



# ANALYSIS OF VARIOUS CONTROL STRATEGIES OF DYNAMIC VOLTAGE RESTORER FOR POWER QUALITY IMPROVEMENT IN DISTRIBUTION SYSTEM

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## ABSTRACT

The development in power electronic technology has created a major awareness regarding power quality in power distribution system. The paper presents various control strategies of Dynamic Voltage Restorer (DVR) for Power Quality improvement in Distribution system. Paper mainly focuses on impact and mitigation of power quality issues like voltage sag/swell in power distribution system with sensitive loads. The power quality issue voltage sag or voltage swell is mitigated by injecting compensating signals using custom power device DVR. DVR is controlled using different control strategies like ABC algorithm, unit-vector theory and SRF theory in this paper. Simulation analysis is carried out for DVR in distribution system with voltage quality issues with different control strategies showing out source voltage with voltage quality problem (sag/swell), compensating signals from DVR and load voltage. Simulation analysis is carried out using MATLAB/SIMULINK software.

**Keywords:** compensation, voltage sag, voltage swell, sensitive load, DVR.

## INTRODUCTION

Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. Modern industrial processes are based a large amount of electronic devices such as programmable logic controllers and adjustable speed drives. The electronic devices are very sensitive to disturbances [1] and thus industrial loads become less tolerant to power quality problems such as voltage dips, voltage swells, and harmonics.

Voltage dips are considered one of the most severe disturbances to the industrial equipment. A machine can be affected by disturbance of 10% voltage drop lasting for 100ms. Voltage dip of 70% (of the normal voltage) with duration shorter than 100ms can result in huge material loss and economy for the industries. Swells and over voltage can over heating tripping of even destruction of industrial equipment such as motor drives. Electronics equipments are very sensitive loads against power quality issues because their control depends on either the peak value or the zero crossing of the supplied voltage, which are influenced by the distortion. As one of the prominent power quality problems, the origin, consequences and mitigation techniques of voltage sag and swell problems are to be prominent in dealing them. The study describes the techniques of correcting the supply voltage sag and swell in a distribution system by power electronics based device called Dynamic Voltage Restorer (DVR). A DVR injects voltage in series with the system voltage to correct the voltage sag [2-4].

A sudden change of current flow in a distribution system can cause voltage sag or swell raising power quality issue. Sag is termed as a short term dip in rms value of supply voltage from 0.9 pu to 0.1 pu and swell is defined as a momentary raise in rms voltage from 1.1 pu to 1.8 pu. Though they are momentary in nature but can affect the connected loads and the system seriously. 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].

There are two approaches to the mitigation of power quality problems. The solution to the power quality can be done from customer side or from utility side [10-12]. First approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by DVR [13]. However, with the restructuring of power sector and with shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions plays a major role in improving the inherent supply quality.

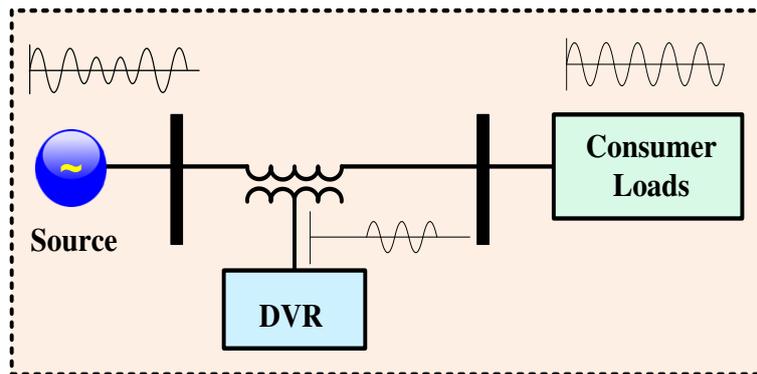


Figure-1. Block diagram of DVR.

