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Analysis of Various Control Schemes of Dynamic Voltage Restorer for Power Quality Improvement in Distribution System

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Abstract*: *One among the contemporary power electronic controller in distribution system is Dynamic voltage restorer (DVR) used to guard the customers from the voltage variations. DVR output compensating signals organize the voltage signal in distribution system. DVR is triggered from the control pulses generated from the control methodology. The paper presents the different control methodologies for DVR to regulate the voltage wave in distribution system from sag/swell. Simulation analysis is conveyed by using MATLAB/SIMULINK tool and simulation results indicate the ability of DVR to regulate sag/swell in distribution system.

Index Terms*: *Compensation, voltage sag, voltage swell, sensitive load, DVR.

I. INTRODUCTION

The Electric Power system is the substantial electric power system which consists of various elements are properly worked to achieve continuous power supply to loads. For achieving load or load demand, maintain qualitated power transfer capability. Certainly Power-Quality (PQ) is the major issue in power system especially in distribution system performance is very sensitive [5] to interruptions. Most of industrial loads behave poor power-quality standards due to usage of power-electronic equipments, variable speed drives, programmable logic controllers, etc. Typical power-quality issues are voltage sags/dips, voltage swells, harmonics distortions, etc.

Generally, Voltage-sags/dips is the most critical issue to many industrial loads because affected by several fault conditions, sudden load switching, etc. The voltage sag is described as voltage decreasing with respect to 10% to 90% of base voltage within a standard time of less than 10s. Voltage swells are also most common PQ issue to many industrial loads affected by sudden switching of capacitor banks, sudden removal of loads, etc. The voltage-swell is described as voltage increment with respect to 10% to 110% of base voltage within a standard time of less than 10s. Due to these issues, the loads in the distribution system affected and discontinuous of power supply. For these issues, a compensation methodology is initiated by utilizing attractive control schemes. A custom-power devices are highly used for enhancing PQ features in distribution system without affecting any loads. In that Dynamic-Voltage Restorer (DVR) plays a vital role for compensating voltage related PQ issues such as voltage-sags/dips, voltage swells, voltage harmonics, etc [2-4].

Presence of sag reduces the life time of connected load and swell damages the load [5,6]. A sudden switching ON of heavy loads and presence of inductive reactance elements in the system might be the reasons for voltage sag. Sudden switching OFF of heavy loads and presence of capacitive reactance elements in the system might be the reasons for voltage swell. Switching ON of capacitive banks or capacitive type of loads can also cause voltage swell. Sag and swell needs to be nullified as quickly as possible such that no connected loads are affected [7-9].

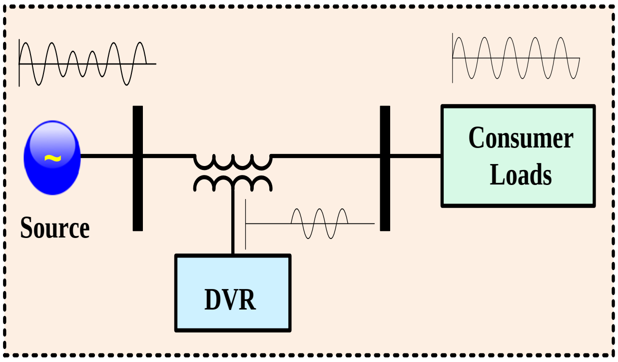

Fig 1: Block diagram of DVR

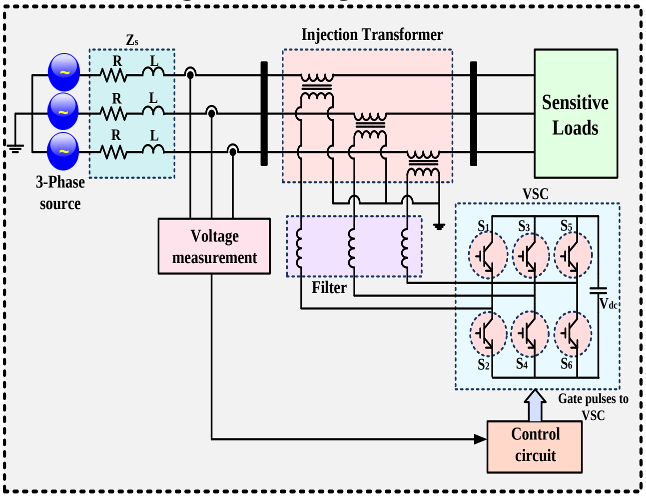

Figure 2: DVR in distribution system with sensitive loads

Generally, there are two methodologies for mitigating voltage-related PQ issues. There is a scope to resolve power quality problems from load or source side [10-12]. Voltage issues in power distribution system have a versatile solution with DVR [13]. The paper presents the different control methodologies for DVR to regulate the voltage wave in distribution system from sag/swell. Simulation analysis is conveyed by using

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MATLAB/SIMULINK tool and simulation results indicate the ability of DVR to regulate sag/swell in distribution system. 'ABC' control, 'unit-vector' control and 'SRF' control methodologies are implemented for generating control gate pulses to DVR in this paper.

