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Review

A comprehensive review of dynamic voltage restorers

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ABSTRACT

During the last half century the Power Quality (PQ) related problems have become important issues. Many solutions have been proposed to address the PQ problems. The most attractive and flexible way is to use power electronic converter based devices such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (DSTATCOM), Unified Power Quality Conditioner (UPQC), Uninterruptible Power Supply (UPS), and other devices usually called custom power devices. Among custom power devices, the DVR is the most economical solution to overcome the voltage-related PQ problems. Intensive research has been done in the field of DVR and the field is rather mature now. But, a survey on the published papers showed that there is not any published paper that reviews the DVR technology. This paper tends to provide a comprehensive review on the DVR topologies, control strategies and applications. We will consider all of the fast voltage compensators, i.e. the devices called Static Series Compensator (SSC), sag corrector, Dynamic Sag Corrector (DySC), and other similar devices are also considered. All of these devices will be called DVR since they operate almost in the same way. Some comparative conclusions are also provided. This paper can be beneficial for the researchers and engineers, who want to do investigations on DVRs.

Contents

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1. Introduction

The number of sensitive and critical loads has increased during the past decades; on the other hand, the number of equipments that worsen the Power Quality (PQ) has also increased. Therefore, PQ has become more and more important. Poor PQ results in financial losses, productivity reduction and data loss. Among the PQ issues, the problems related to the voltage are more important from the view point of sensitive loads and customers. The PQ problems related to voltage mainly include voltage sags, voltage swells, voltage harmonics, fluctuations (flickers), interruptions, and unbalance [1–4].

According to the standards IEEE 1346 [5] and IEEE 1159 [6], a voltage sag is defined as a decrease in the RMS ac voltage (10–90% of the nominal voltage), at the power frequency of duration from 0.5 cycles to one minute. Also according to the standard IEC 61000-2-1 [7], a voltage sag (voltage dip) is a sudden reduction of the voltage at a point in the electrical system, followed by a voltage recover after a short period of time, from half a cycle to a few seconds. Voltage sag is normally caused by short circuit faults such as a single-line to ground fault in power system, by the startup of induction motors of large ratings, and by sudden large load connections. In the mentioned IEEE standards, a voltage swell is defined as an increase in RMS supply voltage increase from 1.1 pu to 1.8 pu of nominal voltage the duration of which is between 0.5 cycles to one minute. The main causes of voltage swells are switching the large capacitors or disconnecting large loads. Voltage swells can cause overheating, tripping or even destruction of industrial equipment such as motor drives, surge arresters and relays [8,9]. Harmonic contamination has become a problem for sensitive loads. The electronic equipment is a very sensitive load against harmonics, because their control depends on either the peak value or the zero crossing of the supplied voltage, which are influenced by the harmonic distortion [10].

To prevent from the effects of voltage disturbances on the sensitive loads, different solutions are available. The most effective and flexible solution is to use power electronic devices as compensators. These compensators include series and parallel and series-parallel compensators which are called custom power devices [11,12]. The series compensators such as Static Series Compensator (SCC), Dynamic Voltage Compensator (DVC) and Dynamic Voltage Restorers (DVR) are considered to be the most economical solutions to compensate voltage in distribution systems. Although, the control strategies and purposes of these compensators may differ from each other, but their operation principle and power circuit architecture are the same. However, the name DVR is mostly used for a series compensator, which compensates the voltage sags/swells.

A DVR is a power-electronic converter-based device that has been designed to protect critical loads from supply-side voltage disturbances. It is connected in series with a distribution feeder and is capable of generating or absorbing real and reactive power at its ac terminals [13]. The first DVR built by Westinghouse for EPRI was installed in August 1996 on the Duke Power Company (North Carolina) 12.47 kV system [14].

DVRs and dynamic sag correctors have attracted more attention than other power quality compensators since they offer an economic solution to cope with voltage sags which are the most common and severe voltage disturbances [15,16]. Many different topologies and control strategies have been presented for DVRs to achieve higher performance with lower cost. Although the field of DVR system is rather mature now, the authors are unaware of any published paper on the comprehensive review of the DVR systems. However some papers have presented general discussions on the topologies and control methods of the DVRs [17–20].

In this paper a review of DVR systems is given. The review includes the hardware topology, control strategies and the applications of DVRs. The rest of the paper is organized as follows. Sections 2 and 3 describe the operation principle and components of a DVR. Section 4 reviews the hardware topologies of DVRs from the view point of both overall architecture of DVRs and the converter that is used in the DVR structure. In Section 5 the control strategies that are commonly used in the DVR will be reviewed. The operation range of DVR is calculated in Section 6. Section 7 describes the possible applications of the DVRs. Special studies on DVR are presented in Section 8.

2. Principle of operation

2.1. Configuration

A typical DVR structure is shown in Fig. 1 [20,21]. As this figure shows, a typical DVR system includes a converter, a DC-link, a low pass LC filter and an injection transformer. As the figure indicates, the ways to provide the power required by DVR can be different resulting in different DVR system configurations. This will be discussed in details in the rest of the paper. It should be noted that some topologies use AC-AC converter instead of the VSI and hence the DC-link is eliminated in these topologies.

2.2. Equivalent circuit

Fig. 2 shows the equivalent circuit of the DVR system. DVR can be assumed as a series controllable voltage source with a series impedance branch. In this equivalent circuit, the effects of the harmonics are neglected. Also, all of the quantities are reflected to the grid side of the injection transformer. The voltage injected by the DVR is controllable in magnitude, phase angle and frequency so that several voltage disturbances can be compensated including voltage sags, voltage swells, voltage harmonics, and voltage flicker. When the source voltage encounters an abnormal condition, the DVR injects a proper voltage in series with the source to protect the critical load from the grid side disturbances. In Fig. 2, the grid voltage, the DVR output voltage (injected to the grid), and the load voltage are indicated by v_G, v_D, and v_L, respectively. Also the grid Thevenin voltage and impedance from the installation point of the DVR are denoted by v_S, and Z_G, respectively. The fundamental component of the converter output voltage is shown by v_C.