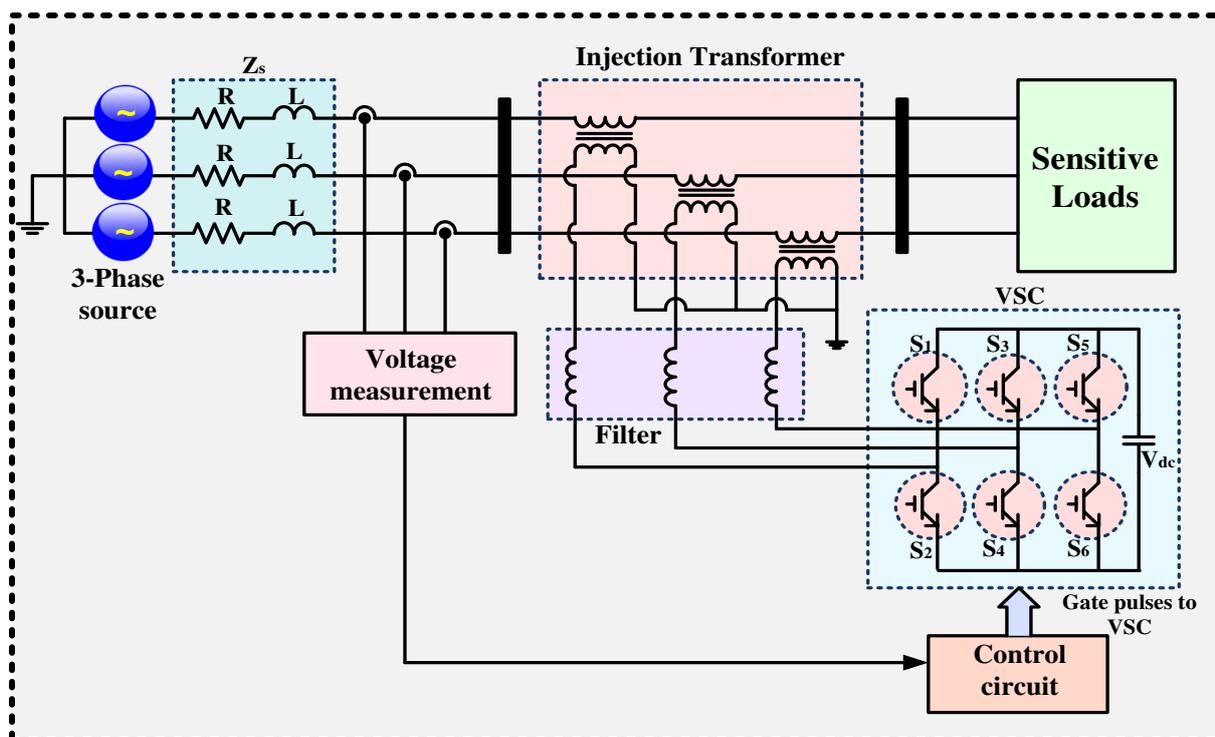


Figure-2. DVR in distribution system with sensitive loads.

Gate pulses to DVR are generated from control circuit to induce required compensation. The paper presents various control strategies of Dynamic Voltage Restorer (DVR) for Power Quality improvement in Distribution system. Paper mainly focuses on impact and mitigation of power quality issues like voltage sag/swell in power distribution system with sensitive loads. The power quality issue voltage sag or voltage swell is mitigated by injecting compensating signals using custom power device DVR.

DVR as shown in Figure-1 is controlled using different control strategies like ABC algorithm, unit-vector theory and SRF theory in this paper. Simulation analysis is carried out for DVR in distribution system with voltage quality issues with different control strategies showing out source voltage with voltage quality problem (sag/swell), compensating signals from DVR and load voltage.

Simulation analysis is carried out using MATLAB/SIMULINK software.

### DYNAMIC VOLTAGE RESTORER (DVR)

Figure-2 shows the in DVR in power distribution system with sensitive loads consists of an injection transformer, Harmonic filter, Storage Devices, a Voltage Source Converter (VSC), and DC link circuit and Control system. During voltage sag/swell conditions in power distribution system, the DVR injects a compensating voltage to restore the load voltages as demanded. The DVR needs a source for this energy and employs a DC link capacitor in general. The Voltage Source converter (VSC) converts the dc voltage from the energy storage unit (or the dc link) to a controllable three phase ac voltage. The nonlinear characteristics of semiconductor devices (VSC) cause distorted waveforms associated with high frequency harmonics at the converter output. To



overcome this problem, a high quality energy supply harmonic filtering unit is used. Three single-phase injection transformers are used to inject the compensating voltage to the system at the load bus. To integrate the injection transformer correctly into the DVR, the MVA rating, the primary winding voltage and current ratings, the turn-ratio and the short-circuit impedance values of transformers are required. The existence of the transformers allow for the design of the DVR in a lower voltage level, depending upon the stepping up ratio.

