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New Compensation Algorithm for Dynamic Voltage Restorer in Medium Voltages Level

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Abstract*— *with the increase in use of electronic equipments there has been rise in problems related to power quality. Power quality is most important parameter in the present era. Dynamic Voltage Restorer (DVR) is a tool for compensating short term power deficiencies in sensitive loads. The compensation ability of the restorer depends on its maximum injection voltage and power capabilities during sag voltages. When voltage drop occurs continuously, DVR can compensate it with effective strategy such as minimum energy algorithm. The minimum energy algorithm minimizes the real power delivering requirement DVR. This method, there will not as much of concern on the energy storage capacity of DVR; however, its limitations on restoring the load voltage and current cause fluctuations of the phase angle. In this paper using TCR for provide reactive power. It is installed on the load side of the network to eliminate the harmonics by injecting current and select best firing angles for the power electronic device.

Index Terms*—*Dynamic Voltage Restorer, sag voltage, swell voltage, restoring flow, TCR/TSC

I. INTRODUCTION

Nowadays, despite the wide usage of sensitive equipment such as personal computers and programmable logic controllers (PLCs), speed of industrial processes is vulnerable against voltage disorders [1-3]. Sag and swell voltages are examples of such vulnerabilities that cause incorrect function of the network. DVR is a transformer source for controlled voltage and is installed between load and the main energy source in order to stabilize the voltage level[4-5]. It is able to detect quick voltage disturbances in network. Fig.1 shows the general structure of the simulated network in this article. DVR protects load against sag and swell voltages using an alternative three-phase voltage with the frequency of the network connected in series with the load voltage. Based on the load sensitivity, in-phase, pre-fault and minimum energy strategies have been developed for designing DVR. If the injected voltage V_d is in phase with source voltage, the method of in-Phase controlling is obtained. The pre-sag technique introduces the difference voltage between sag and pre-fault voltages to the network. Therefore, the pre-fault load voltage is obtained. In the minimum energy method, it is attempted to insert a voltage vector with a phase relative to the supply voltage or in the direction perpendicular to the current to minimize the injected active power.

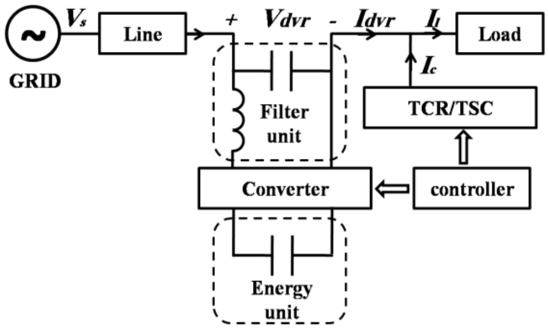

Fig.1: General structure of the simulated network

II. DYNAMIC VOLTAGE RESTORATION

An advanced DVR topology presented that by paralleling with a TCR/TSC compensator at load side, it overcome the phase jumped problem which it bring by traditional minimal energy control [6]. Implemented at medium voltage level, the DVR can be used to protect a group of medium voltage or low voltage consumers [7]. The effect of the DVR on the system is experimentally investigated under both faulted and no faulted system states, for a variety of linear and nonlinear loads[8]. In [9] studied control schemes include the commonly used single voltage loop control, voltage feedback plus reference feed forward control, and double-loop control with an outer voltage loop and an inner current loop. Also [10] Implementation of particle swarm optimization (PSO) application for solving the optimization problem in the field of electric power system is proposed.

A. Components of the Dynamic Voltage Restorer

A DVR consists of the following components: (i) main transformer; (ii) passive filter; (iii) DC source; and (iv) controllable voltage source converter. The most important organ of DVR is the controllable voltage source converter. It is in charge of identifying the error signal and constructing appropriate controlling signals in a short time. It contains two main parts: the control strategy and estimation section where the voltage injection method and the response time of DVR are respectively determined. In this article, the method of minimum energy controlling is utilized.

B. The method of restoring voltage using DVR

As most of sensitive loads are located on the low voltage side of the network, the most appropriate place for installing DVR is before the low voltage bus bar and close to the source.