II. OPERATION OF DYNAMIC VOLTAGE RESTORER

Figure 2 shows the in DVR in power distribution system with sensitive loads comprises of Voltage-Source Converter (VSC), line-injection or interfacing transformer, filter units, storage units, DC-link capacitor and Control scheme, etc. During voltage sag/swell conditions in power distribution system, the DVR provides the compensated voltage which is restored to load system as requirement. The DVR pre-requisites the energy source and employs a DC link capacitor in general. The Voltage Source converter (VSC) transforms the available DC voltage from DC-link relies on battery-energy units for regulating the voltage. A second-order LC filter modules are integrated at output nodes of VSC for attaining sinusoidal injected voltage to achieve load to overcome the non-linear functioning of power-electronic devices. Mainly, the load compensation is carried based on series injection process by integrating line-interfacing transformers as linear working approach as winding turns ratio of 1:1.

III. CONTROL STRATEGIES

A. ABC Theory based Control of DVR

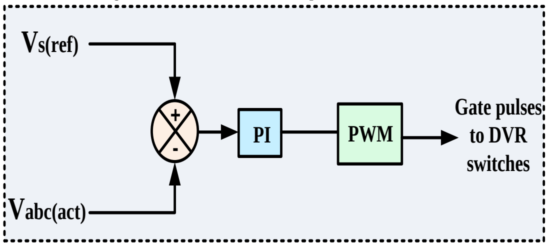

Figure 3: ABC control theory of DVR

The control strategy is implemented on DVR to develop the performance of the DVR. The control technique is used to implement the switching of converter. Hence control technique PI based Simple ABC theory was used here. Based on the comparison, is suggested for compensating voltage issues in distribution system. Figure 3 shows the simple ABC control strategy to produce gate signals to DVR VSC. The Source Voltage Vs is sensed and give it as an input to the transformation block (abc/dq) And same source voltage V_{abc} actual is given as an input to the summing block.

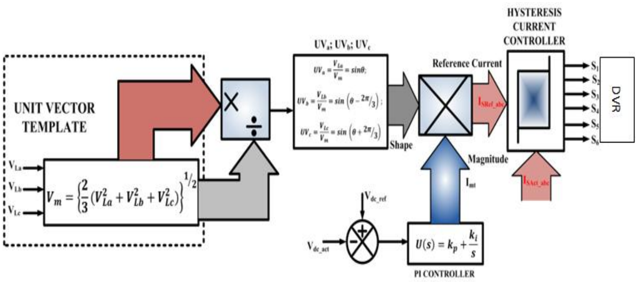

Figure 4: Unit Vector Theory for controlling DVR

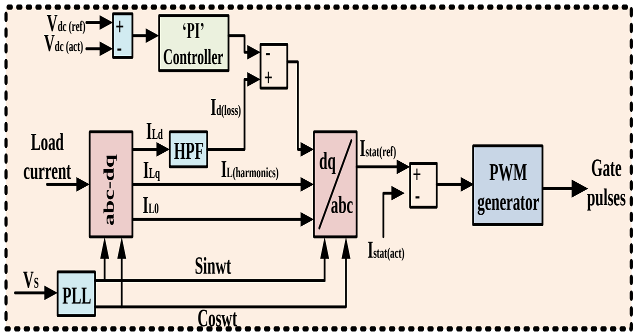

Figure 5: SRF Theory for controlling DVR

The inverse transformation block (abc/dq) this entire process is eliminated here compared to SRF theory. Due to this action, this controller has less processing time; size of controller is reduced and available in less cost compared to SRF controller. The sensed Actual voltage is compared with ABC reference voltage and the compared value is given as an input to the PI controller. The controller output is given as an input to PWM Generator block.