**CONTROL STRATEGIES OF DYNAMIC VOLTAGE RESTORER (DVR)**

**ABC Theory based Control of DVR**

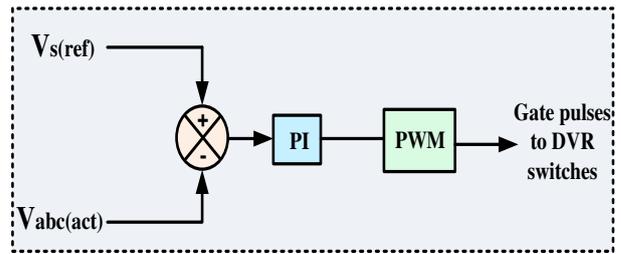


Figure-3. ABC control theory of DVR.

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 mitigation of voltage sag and swell in distribution system. Figure-3 shows the simple ABC control strategy to produce gate signals to DVR VSC. The Source Voltage  $V_s$  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.

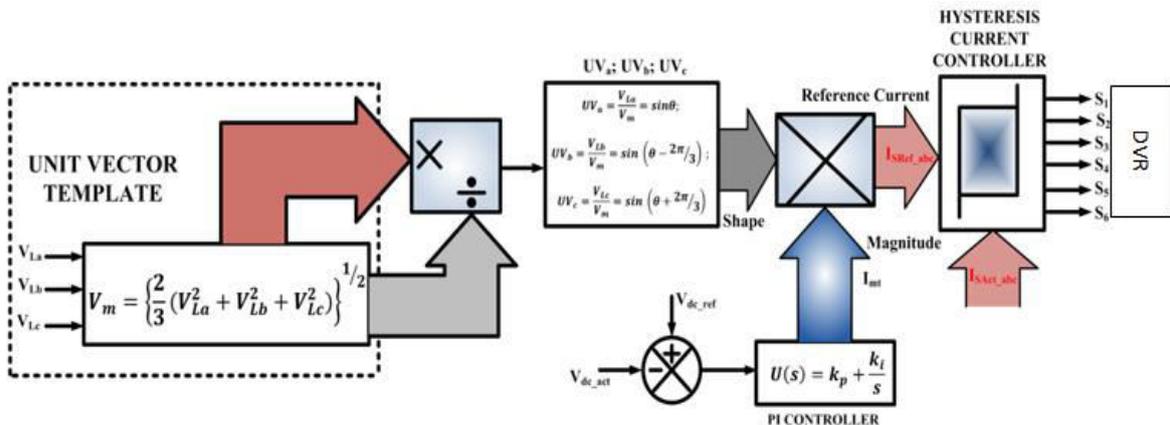


Figure-4. Unit Vector Theory for controlling DVR.