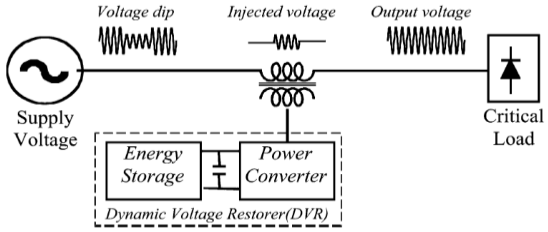

Fig.2: Restoring of the dynamic voltage

As previously mentioned, DVRs are generally utilized to protect sensitive loads against disturbances occurring in the power source. In Fig.2, separate controllers are used to create three asymmetrical voltage components for the compensation of the sag voltage.

III. CONTROL OF A DYNAMIC VOLTAGE RESTORER

A. *Minimum active energy strategy*

The purpose of this method is to keep the injected active power to the distribution system close to zero or to minimize the injected energy to the network. For this purpose, the maximum reactive power of DVR is used to restore sag and swell voltages. However, the disadvantage of this method is the resulting phase-angle jumps in the connected load. In order to remove this deficiency, Thyristor Control Capacitors (TSCs) are employed. Evaluations performed by researchers indicated that this method is economically viable. This is due to the fact that the nominal power of DVR is a percentage of the load power [3].

The following condition must be satisfied for DVR to solely supply reactive power to the network.

$$V_l > V_{ref}\cos\theta \tag{1}$$

Where V_l is the supply side sag voltage, V_{ref} is the load voltage after the compensation action and θ is the load power factor angle defined as the angle between V_{ref} and the load current. is equal to the sum of the currents through DVR, I_d, and TCR:

$$I_l = I_{dvr} + I_c \tag{2}$$

V_{ref} is equal to the sum of the DVR injected voltage, V_{dvr}, and V_l :

$$V_{ref} = V_{dvr} + V_l \tag{3}$$

The active power, P, delivered to the network by DVR is given by Eq. (4).

$$P = V_{dvr} \times I_{dvr} \tag{4}$$

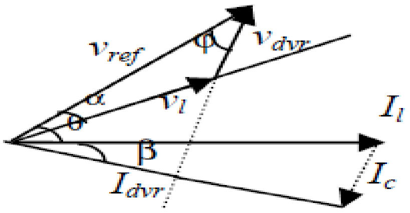

Fig.3: Phasor diagram in sag voltage situation

B. *Analysis of minimum energy injection methods*

The graphs of the different DVR topologies for analyzing voltages, phase angles and currents are given in this section.

1) *Sag voltage*

When sag voltage happens, for the phase angle jump (advance angle), α, of the load voltage with respect to the supply voltage varying within: $0 \leqq \alpha \leqq 90^o$, the corresponding relations between the voltages and currents are shown in Fig.3.

V_{dvr} is calculated as (5):

$$V_{dvr} = \sqrt{V^2_{ref} + V^2_l - 2V_{ref}V_l\cos\alpha} \tag{5}$$

The injection angle, between V_{ref} and V_{dvr} is calculated as in (6):

$$\varphi = \cos^{-1}\left(\frac{V_{ref}^2 + V_{dvr}^2 + V_l^2}{2V_{ref}V_{dvr}}\right) \tag{6}$$

I_c has the minimum value when and I_{dvr} is perpendicular. The active DVR power gradually approaches to zero during the operation. I_C is calculated as Eq(7).

$$I_c = I_l \sin\beta \tag{7}$$

Where β is the angle between $\boldsymbol{I_{dvr}}$ and $\boldsymbol{I_l}$ and can be calculated as:

$$\beta = \frac{\pi}{2} - \varphi - \theta \tag{8}$$

When α >90°, the corresponding phasor diagram is shown in Fig.4:

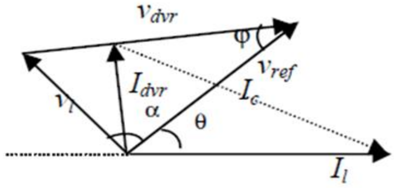

Fig.4: Phasor diagram in sag voltage for α >90°

I_c and I_{dvr} are obtained using Eq.(9).

$$I_c = \sqrt{I_l^2 + I_{dvr}^2 - 2I_lI_{dvr}\cos(\pi/2 - \varphi + \theta)} \tag{9}$$

