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Voltage sag mitigation in an Indian distribution system using dynamic voltage restorer

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ABSTRACT

Now a day's most power quality problems in distribution systems are related to voltage sags. Hence, diverse solutions have been tried to compensate these voltage sags to circumvent financial losses due to voltage sag at industries. Dynamic voltage restorers (DVRs) are now becoming more recognized in industries to diminish the impact of voltage sags to sensitive loads. The DVR, which is placed in series with a sensitive load, must be able to react speedily to a voltage sag if end users of sensitive equipment are to experience no voltage sags. This paper discusses the use of series reactive injection as a voltage regulator. The proposed approach is to develop analytical aspects and to illustrate these by an example of a real Indian distribution system. Voltage sag can be eliminated by continuously injecting very small voltage profile to the system. The scheme combines the method of instantaneous symmetrical components and complex Fourier transform relations. The proposed technique, based on half-cycle averaging, can mitigate voltage sag at desired locations in distribution systems. The proposed methodology is applied in a 4 bus system and a real Indian distribution system.

Introduction

Power quality (PQ) is becoming critical importance for power industry. Poor quality of power is recognized due to the various power line disturbances like voltage sag, swell, harmonics, etc. Recent failure statistics have confirmed that voltage sags represent the most common type of disturbance in the power grid [1–3]. Voltage sag refers to a momentary decrease (0.5–1 min) in RMS voltage between 0.1 and 0.9 p. u at the power frequency. Voltage sag can cause the malfunction of voltage-sensitive loads in factories, buildings, and hospitals [4] and severe process disruptions resulting in substantial economic and/or data losses [5,6]. Voltage sags are characterized by magnitude of sag, phase angle jump, and duration of sag. The need for better power quality has encouraged the end users to install power conditioning equipment to mitigate voltage sags. There are literature that analyze the potential for using classical DC–DC converters as direct AC/AC converters for sag and swell correction. However, their ability to correct deep, asymmetrical sags is limited [7–11]. Therefore, various devices such as DVR, distribution static compensator (STATCOM), flywheel, uninterruptable power supplies (UPS) and tap changing transformers are used to address voltage sags problems [12]. The first DVR was installed in North Carolina, for the rug manufacturing industry [13]. Another was installed to provide service to a large dairy food processing plant in Australia [14].The basic operation of DVR is to inject a voltage of required magnitude, phase angle, and frequency in series with a distribution feeder to maintain the desired amplitude and waveform for load voltage even when the voltage is unbalanced or distorted. DVR is usually built using a DC–AC power converter that is connected in series with a distribution line through three single phase transformers. The DC side of the converter is connected to a DC energy-storage device. The energy state of the device is regulated by taking power from the feeder [15]. Many topologies and control methods have been presented for DVRs. The presented topologies are categorized into two main groups. 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 [16]. In both groups of topologies (AC/DC/AC converter based or the energy storage based topologies), it is necessary to embed a large capacitor in DC-link. The cost of DC-link capacitor is high and it results in high cost and limited applications of DVR [17]. The traditional voltage sag compensator, which is a dynamic voltage

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restorer based on energy storage device with a series-connected voltage-source inverter, is not adequate for compensating deep and long-duration voltage sags. As per the sensitive load concern, deep and long-duration voltage sag are more vulnerable than shallow and short-duration voltage sag. Power quality improvement for larger distribution system using DVR is not reported in previous literature. In this paper, voltage sag mitigation using DVR consist of AC–DC–AC converter, filter, phase angle regulator, tap changing transformer in a special arrangement such that all operation is done by the single unit consist of tap changing transformer, phase angle regulator (PAR) and quadrature booster (QB). Placement of DVR is based on the maximum voltage sag occurrence on a bus in the system. The proposed methodology of DVR will be able to mitigate voltage sag smoothly. The proposed methodologies is applied in 4 bus system and a real Indian distribution systems.

Proposed DVR structure

Many topologies and control methods have been presented for DVRs in the literature. The presented topologies are categorized into two main groups. The first group of the presented topologies uses AC/DC/AC conversion i.e., first rectifier, then capacitor and inverter. The second group of presented topology is DC/AC conversion i.e., inverter operation. The second group of topology is rarely used, because for large voltage sag, only capacitor bank is not capable of supply the required reactive power at the instant of very deep voltage sag i.e., <0.5 p.u. For charging the capacitor external source is not provided therefore the first group of topology is preferred. The cost of the energy storing device is mostly very high. In the proposed method the DVR consist of AC–DC–AC converter, filter, phase angle regulator, tap changing transformer as shown in Fig. 1.

