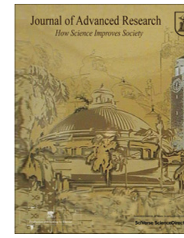
Journal of Advanced Research (2016) 7, 95–103

Cairo University

Journal of Advanced Research



ORIGINAL ARTICLE

Power conditioning using dynamic voltage restorers under different voltage sag types

Ahmed M. Saeed [a], Shady H.E. Abdel Aleem [b,*], Ahmed M. Ibrahim [a], Murat E. Balci [c], Essam E.A. El-Zahab [a]

[a] *Electrical Power and Machines Engineering, Cairo University, Giza 12613, Egypt*
[b] *Mathematical, Physical and Life Sciences, 15th of May Higher Institute of Engineering, 15th of May City, Cairo, Egypt*
[c] *Electrical and Electronics Engineering, Balikesir University, Balikesir, Turkey*

A R T I C L E I N F O

Article history:
Received 13 December 2014
Received in revised form 13 February 2015
Accepted 2 March 2015
Available online 6 March 2015

Keywords:
Dynamic voltage restorers
Faults
Power conditioners
Power quality
Power system harmonics
Unbalanced conditions

A B S T R A C T

Voltage sags can be symmetrical or unsymmetrical depending on the causes of the sag. At the present time, one of the most common procedures for mitigating voltage sags is by the use of dynamic voltage restorers (DVRs). By definition, a DVR is a controlled voltage source inserted between the network and a sensitive load through a booster transformer injecting voltage into the network in order to correct any disturbance affecting a sensitive load voltage. In this paper, modelling of DVR for voltage correction using MatLab software is presented. The performance of the device under different voltage sag types is described, where the voltage sag types are introduced using the different types of short-circuit faults included in the environment of the MatLab/Simulink package. The robustness of the proposed device is evaluated using the common voltage sag indices, while taking into account voltage and current unbalance percentages, where maintaining the total harmonic distortion percentage of the load voltage within a specified range is desired. Finally, several simulation results are shown in order to highlight that the DVR is capable of effective correction of the voltage sag while minimizing the grid voltage unbalance and distortion, regardless of the fault type.

Introduction

Recently, much attention has been focused on the power quality domain in power system networks. Power quality measures the fitness of electric power transmitted from the utilities to the different consumers in the case of the conventional centralized generation or in some cases from the consumers to the utilities in the case of distributed generation. Voltage distortion that may occur due to power system harmonics and voltage sags is widely recognized as the most severe issue affecting power quality, because it affects both the utility company and consumers alike. Nonlinear loads create voltage and current harmonics which may have detrimental effects on consumers' equipment [1–3].

IEEE Standard 1159-1995 defines voltage sags as a root-mean-square (rms) variation with a magnitude between 10% and 90% of nominal voltage and duration typically ranging from a few milliseconds to sixty seconds [4]. Voltage sag takes

* Corresponding author. Tel.: +20 1227567489; fax: +20 25519101.
E-mail address: engyshady@ieee.org (S.H.E. Abdel Aleem).
Peer review under responsibility of Cairo University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jare.2015.03.001
2090-1232

place at nearby feeders with a detrimental feeder subjected to one of the causes of voltage sag. Short circuits due to faults in the power system structure, lightning strokes, high starting currents of induction motors, and inrush currents are the common causes of voltage sags [5]. Voltage sags can be symmetrical or unsymmetrical depending on the causes of the sag. If the individual phase voltages are equal and the phase relationship is 120 degrees, the sag is symmetrical. Otherwise, the sag is unsymmetrical. A three-phase short-circuit fault can produce symmetrical sags. Single line-to-ground, phase-to-phase, or two phase-to-ground faults due to lightning, animals, accidents, and other causes, as well as energizing of large transformers, can cause unsymmetrical sags [6].

A power conditioner is a device proposed to enhance the quality of the power that is delivered to a sensitive electrical load. In addition, it can be defined as a device that acts on delivery of a voltage of the appropriate level and characteristics to facilitate the effective utilization of critical loads. At the present time, one of the power conditioners most commonly used to mitigate voltage sags is the dynamic voltage restorer (DVR). By definition, a DVR is a controlled voltage source inserted between the network and a sensitive load through a transformer injecting voltage into the network in order to correct any disturbance affecting the sensitive load voltage [2,5]. More functions can be included with the DVR such as reactive power compensation, harmonics mitigation, and fault current limitations.