When swell voltage occurs, the corresponding phasor diagram for $0 \leqq \alpha \leqq 90^o$ is shown in Fig.5:

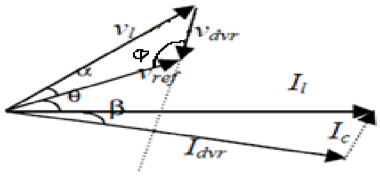

Fig.5: Phasor diagram in swell voltage for 0<α< 90°

V_{dvr} is given as:

$$V_{dvr} = -\sqrt{V^2_{ref} + V^2_l - 2V_{ref}V_l\cos\alpha} \tag{10}$$

φ is calculated as:

$$\varphi = \cos^{-1}\left(\frac{V_{ref}^2 + V_{dvr}^2 - V_l^2}{2V_{ref}V_{dvr}}\right) \tag{11}$$

I_C is calculated as:

$$I_c = I_l \sin\beta \tag{12}$$

β is calculated as:

$$\beta = \frac{\pi}{2} - \varphi - \theta \tag{13}$$

The phasor diagram of the swell voltage for α> 90 is shown in Fig.6:

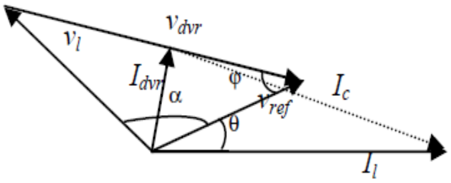

Fig.6: Phasor diagram of the swell voltage for α> 90

I_C can be calculated as Eq(14).

$$I_c = \sqrt{I_l^2 + I_{dvr}^2 - 2 I_l I_{dvr} \cos(\pi/2 - \varphi + \theta)} \tag{14}$$

2) DVR algorithm

Using the following equation, the instantaneous values of the three phase voltages V_a, V_b and V_c are converted into V_a the $\alpha\beta$ coordinate system. The result is a vector consisting of $V_{s\alpha}$ and $V_{s\beta}$.

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{15}$$

The resulting vector is then converted into the dq-coordinate system to generate voltages V_{sq} and V_{sd} using the following expression.

$$\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \tag{16}$$

In addition, the reference voltages V_{dref} and V_{qref} are determined according to the specified controlling strategy. The error voltages V_{derror} and V_{qerror} are obtained by comparing the q and d voltage components with their corresponding reference voltages V_{dref} and V_{qref}. The resulting difference voltages V_{dinj} and V_{qinj} are then injected into the network by DVR. In order to create the injected voltages, V_{dinj} and V_{qinj} are transferred back to the αβ coordinate system by an appropriate inverse transfer matrix. The resulting vector in the αβ coordinate system is then converted back into the original coordinate system using the following expression.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ \sqrt{\frac{3}{2}} & -\frac{1}{2} \\ -\sqrt{\frac{3}{2}} & -\frac{1}{2} \end{bmatrix}^{-1} \begin{bmatrix} V_{\beta inj} \\ V_{\alpha inj} \end{bmatrix} \tag{17}$$

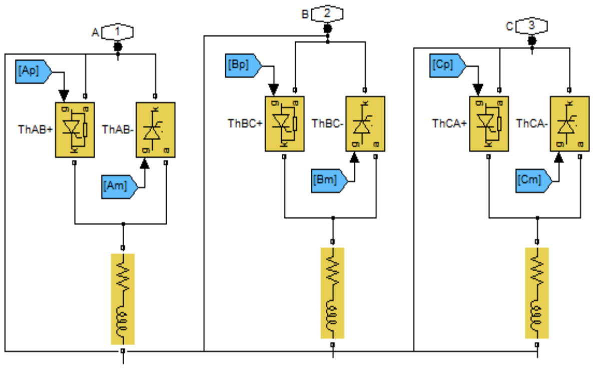

Fig.7: TCR diagram

Finally the resulting instantaneous voltages Va0, Vb0 and Vc0 are sent to the voltage source convertor (VSC) block. Voltages which are generated by VSC are applied to a three-phase series-connected star-delta transformer. As a result, suitable serial voltages in accordance to the existing voltage errors are injected into the network to restore the sag and swell voltages back to their pre-fault conditions. While utilizing the strategy of minimum energy, the lowest real power is delivered to the system by DVR. However, there active power injected to the network by DVR is at its highest required level.

