

Application of Dynamic Voltage Restorer for Voltage Balancing with ASD Load Using DQO Transformation

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Abstract

Dynamic voltage restorer has been considered the very effective solution for the mitigation of voltage sags and swells in the distribution network. DVR has other added features such as harmonics and power factor correction capability due to which it has gained a widespread importance. In this paper, the effectiveness of dynamic voltage restorer for voltage balancing is presented. The dqo based control algorithm is considered. The system is connected to the adjustable speed drive load. The MATLAB/Simulink demonstrates the validity and superiority of proposed control strategy during various voltage unbalancing conditions on low voltage distribution system.

Index Terms: Adjustable speed drive (ASD), custom power, dynamic voltage restorer (DVR), power quality.

Introduction

Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage [1, 4]. With the increasing developments in power electronics and the modern microprocessor based loads, the need of quality in power is felt. Several steps have been taken to compensate for the fluctuations observed on the distribution networks in order to ensure highest possible power quality for the customers.

Power quality problem: “Any power problem manifested in voltage, current, or frequency deviations that result in the failure or misoperation of customer equipment” [2]. Power quality problems are associated with power systems with broad ranges of time frames such as long duration variations, short duration variations and other disturbances.

Fig. 1 describes the demarcation of the various power quality issues defined by IEEE Std. 1159-1995[3].

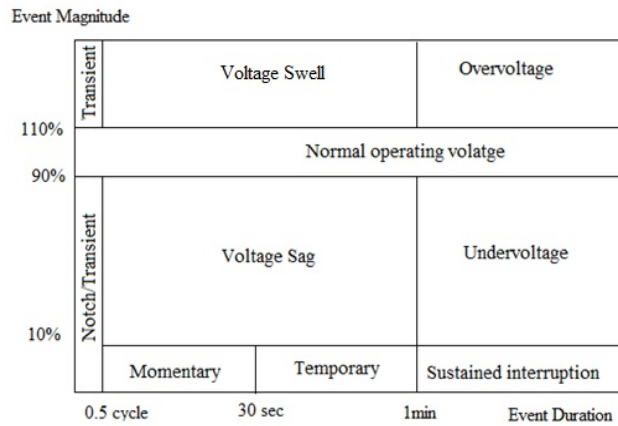


Figure 1: Definitions of events by IEEE Std.1159-1995.

Voltage sags can occur at any instant of time, with amplitudes ranging from 10 – 90% and a duration lasting for half a cycle to one minute [5]. Voltage swells are not as important as voltage sags because they are less common in distribution systems.

There are many different methods to mitigate voltage quality problems like voltage sags, swells or unbalancing in the line but the use of a custom Power device is considered to be the most efficient. Each of custom power devices has its own advantages and limitations. Dynamic Voltage Restorer is one of the most effective device for mitigation of voltage unbalancing problems.

There are numerous reasons why the DVR is preferred over the others. A few of these reasons are presented as follows. The DVR is preferred over SVC because the SVC has no ability to control active power flow [6]. Another reason is that the DVR is less costly and requires low maintenance as compared to the UPS. Also it has higher energy capacity and lower costs as compared to the SMES device. Furthermore, the DVR is smaller in size and costs less when compared to the DSTATCOM. Based on these reasons, the DVR is considered as an effective custom power device. DVR has other added features such as harmonics reduction and Power Factor correction capability. Compared to the other devices, the DVR clearly provides the best economic solution for its size and capabilities.

This paper, introduces DVR, its operating principles and structures. Meanwhile the application of DVR in power system network for balancing the voltage of three phase supply system with ASD as load is proposed.

Dynamic Voltage Restorer

Dynamic voltage restorer is a series connected power-electronic converter-based device with the distribution feeder to protect critical loads from all supply-side

disturbances other than outages. It can provide the most cost effective solution to mitigate voltage imbalance by establishing the proper voltage quality level that is required by customer. When a fault happens in a distribution network, sudden voltage sag will appear on adjacent loads. DVR installed on a sensitive load, restores the line voltage to its nominal value within the response time of a few milliseconds thus avoiding any power disruption to the load. The DVR works independently of the type of fault or any event that happens in the system, provided that the whole system remains connected to the supply grid.