B. Unit Vector Theory based Control

The schematic diagram of Unit-Vector control theory to control the VSC of DVR is depicted in figure 4. At first sense the load voltages by using analyzing schemes, these voltages are integrated to unit-vector template for getting the unit-vector voltages.

The three phase balanced load voltages are

$$V_{La} = V_{ma}\sin\theta$$
$$V_{Lb} = V_{mb}\sin\left(\theta - {}^{2\pi}/_{3}\right)$$
$$V_{Lc} = V_{mc}\sin\left(\theta + {}^{2\pi}/_{3}\right) \quad (1)$$

The generated unit vector template is,

$$V_m = \left\{\frac{2}{3}\left(V_{La}^2 + V_{Lb}^2 + V_{Lc}^2\right)\right\}^{1/2} \quad (2)$$

The in-phase unit voltages are attained from the above Eqns. (1) and (2) such as;

$$UV_a = \frac{V_{La}}{V_m} = \sin\theta;$$
$$UV_b = \frac{V_{Lb}}{V_m} = \sin\left(\theta - {}^{2\pi}/_{3}\right);$$
$$UV_c = \frac{V_{Lc}}{V_m} = \sin\left(\theta + {}^{2\pi}/_{3}\right); \quad (3)$$

The generated unit-vector outcome voltages are (UV_a, UV_b, UV_c) are combined to form a reference current by utilizing active current component (Imt). The "Imt" component is attained from DC-link controller, in that, by PI controller and generates the magnitude of active current component. The error & outcome of PI controller at n^{th} sampling period is illustrated in Eqn. (4) and (5)

$$V_{dcerr} = V_{dcref}^{*} - V_{dcact} \quad (4)$$
$$I_{mt} = I_{mn} - K_{pv} * \left(V_{dcerr(n)} - V_{dcerr(n-1)}\right) + K_{iv} * \left(V_{dcerr(n)}\right) \quad (5)$$

The reference currents are acquired by multiplying the outcome of unit vector template and current component (I_{mt}). The reference currents ($I_{aref}^{*}, I_{bref}^{*}, I_{cref}^{*}$) are illustrated as;

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$$I^{*}_{aref} = UV_a * I_{mt}$$
$$I^{*}_{bref} = UV_b * I_{mt}$$
$$I^{*}_{cref} = UV_c * I_{mt} \quad (6)$$

The reference current of shunt-VSI of UPQC is generated by unit-vector control theory and the actual current is detected by analyzers. Both are compared, to obtain a current error for generation of optimal switching states to the VSC topology of DVR by using Hysteresis Current controller (HCC).

C. Synchronous Reference Frame Theory based Control

The schematic diagram of Synchronous Reference Frame Theory based Control of DVR is illustrated in figure 5. One unfussy methodology to generate reference currents is SRF theory and here the three-phase 'abc' frame load currents are transformed to 'dq' frame so that the filter functioning eliminates the harmonic contents. After transformation, the stationary components are transformed to rotary components. These rotator parameters are again inverse-transformed to generate reference components. The reference components are then compared with actual currents to generate control gate pulses to DVR switches. Table-I indicates the SRF control theory for controlling DVR switches gives better flexibility with reduced complexity involving less mathematical calculations.

Table.1
Comparison of Control strategies

Control	Complexity	Mathematical Calculations
ABC Theory	High	High
Unit Vector Theory	High	High
SRF Theory	Low	Moderate

IV. MATLAB/SIMULINK RESULTS

The simulation analysis is carried under the effectiveness of the voltage sag and voltage swell with compensation scheme.

A. DVR with ABC Control

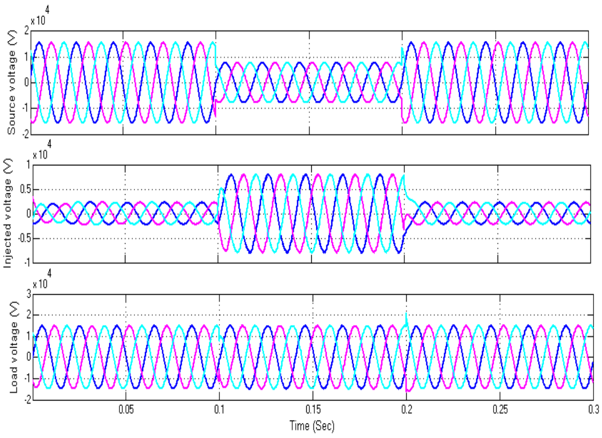

Fig.6 Three-phase voltage in source, compensating voltage and three-phase voltages at load for Sag compensation