IV. ANALYSIS OF TCR

According to IEEE definition, TCR is a self controller handled by thyristors. The effective reactance is achievable by controlling the thyristors firing angles within a limited range. A pair of thyristors in TCR is connected in anti-parallel mode. Each of these two thyristors is forced into conduction by application of a pulse to its gate input in one of the two positive and negative half cycles of the supplied voltage. It will then block the current flow after the ac current crosses zero. If thyristors are fired at the crest voltages, the thyristors current flows are maximum. The current in the reactor can be changed from maximum to zero by varying the firing delay angle in regard to the peak of the applied voltage in each half-cycle. Basically, the current flow is reactive and approximately lags 90 degrees behind the voltage. Fig.7 shows a three-phase TCR.

V. RESULTS OF SIMULATIONS

In this part we examine and analyze their sluts of applying the DVR technique to a MATLAB/Simulink software model of the system. The simulated system is shown in Fig.8. In the utilized simulation we used a programmable voltage source to generate symmetrical percentage-based faults. In addition, a TCR phase compensator is used along with the main DVR. In Figure 10 the V_{dvr} and V_{inj} waveforms for30% swell voltage within the time limits [0.1, 0.2] seconds are shown. In Figure11 the V_{dvr} and V_{inj} waveforms for 40% sag voltage, within the time limits [0.1, 0.2] seconds are shown.