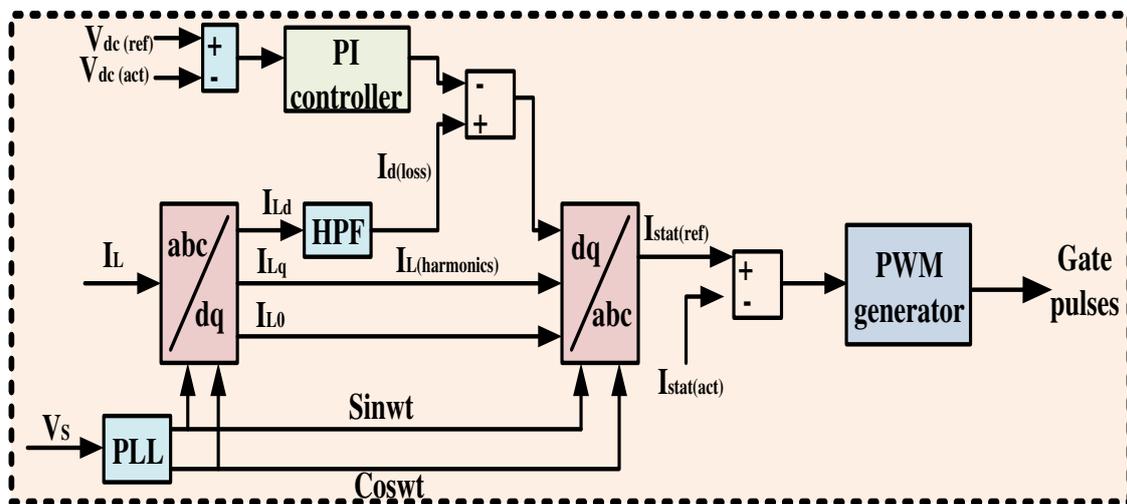


Figure-5. SRF Theory for controlling DVR.



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.

### 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:

$$\begin{aligned} V_{La} &= V_{ma} \sin\theta \\ V_{Lb} &= V_{mb} \sin(\theta - 2\pi/3) \\ V_{Lc} &= V_{mc} \sin(\theta + 2\pi/3) \end{aligned} \quad (1)$$

The generated unit vector template is,

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

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

$$\begin{aligned} UV_a &= \frac{V_{La}}{V_m} = \sin\theta; \\ UV_b &= \frac{V_{Lb}}{V_m} = \sin(\theta - 2\pi/3); \\ UV_c &= \frac{V_{Lc}}{V_m} = \sin(\theta + 2\pi/3); \end{aligned} \quad (3)$$

The generated unit-vector outcome voltages ( $UV_a, UV_b, UV_c$ ) are combined to form a reference current by utilizing active current component ( $I_{mt}$ ). The " $I_{mt}$ " 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  $n^{\text{th}}$  sampling period is illustrated in Equation (4) and (5):

$$V_{dcerr} = V_{dcref}^* - V_{dcact} \quad (4)$$

$$I_{mt} = I_{mn} - K_{pv} * (V_{dcerr(n)} - V_{dcerr(n-1)}) + K_{iw} * (V_{dcerr(n)}) \quad (5)$$

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:

$$\begin{aligned} I_{aref}^* &= UV_a * I_{mt} \\ I_{bref}^* &= UV_b * I_{mt} \\ I_{cref}^* &= UV_c * I_{mt} \end{aligned} \quad (6)$$

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). Hysteresis loop or band (HL) is acts as the boundary limit of compensation current. This current is controlled in between these lower/upper hysteresis limits to control the inside the hysteresis band followed by reference current generated by UVC theory.

### Synchronous Reference Frame Theory based Control

The schematic diagram of Synchronous Reference Frame Theory based Control of DVR is illustrated in Figure-5. The Source Voltage  $V_s$  is sensed and give it as an input to the transformation block (abc/dq) and same source voltage ( $V_s$ ) is given as an input to the PLL block. The PLL block generates sin,cos functions. This is given as an input to the inverse transformation block (abc/dq). The input transformation block results the  $V_d, V_q$  and  $V_o$  and information is compared with  $V_{dact}, V_{qact}$  and  $V_{oact}$  which are the actual parameters of the quadrature and  $V_o$  axis is compared with 0 p.u. The error generated is given as an input to the PI controller. The PI controller output is again given as an input to dq/abc block, and PLL information is given as an input to dq/abc block. This block gives us the pulse information which is given as an input to PWM generator and from which the gate pulses are generated for VSC of DVR.

**Table-1.** Comparison of Control strategies.

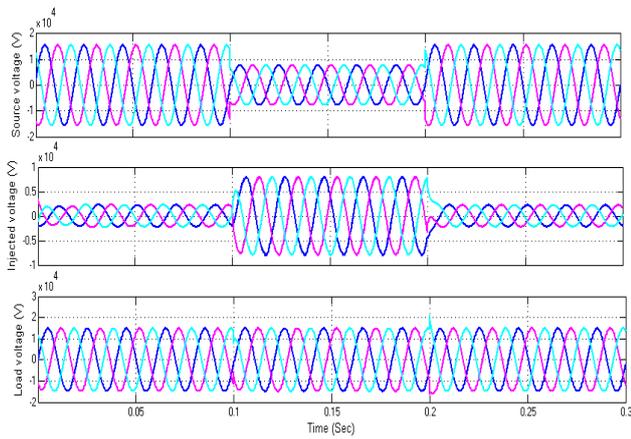
Control	Complexity	Mathematical Calculations
ABC Theory	High	High
Unit Vector Theory	High	High
SRF Theory	Low	Moderate

Table-1 illustrates the SRF control theory for controlling DVR switches gives better flexibility with reduced complexity involving less mathematical calculations.

