Mitigation of Voltage Swells Disturbances in Low Voltage Distribution System Using Dynamic Voltage Restorer (DVR)

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Abstract – This paper discusses the mitigation of power quality disturbance in low voltage distribution system due to voltage swells using one of the powerful power custom devices namely Dynamic Voltage Restorer (DVR). The DVR normally installed between the source voltage and critical or sensitive load. The new configuration of DVR has been proposed using improved d-q-o controller technique.. The simulations are performed using Matlab/Simulink's SimPower Toolbox. The proposal is then implemented using 5KVA DVR experimental setup. The simulation and experimental results demonstrate the effective dynamic performance of the proposed configuration.

Keywords – Dynamic Voltage Restorer, d-q-o controller, voltage swells, distribution system , sensitive load.

I. INTRODUCTION

Recently the growth in the use of sensitive loads in all industries has caused many disturbances such as voltage sags, swells, transient and unbalance. These types of disturbances which caused malfunction or shut down and tend to revenue losses.

Several methods are available to prevent equipment mal operation due to voltage swells. One of commonly used methods is the use of DVR in order to mitigate voltage swells condition. The series voltage controller, also known under the name "Dynamic Voltage Restorer" or DVR [1-2].

DVR is an important tool to mitigate disturbances related to power quality problems in the distribution network. One of the crucial disturbances in the electrical network is voltage swells. The existing DVR as shown in Figure 1 ,consists of a Voltage Source Inverter (VSI), series injection transformer, filtering scheme and an energy storage device may that be connected to the dc-link[2-3].

Voltage sags/swells can occurs more frequently than other power quality phenomenon. These sags/swells are the most important power quality problems in the power distribution system. IEEE 519-1992 and IEEE 1159-1995 describe the voltage sags/swells as shown in Figure 2[1-4].

The main objective of this paper is to investigate and proposes a new configuration of DVR in order to develop such device for voltage swells mitigation in the network. The capacity of the developed device is about 5KVA. This prototype is evaluated and tested in the laboratory and later it will be tested in the industry

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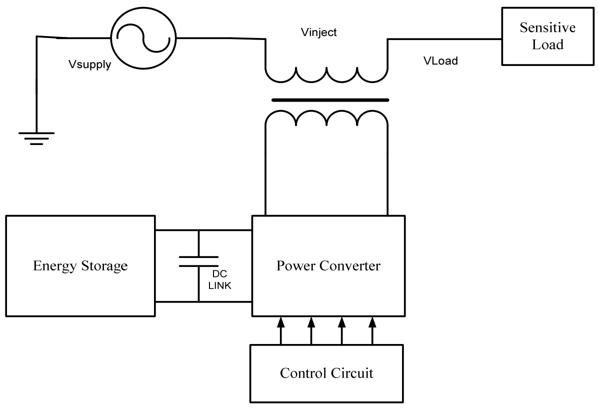

Fig. 1: Schematic diagram of Conventional DVR

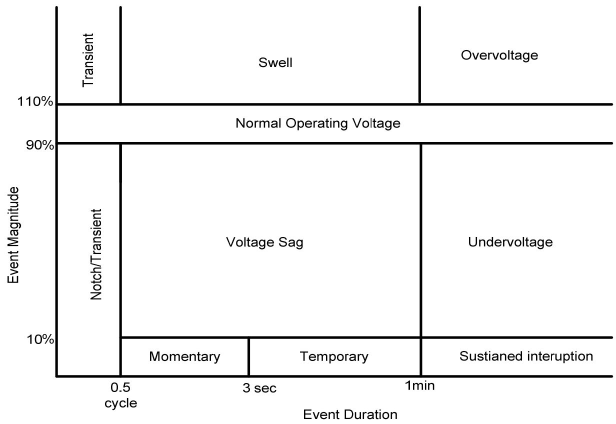

Fig. 2: Voltage Reduction Standard of IEEE Std 1159-1995

This paper also addressed the new technique of DVR controller in order to compensate voltage swells in low voltage distribution system. The proposed controller shows the capability of mitigating voltage swell effectively.
This paper is divided into four sections. The explanation of each sections are as follows: Description of DVR and explain of its functioning are discussed in section I. Section II describes a new configuration of DVR's controller. The Simulation results are discussed in Section III. Finally the experimental results obtained are presented in section V.