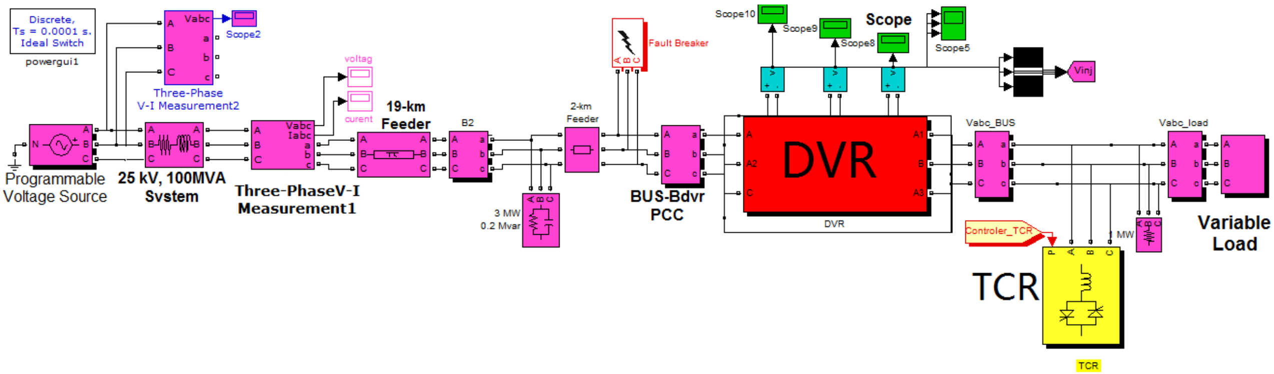

Fig.8: DVR simulated system

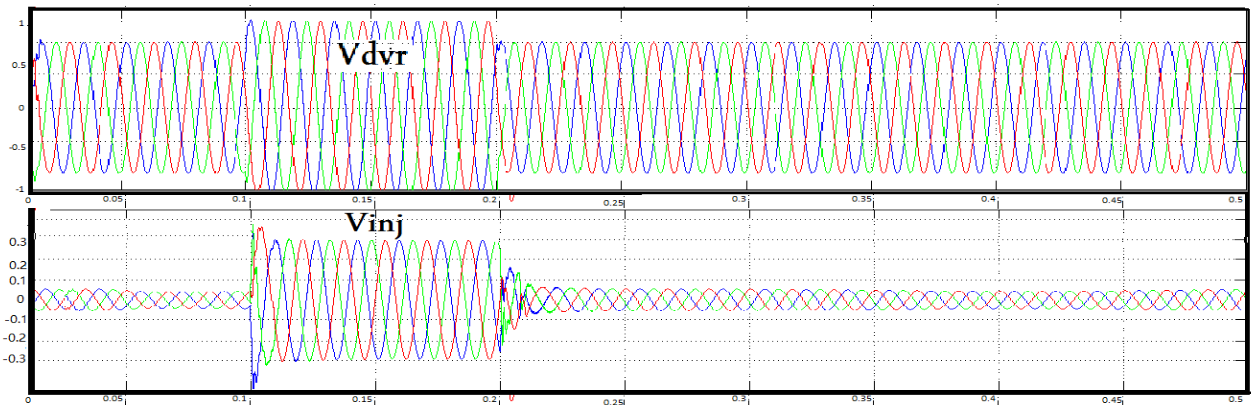

Fig.9: 30% swell voltage in the network

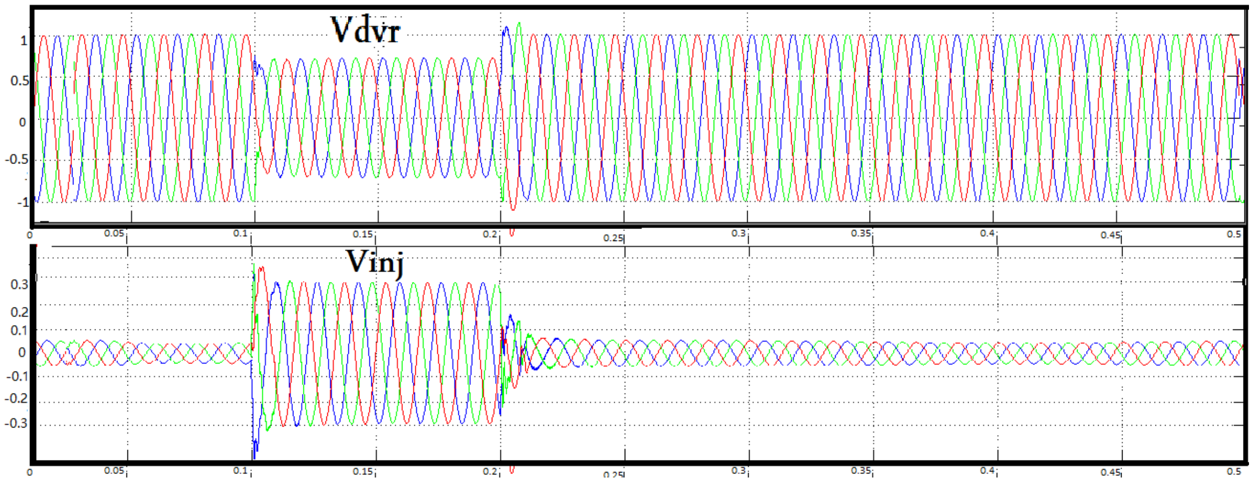

Fig.10: 40% sag voltage in the network

Symmetrical circuit faults are applied by the Fault Breaker block shown in Figure 8. Consequently, DVR injects suitable voltage to restore the required pre-fault voltage level. These are shown in Figures 11, 12, and 13. The restored voltage is shown in Figure 14.