The DVR has two modes of operation which are: standby mode and boost mode. In standby mode ($V_{DVR}=0$), the booster transformer's low voltage winding is shorted through the converter. No switching of semiconductors occurs in this mode of operation. The DVR will be most of the time in this mode. In boost mode ($V_{DVR}>0$), the DVR is injecting a compensation voltage through the booster transformer due to a detection of a supply voltage disturbance

The general configuration of the DVR consists of an Injection / Booster transformer, a Harmonic filter, a Voltage Source Converter (VSC), and a Control and Protection system as shown in fig 2.

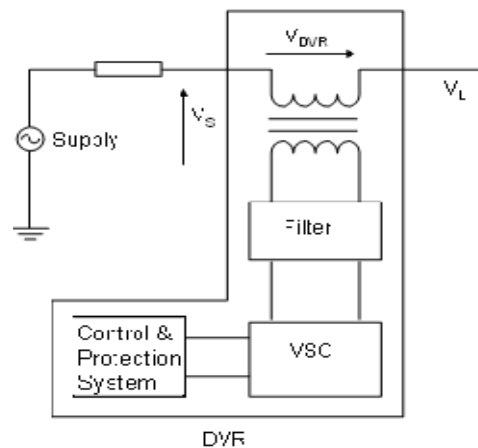


Figure 2: DVR series topology.

The Injection / Booster transformer

The Injection / Booster transformer is a specially designed transformer that attempts to limit the coupling of noise and transient energy from the primary side to the secondary side [7]. It connects the DVR to the distribution network via the HV-windings and transformers and couples the injected compensating voltages generated by the voltage source converters to the incoming supply voltage. In addition, the Injection / Booster transformer serves the purpose of isolating the load from the system.

Harmonic Filters

The main task of harmonic filter is to keep the harmonic voltage content generated by

the inverter within tolerable limits. These filters are placed at the high voltage side to avoid introductions in phase angle shift, which can disrupt the control algorithm [8].

Voltage Source Converter

A VSC is a power electronic system consisting of a storage device and switching devices, which can generate a sinusoidal voltage at any required frequency, magnitude, and phase angle. In the DVR application, the VSC is used to temporarily replace the supply voltage or to generate the part of the supply voltage which is missing.

Control and Protection System

The control mechanism of the general configuration typically consists of Digital Signal Processing (DSP) boards. The software on the DSP board provides the controls such as detection and correction. Filters are commonly used for these purposes [9].

Principle of Operation

The basic principle of a DVR is inserting a voltage of required magnitude and frequency so that the load-side voltage to the desired amplitude and waveform can be restored. Usually a DVR is connected to protect sensitive loads during faults in the supply system [11].

Fig. 3 [10] shows the equivalent circuit of the DVR. When the source voltage is drops or increases; the DVR injects a series voltage V_{inj} through the injection transformer so that the desired load voltage magnitude V_L can be maintained.

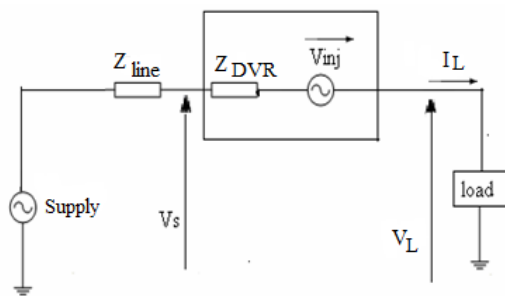


Figure 3: Equivalent circuit of DVR.

The series injected voltage V_{inj} of the DVR can be written as

$$V_{inj} = V_L + V_s \quad (1)$$

Where

V_L is the desired load voltage magnitude

V_s is the source voltage during sags/swells condition

The load current I_L is given by,

$$I_L = ((P_L \pm J*Q_L) / V_L) \quad (2)$$

Proposed Method

Main Circuit

Fig. 4 shows the configuration of the proposed DVR design using MATLAB/SIMULINK, where the outputs of a three-phase half-bridge inverter are connected to the utility supply via wye-open connected series transformer. With the occurrence of voltage disturbance, the inverter output can be steered in phase with the incoming ac source while the load is maintained constant with the aid of dqo transformation based control scheme. The output of inverter is installed with capacitors and inductors for the filtering scheme.

To evaluate the DVR and its operation in different situations, a system including a DVR, which is connected to the network, has been simulated in MATLAB/SIMULINK.