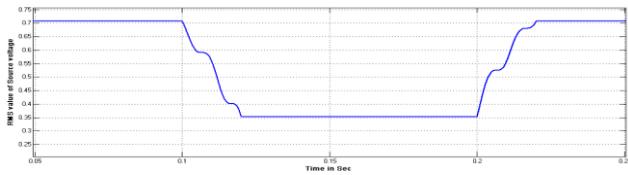
## RESULTS AND DISCUSSIONS

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

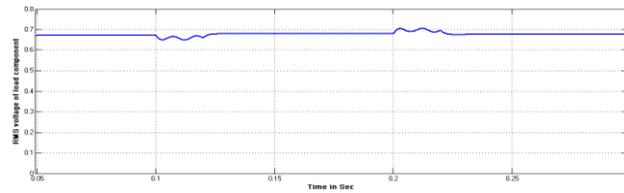
### Case 1: DVR with ABC Control



**Figure-6.** Source voltage, Injected voltage and Load voltages for Sag compensation.

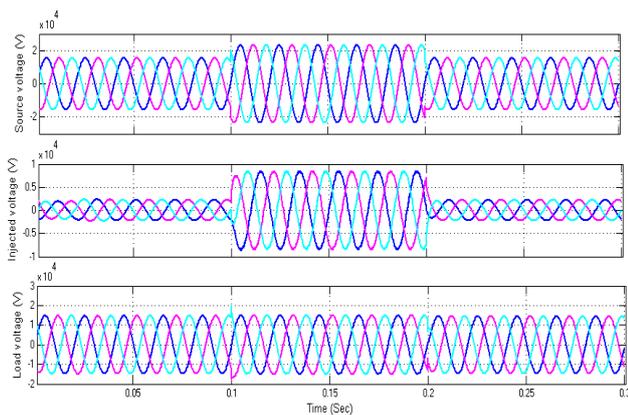


**Figure-7.** RMS voltage of source component during sag.

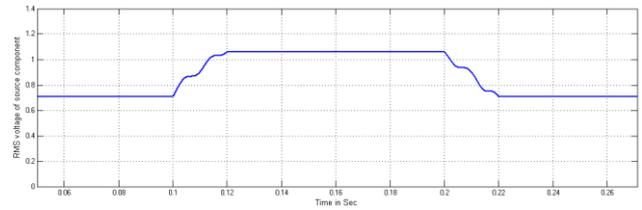


**Figure-8.** RMS voltage of load component during sag.

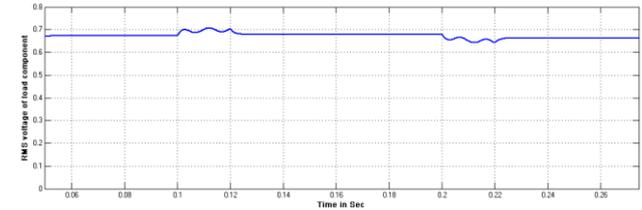
Figure-6 shows the Source voltage, Injected voltage and Load voltages for Sag in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude. Figure-7 represents RMS voltage of source component during sag. Figure-8 represents RMS voltage of load component during sag.