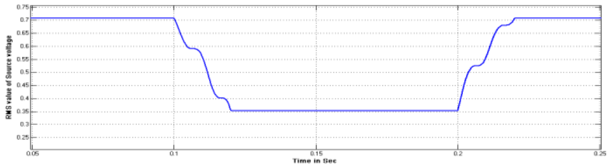

Fig.7: RMS voltage of source component during sag

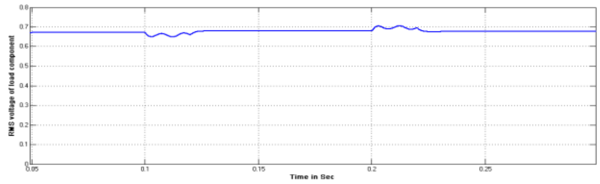

Fig.8: RMS voltage of load component during sag

Figure 6 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for Sag compensation. Sag observed from time duration 0.1 sec to 0.2 sec in source voltage is nullified in load voltages. Figure 7 represents RMS voltage of source component during sag. Figure 8 represents RMS voltage of load component during sag.

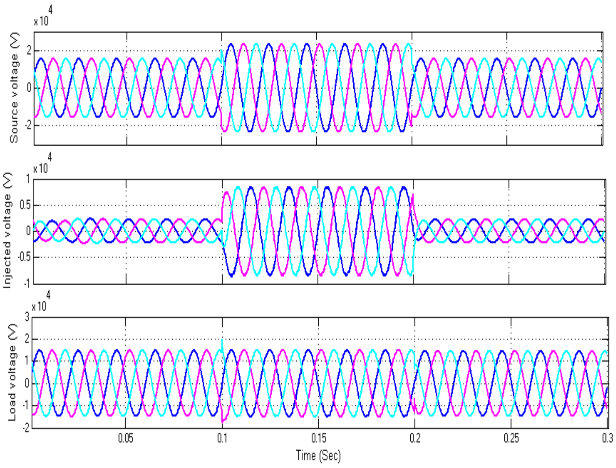

Fig.9 Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation

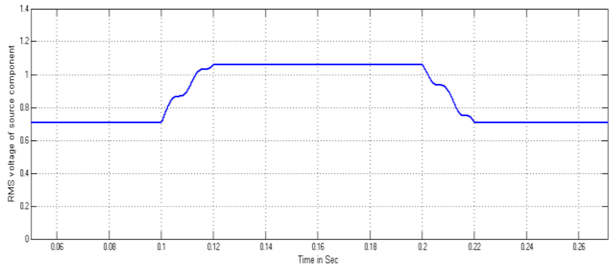

Fig.10: RMS voltage of source component during swell

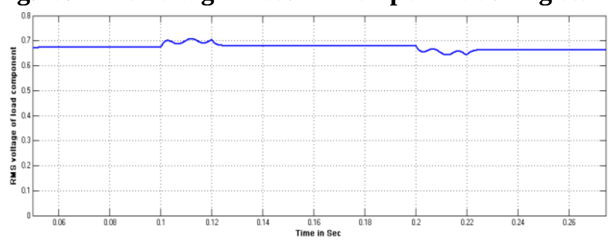

Fig.11: RMS voltage of load component during swell

Figure 9 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation. Swell observed from time duration 0.1 sec to 0.2 sec in source voltage is nullified in load voltages. Figure 10 represents RMS voltage of

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source component during swell. Figure 11 represents RMS voltage of load component during swell.

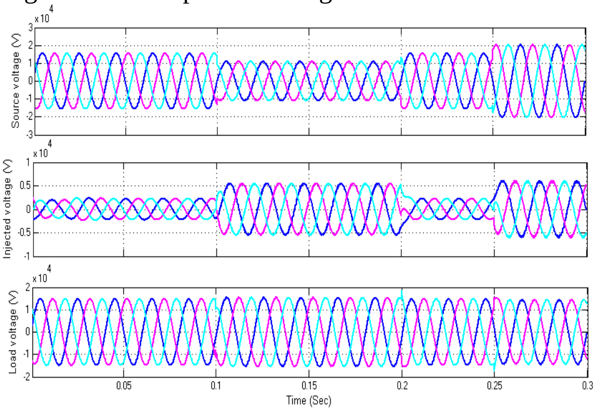

Fig.12 Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag & Swell compensation