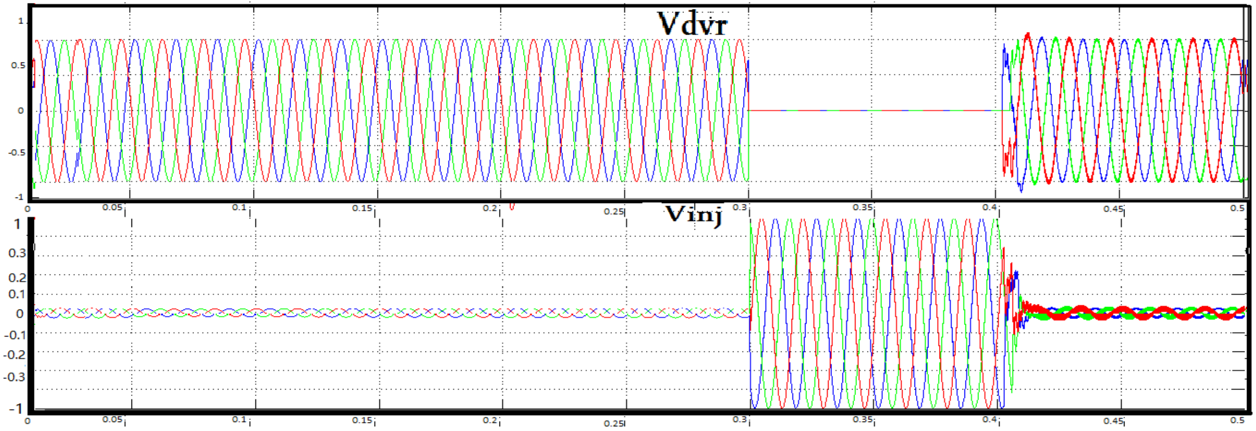

Fig.10: 40% sag voltage in the network

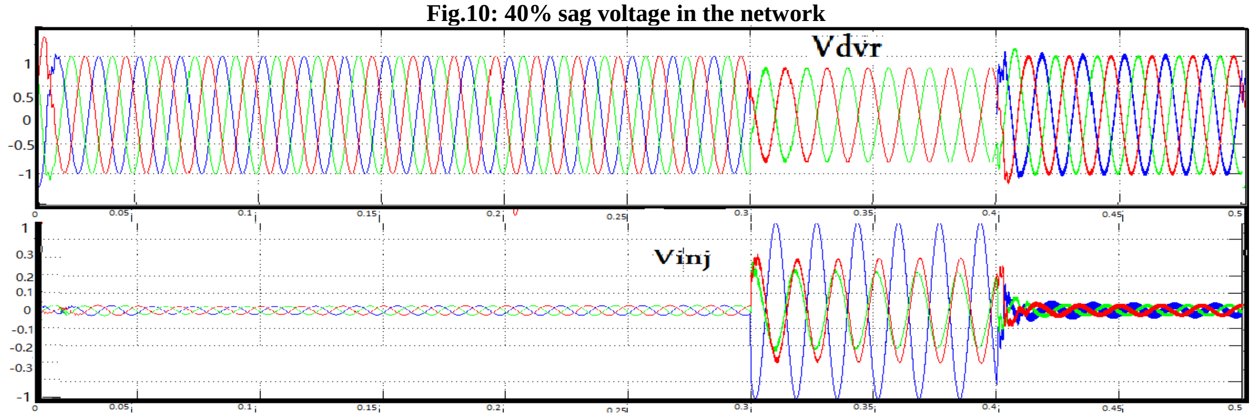

Fig.10: 40% sag voltage in the network

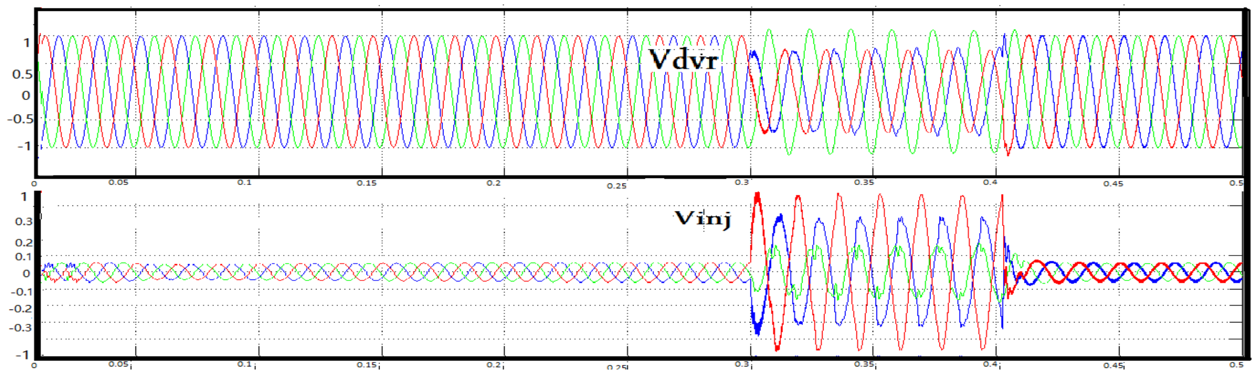

Fig.10: 40% sag voltage in the network

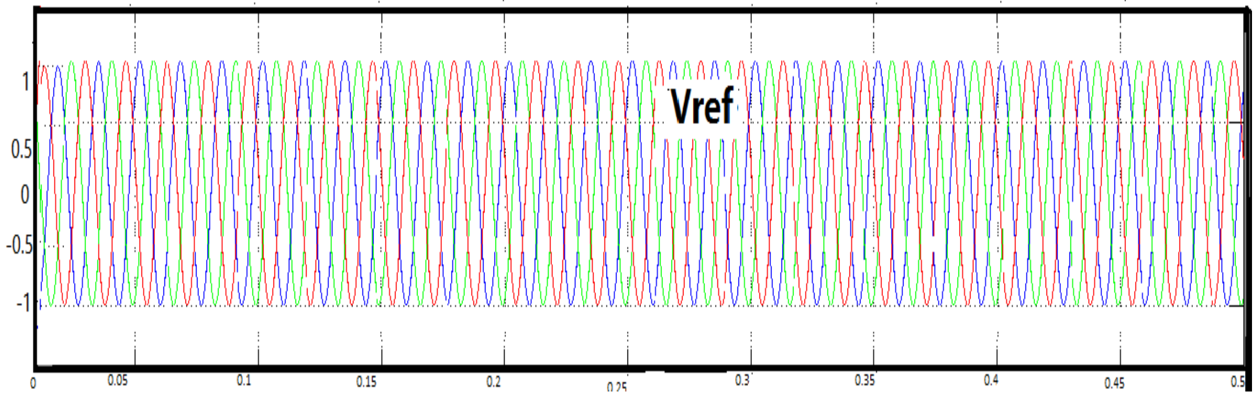

Fig.10: 40% sag voltage in the network