DVRs' controllers have an important effect on the system dynamic response, stability and steady-state accuracy [7–14]. In the literature, there are many types of controllers that can be used in the DVR compensation practice, such as feedback and feed-forward [8], double-vector [9], proportional and integral (PI) [10], fuzzy and adaptive PI-fuzzy controllers [11,12], which are widely used in low-voltage small capacity DVR applications. Recently, a novel software phase-locked loop (SPLL) is proposed by combining the advantages of least-error-squares (LES) filters and the instantaneous symmetrical components method, which has a fast phase-lock tracking ability and guarantees no data fluctuation of the sag detection algorithm under non-sinusoidal conditions [13]. Additionally, a new strategy with the positive and the negative sequence extractions (PNSE) from the fundamental and the higher distorted harmonic orders is proposed [14], which improves the dynamic response of the DVR with an accurate steady-state compensation. Despite the valuable development added by such novel algorithms, they are mainly dedicated to high/medium-voltage applications which need large capacity dynamic voltage restorers with enhanced capability controllers, especially for the utilities that have complex non-typical industrial consumers and may considerably suffer from parameters uncertainty and/or wide range of operation circumstances, such as the grids integrated with large-scale wind and/or solar power resources.

In this paper, modelling of a DVR using PI controller for voltage correction using MatLab software is presented. The pre-sag compensation method has been used as the control strategy to maintain the voltage at the terminals of a sensitive load at its rated value. In other words, the voltage injected by the DVR will be the difference between the voltage at the point of common coupling before and during the sag [2,5].

The performance of the device under different voltage sag types is described, where the voltage sag types are introduced using the different types of short-circuit faults included in the environment of the MatLab/Simulink package. The robustness of the proposed device is evaluated using the common voltage sag indices described in [15] and the voltage and current unbalance percentages given in [16], where maintenance of the total harmonic distortion percentage of the load voltage in a specified range complying with IEEE Standard 519-1992 is desired [17]. Finally, several simulation results are shown in order to highlight the viability of the proposed device.

The proposed methodology

Dynamic voltage restorer

A dynamic voltage restorer is a solid-state power electronic switching device which is connected in series to the load voltage bus in order to inject a dynamically controlled voltage. This voltage can remove any detrimental effects of a bus fault on a sensitive load voltage.

Fig. 1 shows a schematic diagram of a typical DVR structure which is used for voltage recovery. It consists of the following units:

(i) Energy storage unit: This is DC storage energy with a proper capacity which supplies the DVR during compensation by the required real power. It can be simply a capacitor or a battery. Recently, super capacitors, fly wheels, and super-magnet conductors are emerging as energy storage devices with a fast response. Unfortunately, difficult maintenance and the high cost of these facilities compared with conventional facilities have been noted in the power quality markets, delaying their widespread deployment in a broad sense.

(ii) Injection transformer: The DVR transfers the voltage which is required for the compensation from the voltage source converter to the distribution network through the injection transformer [18]. The high voltage side is normally connected in series with the distribution network while its low voltage side is connected to the power circuit of the DVR.

(iii) Voltage source converter (VSC): This is a power electronic configuration which is used to generate a sinusoidal voltage with the required magnitude, phase, and frequency. Its dc input is the energy storage unit.

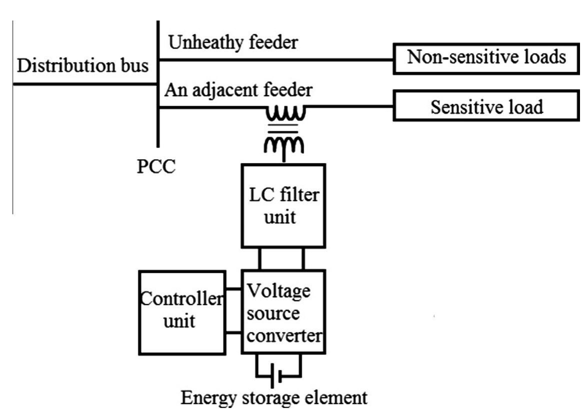


Fig. 1 Schematic diagram of a typical DVR structure.