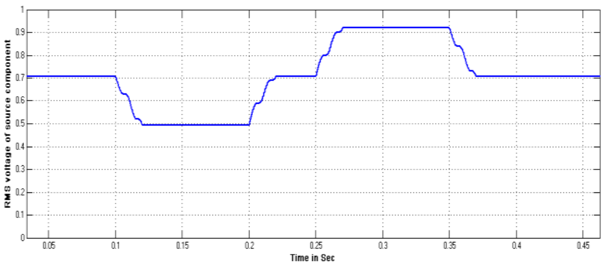

Fig.13: RMS voltage of source component during sag & swell condition

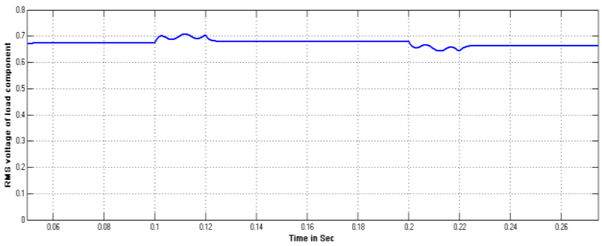

Fig.14: RMS voltage of load component during sag & swell condition

Figure 12 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag and Swell compensation. Sag observed from time duration 0.1 sec to 0.2 sec and swell from 0.25sec to 0.3 sec in source voltage and both sag and swell are nullified in load voltages. Figure 13 represents RMS voltage of source component during sag and swell. Figure 14 represents RMS voltage of load component during sag and swell.

B. DVR with Unit vector theory Control

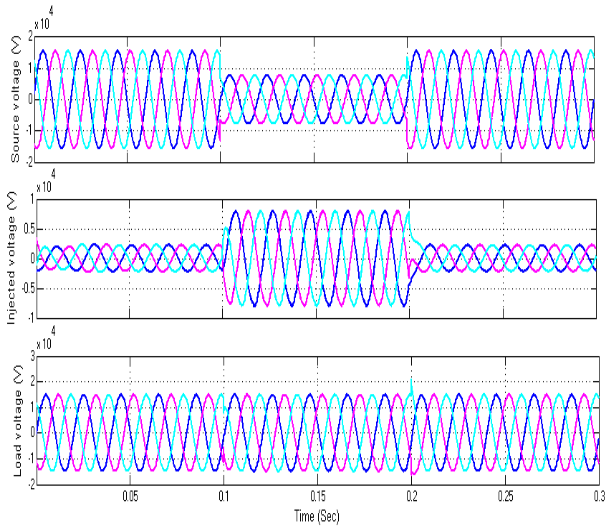

Fig.15 Source voltage, Injected voltage and Load voltages for Sag compensation

Figure 15 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag compensation. Sag observed from time duration 0.1 sec to 0.2 sec in source voltage and sag is nullified in load voltage.

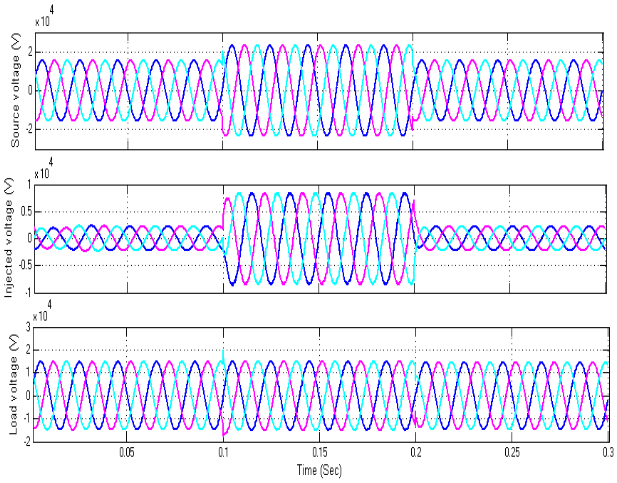

Fig.16 Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation

Figure 16 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation. Swell observed from time duration 0.1 sec to 0.2 sec in source voltage and swell is nullified in load voltage. Figure 17 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag and Swell compensation. Sag is observed from time duration 0.1 sec to 0.2 sec and swell from 0.25sec to 0.3 sec in source voltage and both sag and swell are nullified in load voltages.

