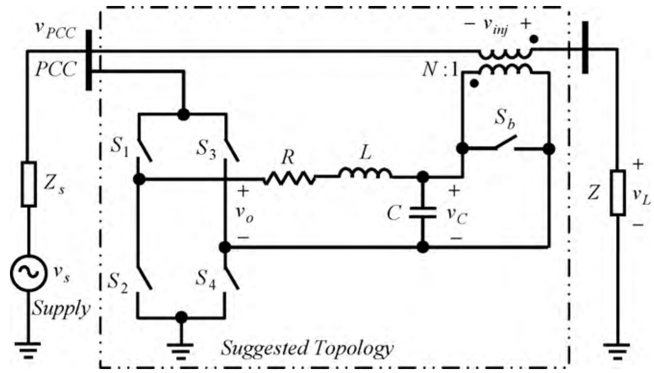

Fig. 2. Proposed topology.

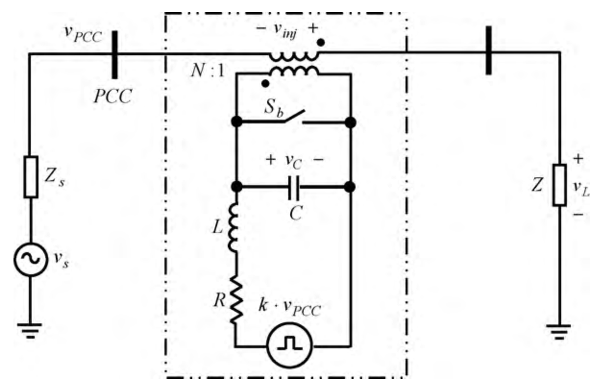

Fig. 3. Simplified model of the proposed DVR.

anced voltage sags has not been investigated. A high voltage DVR using multilevel topology with isolated dc energy storage has been presented in [12,13].

In this paper, a new topology is presented for a single-phase DVR which is able to compensate several types of disturbances such as voltage sags, swells, harmonics and flickers without using any dc-link. Then, a new control method is presented for used ac/ac single-phase converter. The simulation and experimental results verify the performances of the proposed DVR and its control method in voltage restoration.

2. Proposed topology

Fig. 2 shows the topology of the proposed DVR. The proposed topology consists of a single-phase direct ac/ac converter, an LC low-pass filter with damping resistor, R, an injection transformer with a turn ratio of N:1 (N for filter side) and a bypass switch. The principle operation of the proposed DVR can be described in Fig. 3. The output voltage of the converter (v_o) is defined by $k \cdot v_{\mathrm{PCC}}$ (v_{PCC} is the PCC voltage) where $k = -1, 0, 1$. This voltage is passed through the LC low-pass filter in a way that the generated harmonics by switching are filtered out. As a result, a sinusoidal voltage across the injection transformer is generated. The injection transformer is used to isolate the distribution system and the DVR. The load is rep-

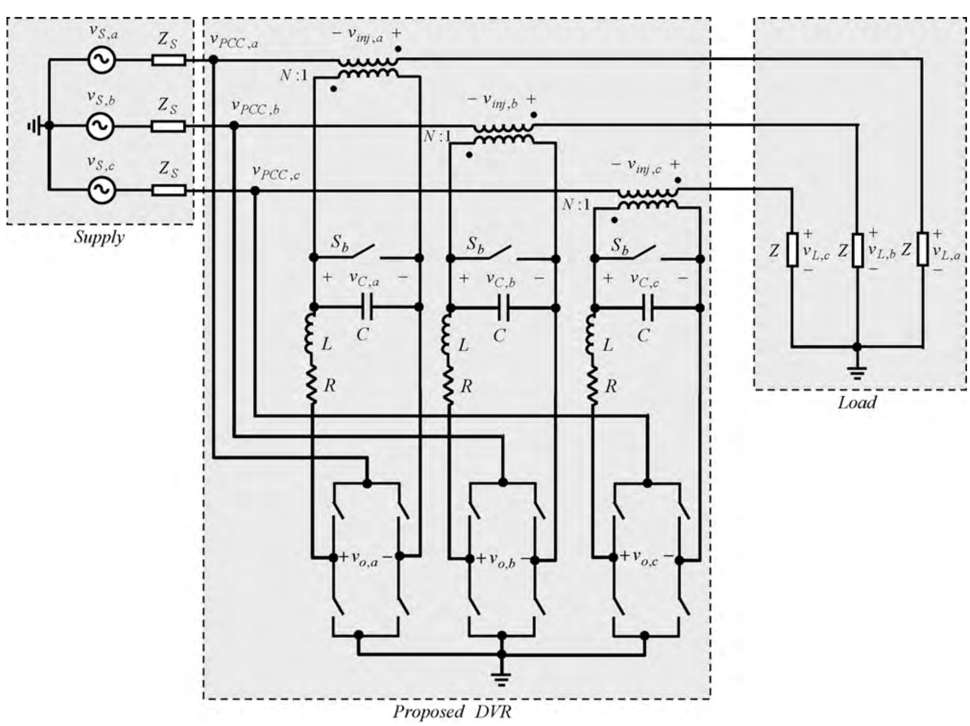

Fig. 4. Three-phase DVR based on the proposed single-phase units.