DVR is connected in series between the source voltage or grid and sensitive loads through injection transformer. There are several types of energy storage been used in the DVR such as battery, superconducting coil, and flywheels. These types of energy storages are very important in order to supply active and reactive power to DVR. The controller is an important part of the DVR for switching purposes. The switching converter is responsible to do conversion process from DC to AC. The inverter ensures that only the swells or sags voltage is injected to the injection transformer [5-9].

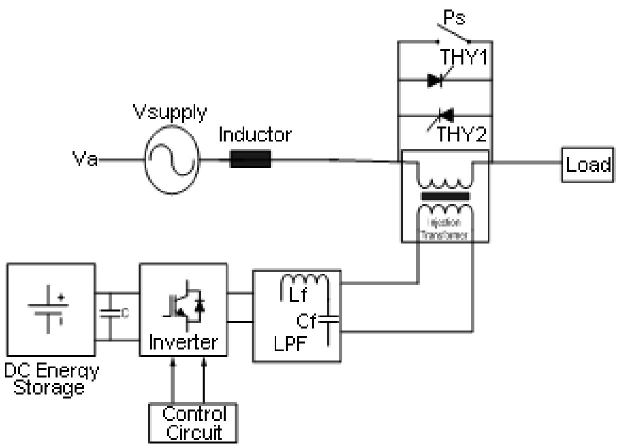

Fig. 3: Typical DVR circuit topology (single-phase representation)

Fig. 3 shows the existing has a VSI and the injection transformer. The VSC consists of six IGBT's (Insulated Gate Bipolar Transistors), three ac inductors and capacitor s respectively, one dc capacitor and energy storage. The selection of IGBT's, interfacing inductor; dc capacitor and the filter are as per the design for a dynamic voltage restorer [10-12]. In order to protect DVR from any disturbances a hybrid switch been used and its operation will be discussed later.

As noted in the previous section, the function of DVR is to inject the difference voltages between the voltage source and the sensitive load. The sources of injection voltages are available from the energy storage device which is capable to supply real and reactive power. The DC energy storage rating determines the maximum injection capability of the DVR. The injection transformer consists of the high and low voltages side. The booster voltages can occur through injection transformer which consists of high and low voltages. The source supply is connected in series with the high voltage side where as the converter is connected at the voltage side [13-14].

II. THE NEW PROPOSED CONFIGURATION OF DVR

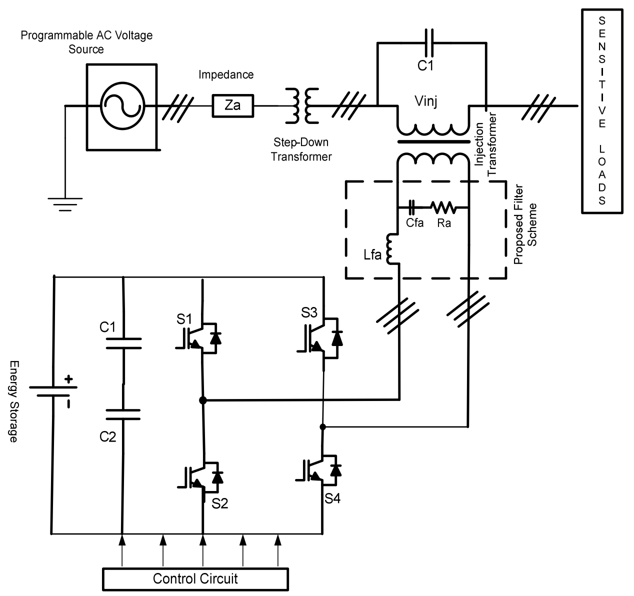

Fig. 4: The Proposed Configuration of DVR

The new configuration of the proposed DVR is shown in Fig. 4. This new configuration using the three single phase of the injection transformer. The injection transformer can be connected either in delta/open or star/open configuration. In this research the series injection transformer was configured as delta/open. The DVR power circuit consists of the 3-leg inverter which has 6 IGBT switches and the battery as a dc energy storage. The low pass filters are used to convert the PWM inverted pulse waveform from DC to AC conversion in the VSI. In this configuration, the filters are installed in both the high voltage side and the low voltage side.