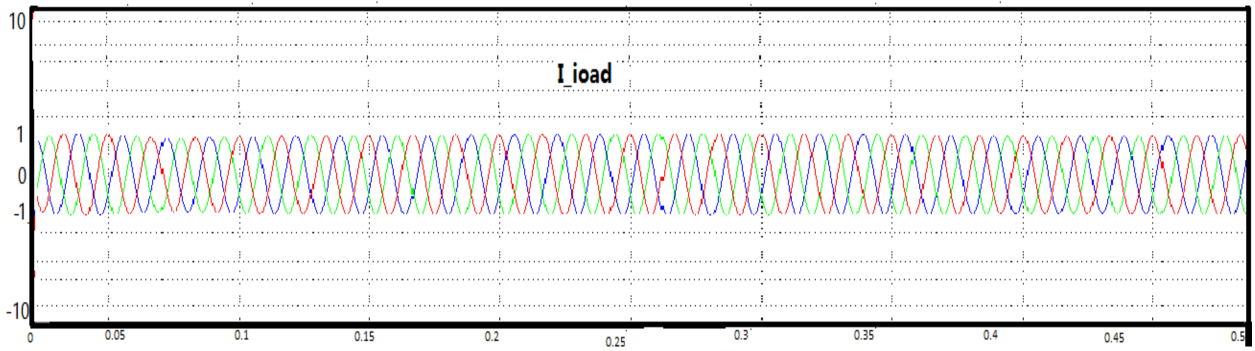

Fig.10: 40% sag voltage in the network

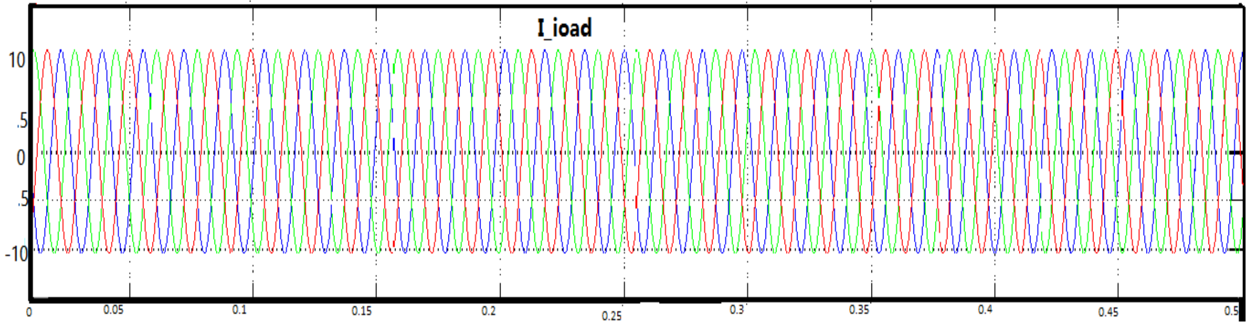

Fig.10: 40% sag voltage in the network

The load current before the TCR compensation is shown in Figure 15. The load current after the TCR compensation is shown in Figure 16.