The AC–DC–AC converter, converts AC (taken from the grid) to DC signal in the first stage, then by doing proper switching operation we get reduced magnitude AC at the output. This output voltage of the converter pass through the low pass filter in such a way that the generated harmonics by switching are filtered out. As a result pure sinusoidal voltage is appeared across the primary of the tap changing transformer. The tap changing transformer is used to reduce the voltage magnitude for smooth operation. The output from the tap-changing transformer is fed to the PAR to generate the required phase angle (the angle must be same with the phase angle of the current following in the branch). For phase advance compensation, the voltage in advance with the line current is to be injected, and then it is added with the source voltage. Phase advance operation is done by the Quadrature booster, and finally the voltage is injected to the line by the transformer having 1:1 turn's ratio. This transformer isolate the DVR from the line.

If we use individual device like PAR, tap-changing transformer and QB for specific operation, the whole arrangement will become very costly (two transformers are used), will result more voltage drop and chance of change in phase angle. Therefore in this paper a special type of arrangement is proposed where all operation is done by the single unit and overcome the above problem. The simplified schematic diagram of proposed structure of DVR is shown in Fig. 2.

It has two stage of operation, in the first stage rectifier operation and in the second stage inverter operation. It does not require any external charging device. The storing device is charged through the grid supply. It can capable of producing any range of voltage, by proper selection of the firing angle.

The line-filter is inserted to reduce the switching harmonics generated by the AC–DC–AC Voltage source converter (VSC). The used filter on the output of the converter is a passive LC filter with damping resistor. In order to design this filter, following assumptions have been considered.

1. The resonant frequency of the filter has been assumed to be about 10 times larger than the fundamental frequency of the grid.
2. The voltage drop of the fundamental component has been considered less than 5%.
3. The generated angle difference in the filter has been considered to be less than 0.1 rad.

For the fundamental component, $L = 8\ \text{mH}$, $C = 11\ \mu\text{F}$ and $R = 0.1\ \Omega$ have been considered for filter design. Phase angle regulator is used for generating the required phase angle, and that phase angle must be same as that of the phase angle of current flowing in the branch. By special arrangement of the transformer connection, we get the 90° phase lag which is necessary for phase advance compensation. This Compensation technique is injecting reactive component only. We have to make the DVR voltage such that, it is in quadrature with the current. Tap changing transformers are used to reduce the converter output voltage magnitude to smallest possible range. The tap of the transformers are fixed during the operation.

Control scheme

It is important to calculate the steady state quantities using half cycle average method for extraction of sinusoidal symmetrical components [15]. Let V_{sa}, V_{sb} and V_{sc} be the three instantaneous source bus voltage, Similarly current i_a, i_b and i_c are the three phase instantaneous current. The power invariant instantaneous symmetrical component are defined by

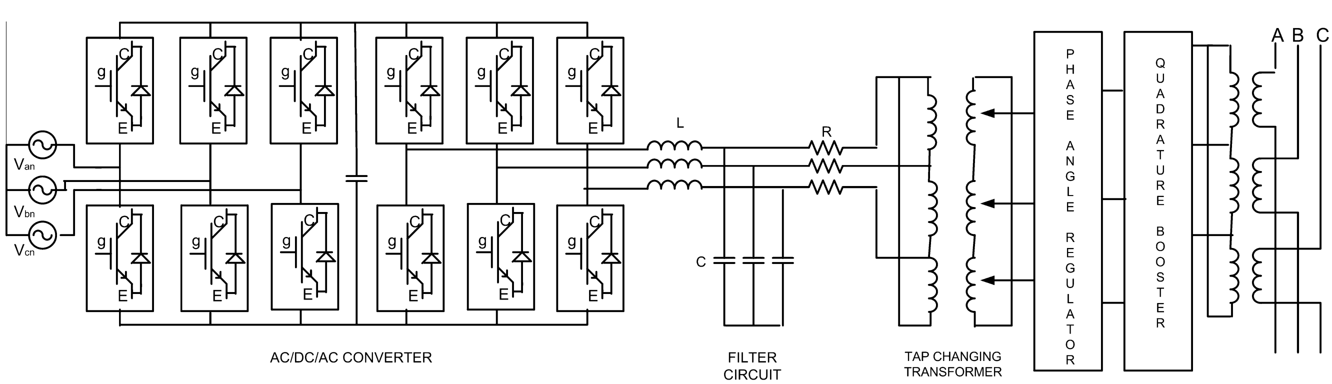

Fig. 1. Schematic diagram of proposed structure of DVR.