When it is place in low voltage side, high order harmonics from the three phase voltage source PWM inverter is by pass by the filtering configuration and its impact on the injection current rating can be ignored[15]. The type of this filtering configuration can also eliminate switching ripples produced by the converter.
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III. THE CONTROL OF DVR SYSTEM

The Control of the proposed configuration of DVR system using d-q-o Park's transformation technique. Fig. 5 show the main components of the control system The control system consists of 6 blocks and each, block has its function and can be described as follows:

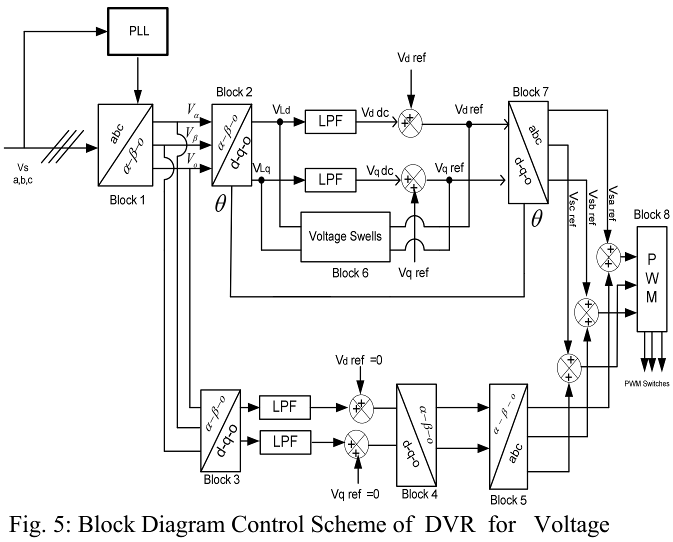


Fig. 5: Block Diagram Control Scheme of DVR for Voltage Swells

Block 1 is used to convert the three phase load voltages (V_{sa}, V_{sb}, V_{sc}) into the α-β-o coordinates as in equation (1)

$$\begin{bmatrix} V_\alpha \\ V_\beta \\ V_o \end{bmatrix} = S \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

where S = $$\sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{bmatrix} \quad (1)$$

Block 2 and block 3 is the α-β-o to d-q-o transformation blocks which are used to convert the three phase load voltages reference components $V_{\alpha\text{-ref}}$, $V_{\alpha\text{-ref}}$ and Vo_{ref} to $V_{d\,ref}$, $V_{q\,ref}$ and $V_{o\,ref}$ by using equation (2), (3),(4) and (5)

$$V_d = \frac{2}{3}\left[V_a \cos\theta \quad V_b \cos\left(\theta - \frac{2\pi}{3}\right) \quad V_c \cos\left(\theta + \frac{2\pi}{3}\right)\right] \quad (2)$$

$$V_q = \frac{2}{3}\left[-V_a \sin\theta \quad -V_b \sin\left(\theta - \frac{2\pi}{3}\right) \quad -V_c \sin\left(\theta + \frac{2\pi}{3}\right)\right] \quad (3)$$

$$V_o = \frac{1}{3}\left[V_a + V_b + V_c\right] \quad (4)$$

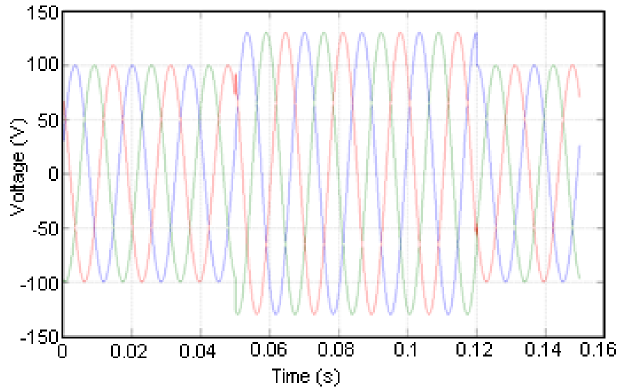
$$\begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix} \quad (6)$$