TABLE 1: Values of simulation parameters

Source Voltage	25 kV
Line impedance	L = 6.6 H r = 2.5Ω
19 Km line feeder	[R1 R0] (Ω/km) = [0.1153 0.3963] [L1 L0] (H/km) = [1.048e-3 2.73e-3] [C1 C0] (F/km) = [11.33 e-3 5.338e-3]
Parallel RLC load	QL= 0 VAR Qc= 200 kVAr P = 3 W
Variable load	[Current (A) Pf] = [3000 0.8] [Amplitude (A) F(Hz)] = [2000 60]

VI. ANALYZING ENERGY

Conventional DVR must supply appreciable active power to the network. However, as shown in the above figures, the active power supplied by the proposed DVR method in this work is negligible. The DVR active power approaches zero by optimizing the DVR control parameters and using the TCR compensation. Figure 17 shows the injected active power supplied to the network. As shown in this figure, the active power is negligible and near zero. Figure 18 shows the injected reactive active power supplied to the network.

VII. CONCLUSION

Using the MATLAB/Simulink software package, a DVR system is simulated in a 25kV distribution network employing the minimum active energy injection method. Specifications of different DVR techniques in terms of their active and reactive power injection capabilities along with their injected voltages to the network were presented. While utilizing the minimum energy strategy the lowest amount of real power is delivered to the network, whereas the highest amount of reactive power is injected to the network. However, the minimum energy injection method, when compared to the conventional pre-sag method, may lead to phase angle jumps of the connected load in the network. Some loads are known to be sensitive to phase angle jumps. As a feature of this article, this disadvantage is appreciably eliminated by installing the TCR compensation system.

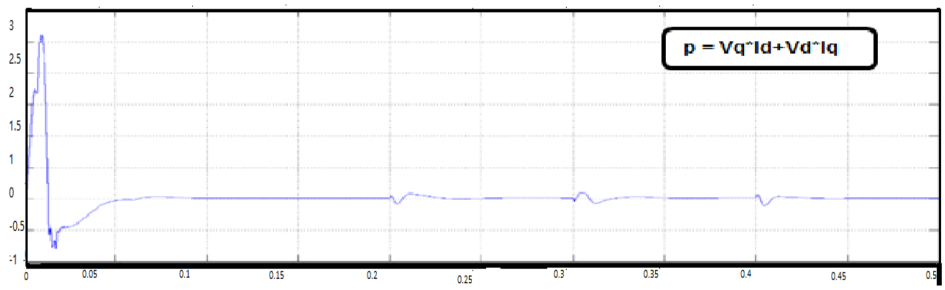

Fig.11: The injected active power (P)

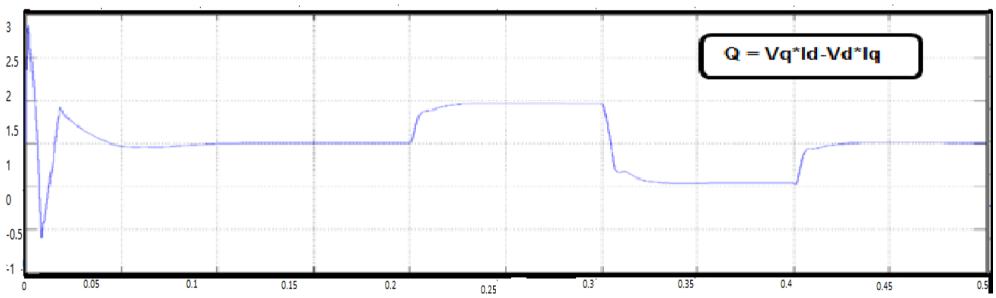

Fig.12: The injected reactive power (Q)

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