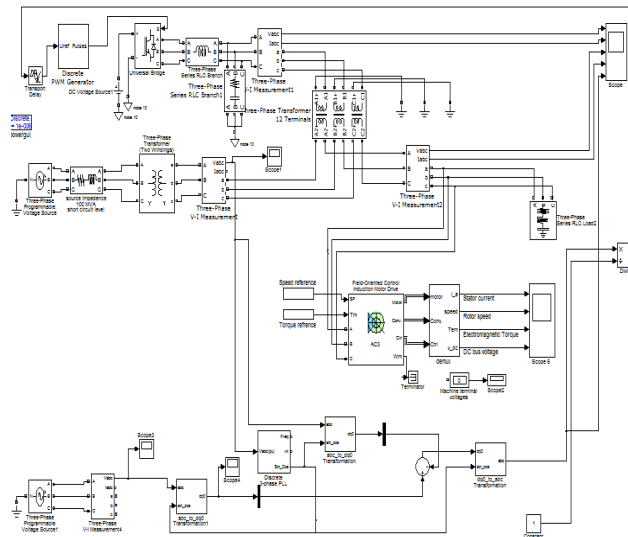


Figure 4: Proposed system configuration.

Control Algorithm

The dqo transformation or Park's transformation is used to control of DVR. The dqo method expresses the voltage error and phase shift information as instantaneous space vectors with start and end times. The voltage is converted from abc reference frame to d-q-o reference. For simplicity, zero phase sequence components is ignored.

The detection of error in voltage is carried out in each of the three phases. The control scheme for the proposed system is based on the comparison of a reference voltage and the measured terminal voltage (V_a , V_b , V_c). The error signal allows generation of a commutation pattern by means of the sinusoidal pulse width modulation technique (SPWM) [10].

The injection voltage is generated by difference between the reference load voltage and supply voltage and is applied to the VSC to produce the preferred voltage, with the help of pulse width modulation (PWM).

Fig 5 shows the basic control scheme and parameters that are measured for control purposes. The control algorithm produces a three phase reference voltage to the series converter that tries to maintain the load voltage at its reference value. The d-reference component is set to a rated voltage and the q-reference components are set to zero [11].

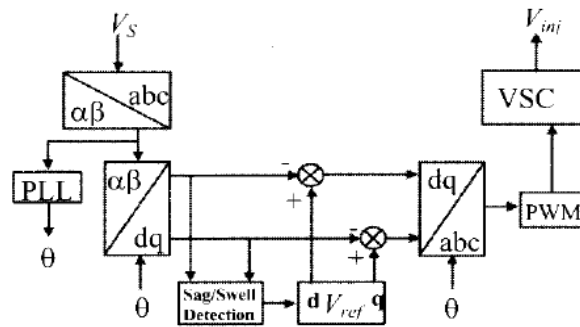


Figure 5: Control structure of DVR [11].

Equation (3) defines the transformation from three phase system a, b, c to dqo stationary frame. The theta (θ) is defined by the angle between phase A to the d-axis phase. A is aligned to the d-axis that is in quadrature with the q-axis.

$$\begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta - \frac{2\pi}{3}) & 1 \\ -\sin(\theta) & -\sin(\theta - \frac{2\pi}{3}) & 1 \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (3)$$

Simulation and Results

Analysis of the influence of induction motor loads on the mitigation ability of the DVR has been performed by simulation studies using MATLAB/SIMULINK. The system parameters and constant values and adjustable speed drive parameters are listed in Table I and Table II respectively. It is assumed that the voltage magnitude of the load bus is maintained at 1 pu during the period of unbalanced voltage.

Table I: system parameters and constant values

System Parameters	
Main Supply Voltage Per Phase	200 V
Line Impedance	Ls = 0.5 mH Rs = 0.1 Ω
Series Transformer Turns Ratio	1:1
Dc Bus Voltage	300 V
Filter Inductance	1mH
Filter Capacitance	1 μ F
Line Frequency	50 Hz
Load Resistance	40 Ω
Load Inductance	60mH
Carrier Frequency of PWM	1080 Hz

Table II: Field-Oriented Control Induction Motor Drive Parameters Referred To Rotor.

Motor Parameters	
Rated Power	2238VA
Rated Voltage	440Vrms
Frequency	50Hz
Combined Rotor and Load Inertia	0.089 kg.m ²
Stator Resistance	0.435 Ω
Stator Reactance	2 mH
Rotor Resistance	0.816 Ω
Rotor Reactance	2 mH
Magnetizing Inductance	69.31mH
Pair of Poles	2
Shaft Mechanical Torque	2Nm

The results of the simulation conducted in MATLAB considering different conditions are represented in this paper.