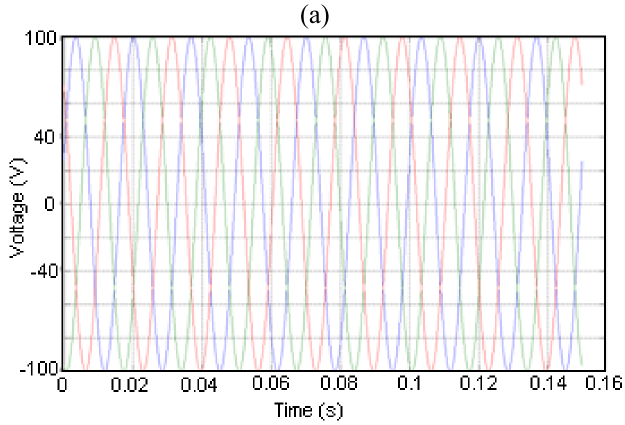
Block 4 is used to convert the d-q-o to α-β-o and the transformation of the α-β-o to a-b-c has been done by block 5. The angle θ of the source voltage can be obtained using three-phase PLL. The information extracted from the PLL is used for detection and reference voltage generation. Block 6 is the detection scheme for the voltage unbalance compensator. Fig. 5 shows that the synchronous frame variables - V_d and V_q - are used as inputs for low pass filters to generate voltage references in the synchronous frame. Block 7 receives the components of the load voltage vectors Vd ref and Vq ref and transforms them to three-phase coordinates using equation (6). The generation voltages are used as the voltage reference. The DC link error in Figure 5 is used to get optimized controller output signal because the energy on the DC link will be changed during the unbalance voltage. Block 8 is the PWM block which provides the firing for the Inverter switches (PWM1 to PWM6). The injection voltage is generated according to the difference between the reference load voltage and the injection voltage is generated according to the difference between the reference load voltage and the supply voltage and is then applied to the voltage source converter (VSC).

IV. MATLAB BASED SIMULATION OF DVR SYSTEM

The performance of the designed DVR, as shown in Fig. 4, is evaluated using Matlab/Simulink. Table I provides the specification of the simulation and experimental results of the DVR.

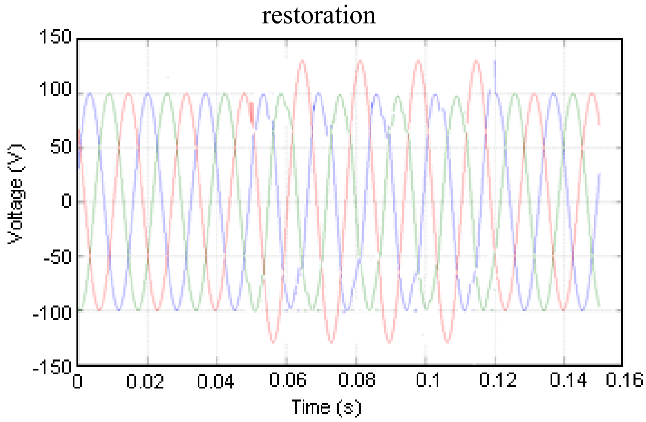


(a)



(b)

Fig. 6:(a) Balanced voltage swells (b) Load voltage after restoration



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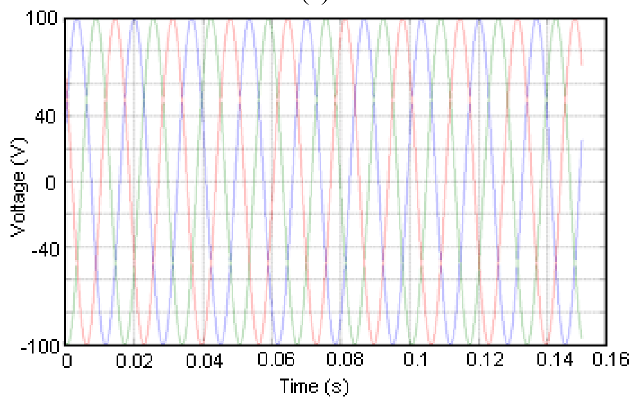