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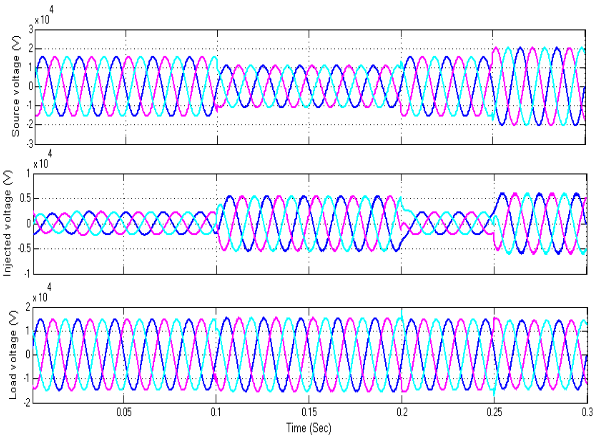

Fig.17 Source voltage, Injected voltage and Load voltage for Sag and Swell

C. DVR controlled from SRF theory

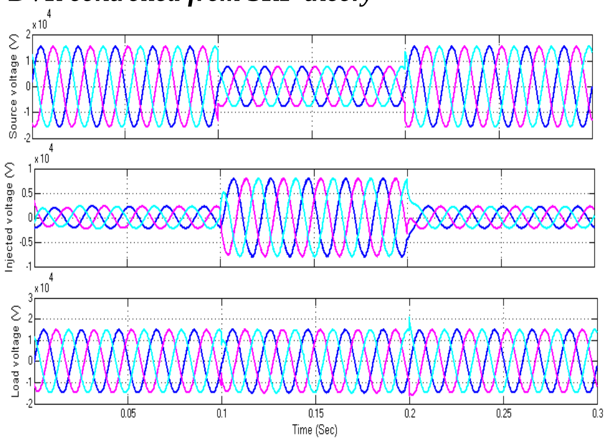

Fig.18 Source voltage, Injected voltage and Load voltages for Sag compensation

Figure 18 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag compensation. Sag observed from time duration 0.1 sec to 0.2 sec in source voltage and sag is nullified in load voltages.

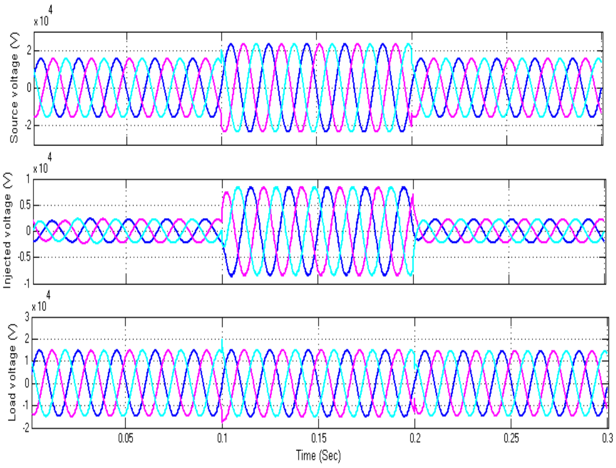

Fig.19 Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation

Figure 19 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for Swell compensation. Swell observed from time duration 0.1 sec to 0.2 sec in source voltage and swell is nullified in load voltages.

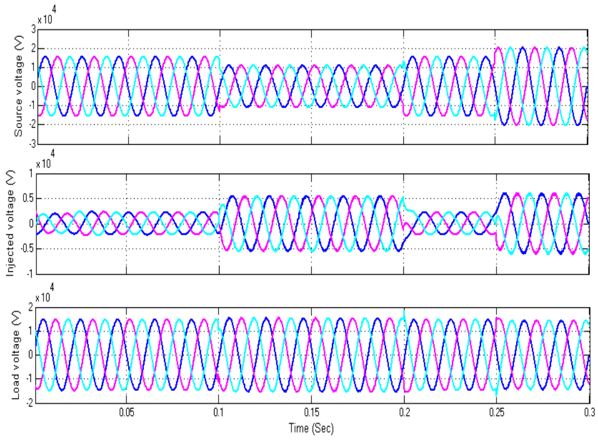

Fig.20 Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag and Swell compensation

Figure 20 illustrates Three-phase voltage in source, compensating voltage and three-phase voltages at load for sag and Swell compensation. Sag is observed from time duration 0.1 sec to 0.2 sec and swell from 0.25sec to 0.3 sec in source voltage, both sag and swell are nullified in load voltages.

V. CONCLUSION

The paper presents the different control methodologies for DVR to regulate the voltage wave in distribution system from sag/swell. RMS voltages of source and load components are shown during sag period and swell period. DVR compensates for sag and swell in source voltage presenting constant voltage at load point. Three control strategies are presented and SRF theory for controlling DVR is found simple in operation.

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