In first case, the supply voltage of one phase is increased by 12.5%. The DVR compensates the voltage and thus balanced voltage is available at load. The results of simulation are as shown in fig 6. The comparison of FFT analysis depicts the vast improvement in total harmonic distortion on the load side of the system which is connected to DVR.

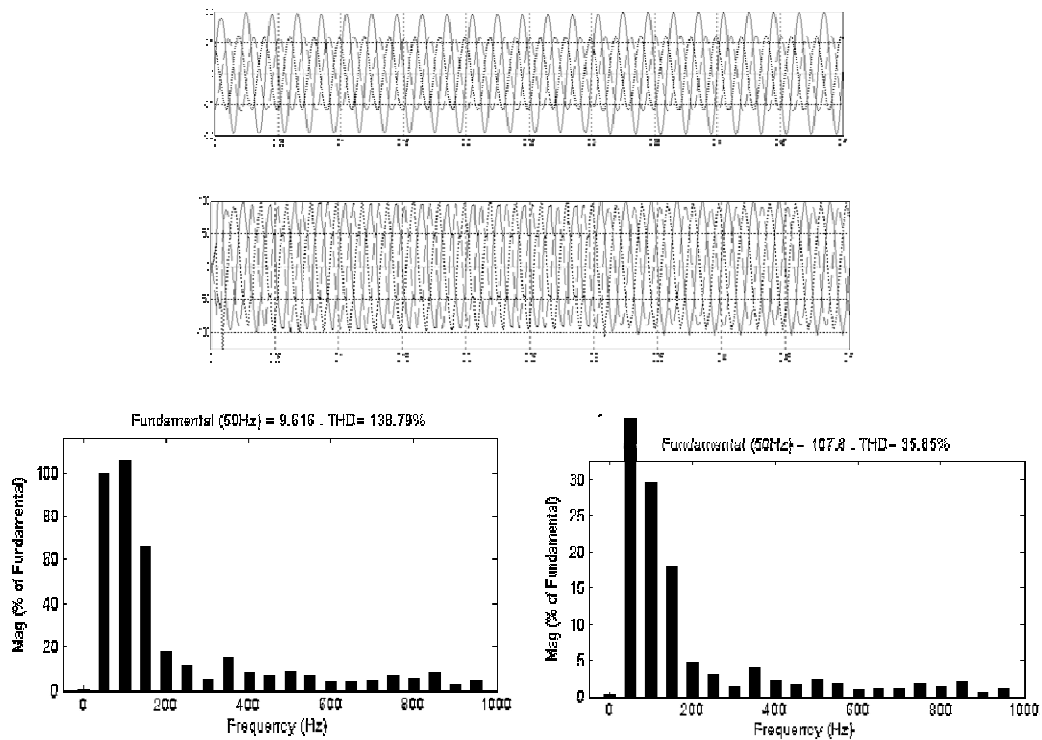
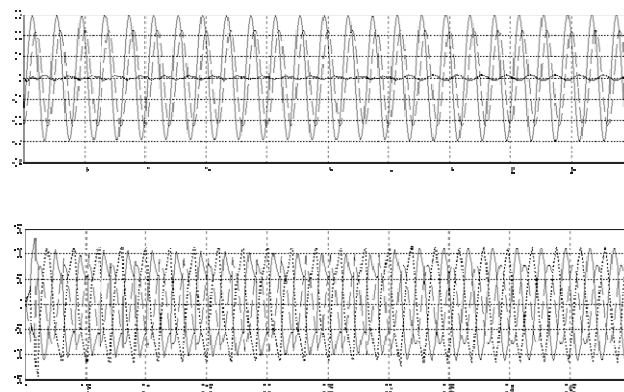


Figure 6: (a) Source voltage (pu) (b) Voltage at load (c) Percentage of total harmonic distortion on the load without DVR (d) Percentage of total harmonic distortion on the load with DVR

In second case, the source resistance of line impedance is altered from 0.1Ω to 0.001Ω . The results are as shown in fig 7. The voltage at load is regained and considerable improvement of total harmonic distortion is seen.