(b)

Fig. 7:(a) One phase voltage swells (b) Load voltage after restoration

Investigation on the DVR performance can be observed through testing under various disturbances condition on the source voltage. The proposed control algorithm was tested for balanced and unbalanced voltages swells in the low voltage distribution system .

Table 1: Main Specification of the DVR

PARAMETER	VALUE
Nominal grid voltage	200V (L-L)
Nominal load voltage	120V(L-L)
Maximum series voltage Injection	100V(L-L)
Switching/sampling frequency	10 KHz
Max. inverter dc-bus voltage	120 V
Capacitor of dc- bus	26µF
Filter inductance	2.7mF
Filter capacitance	50µF

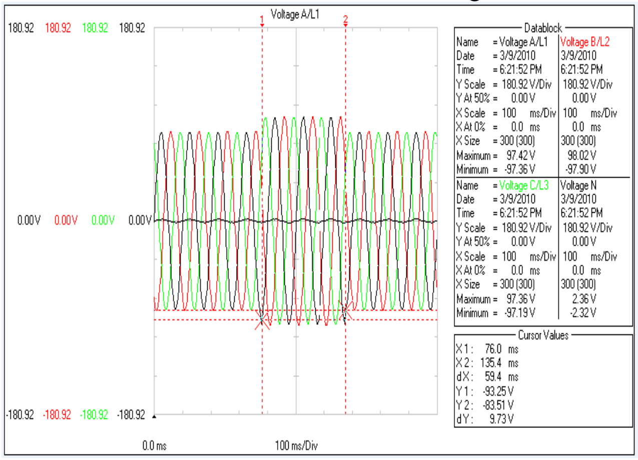
In case of unbalance voltage swells, this phenomenon caused due to single phase to ground fault. One of the phase of voltage swells has increased around 20-25% with duration time of swells is 0.06 s. The swells voltage will stop after 0.12 s. At this stage the DVR will injects the missing voltage in order to compensate it and the voltage at the load will be protected from voltage swells problem.

V. Experimental Results

The actual hardware to verify the effectiveness of the proposed system, a 5KVA prototype has been built based on the new configuration of DVR as shown in Fig. 3. Fig. 3 describes the system configuration of the prototype developed. The mains supply is three phase, 50Hz, 120/120 V and the turn ratio of the series transformer is 1:1. The switching frequency of the inverter is 5 kHz. The filtering capacitor and inductor are 50uF and 2.7mH respectively. To start up the test, the loads are first powered by the utility, the low voltage prototype DVR was fed with a programmable AC power source 6560/6590. The prototype is rated to protect 5KVA load with 25% voltage swells from their nominal voltage. All the components part of the DVR has been integrated according to the parameters in the Table 1. A DSP TMS320F2812 board was used for the control scheme. The sampling frequency is set at 10 kHz. The source voltages V_{sa}, V_{sb}, V_{sc} are measured by the voltage sensor, then its signals are entered into the DSP board. The output currents of the inverter is measured by using current sensor and then sensed by the DSP board to boost up the voltage response of the DVR. In the experiment, a 25% three phase and single phase swells are generated from their nominal voltage. The experimental results obtained for both conditions are shown in Figs. 9 and 10 respectively.

Fig. 9(a) shows the waveform of utility voltage when the tested system suffered a disturbance of 25% voltage swell. Balanced voltage swells are created immediately after a fault. The DVR injects fundamental voltage in series with the supply voltage. Fig. 9(b) shows the load terminal voltages which are restored through the compensation by DVR.

Next, the performance of DVR for one single phases to ground fault is also investigated. Fig. 10(a) shows the series of voltages components for unbalanced conditions for one phase to ground fault. The DVR load voltages voltages are shown in Fig. 10(b). From the results, the swells load terminal voltage is restored and help to maintain a balanced and constant load voltage.