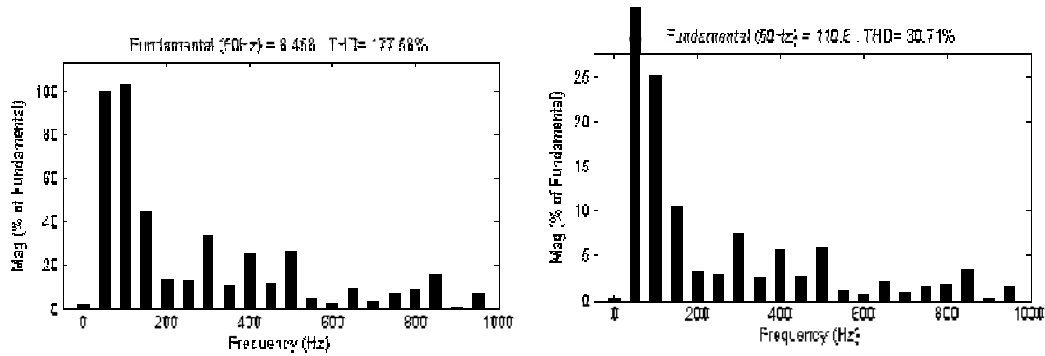


Figure 7: (a) Source voltage (b) Load voltage (pu) (c) percentage of total harmonic distortion on the load without DVR (d)) percentage of total harmonic distortion on the load with DVR

The third case represents the single line to ground fault in the system which is effectively balanced by DVR at the load side by recovering the missing cycles shown in the waveform in fig 8. This case also represents the problem of single-phasing commonly encountered in power system network. The comparison of FFT analysis of the voltage waveform at the load side of the system with and without DVR depicts enormous improvement in the total harmonic distortion.

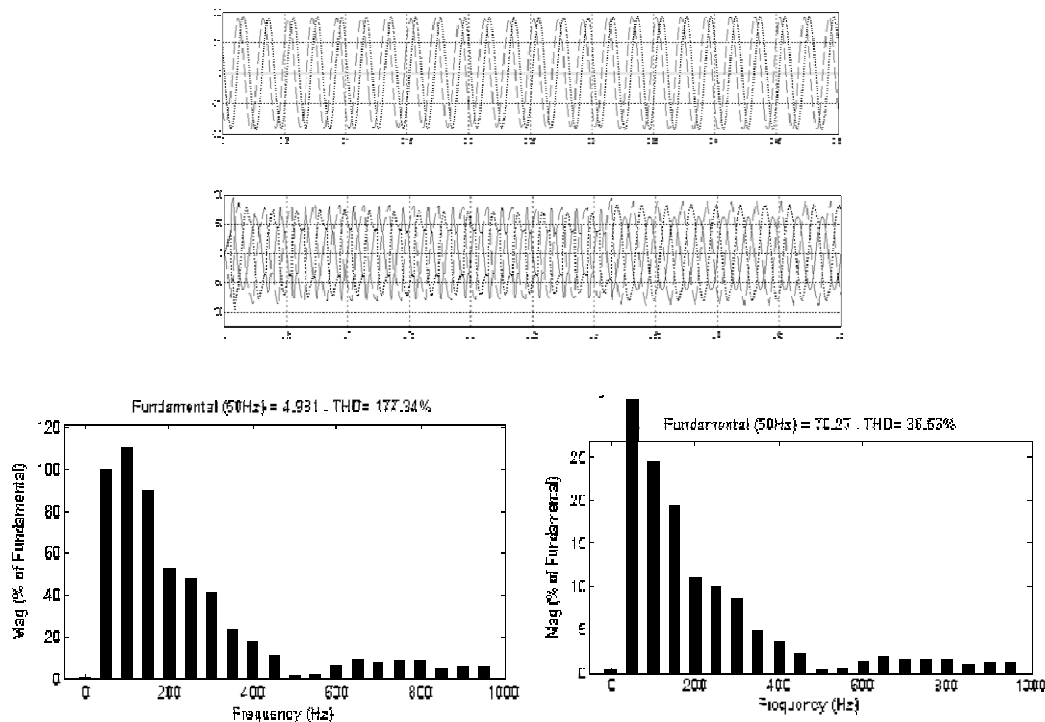


Figure 8: (a) Source voltage (b) Load voltage (pu) (c) percentage of total harmonic distortion on the load without DVR (d) percentage of total harmonic distortion on the load with DVR

Conclusion

The modeling and simulation of a DVR using MATLAB/SIMULINK has been presented. This paper proposed a low voltage dynamic voltage restorer connected to adjustable speed drive load. The dqo control algorithm which is a scaled error of the between source side of the DVR and its reference was implemented to restore the missing cycles of voltage. The proposed method can compensate for most of the voltage faults such as harmonics and any kind of voltage unbalance on the supply networks.

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