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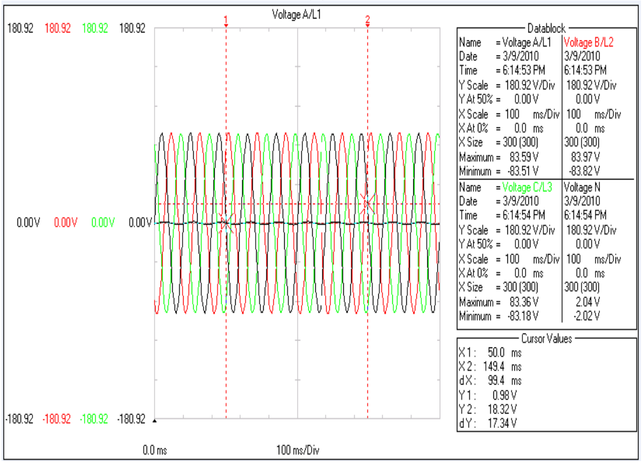
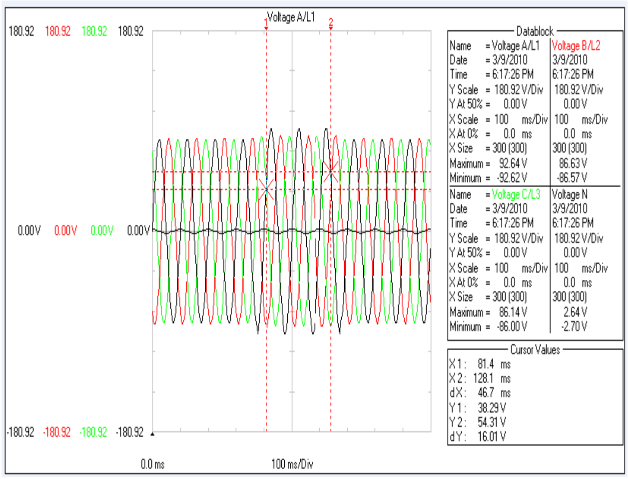


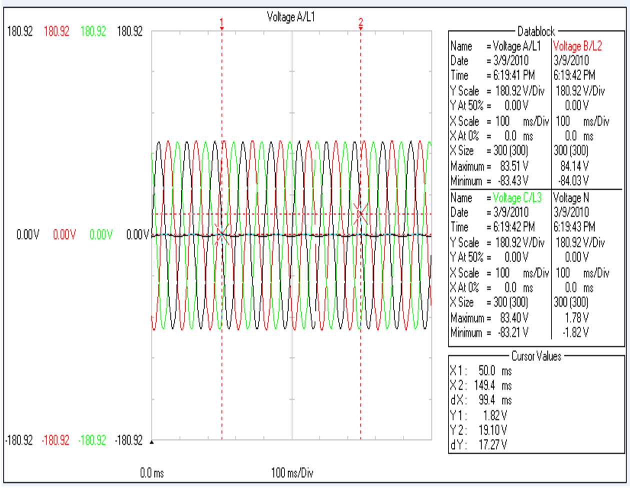
(b)

Fig. 9:(a) Three phase voltage swell (b) Load voltage after restoration

In Fig. 9(b) and 10(b) illustrate the voltage restoration performances of the DVR during the source side three phase and one phase voltage swells respectively. As can be seen from the Figures voltage at sensitive load is maintained to constant magnitude



(a)



(b)

Fig. 10:(a) One phase voltage swells (b) Load voltage after restoration

VI. CONCLUSION

A new compensation voltage control scheme was proposed in this paper. This paper discusses the aspect related with the specification and control of the DVR for voltage swell mitigation in low voltage distribution network. The proposed method can protect customer's equipment from potential voltage swells. This was proved with several simulation and experimental results. These results validate the proposed strategy for the detection and control of the DVR. These results also shown that the DVR compensation is fast and the source voltage fault can be compensated by series voltage injection transformer .

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BIOGRAPHIES

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