**Figure-9.** Source voltage, Injected voltage and Load voltage for Swell.

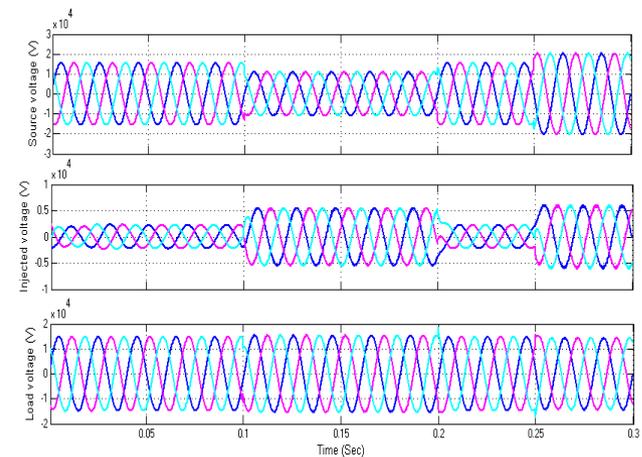


**Figure-10.** RMS voltage of source component during swell.

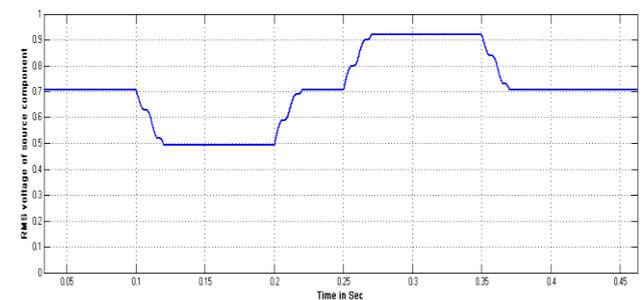


**Figure-11.** RMS voltage of load component during swell.

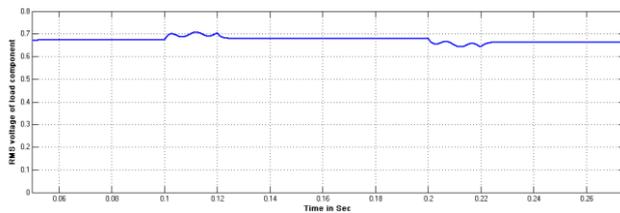
Figure-9 shows the Source voltage, Injected voltage and Load voltages for Swell in power system. Swell is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude. Figure-10 represents RMS voltage of source component during swell. Figure-11 represents RMS voltage of load component during swell.



**Figure-12.** Source voltage, Injected voltage and Load voltage for Sag and Swell.



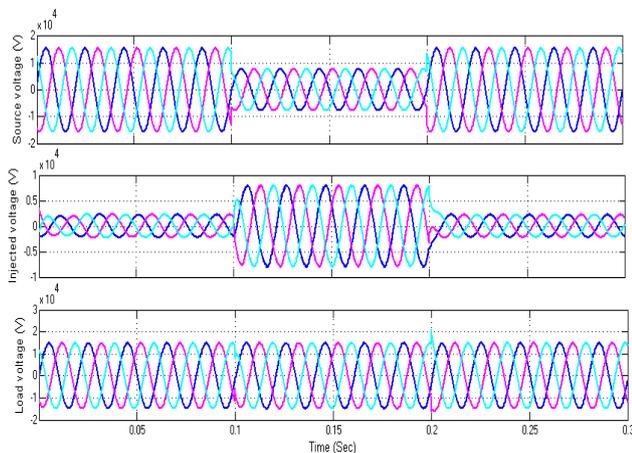
**Figure-13.** RMS voltage of source component during sag & swell condition



**Figure-14.** RMS voltage of load component during sag & swell condition.

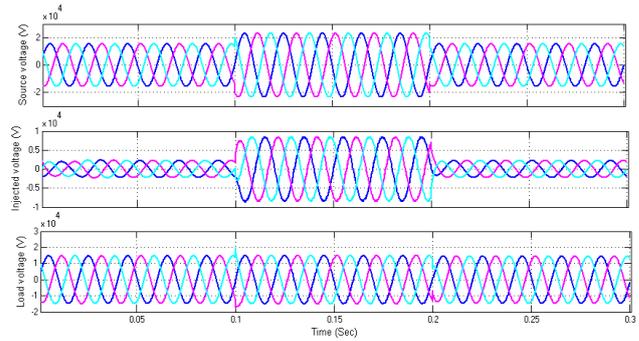
Figure-12 shows the Source voltage, Injected voltage and Load voltages for Sag and swell in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec and swell is observed during 0.25 sec to 0.3 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude compensating sag and swell in power system. Figure-13 represents RMS voltage of source component during sag and swell. Figure-14 represents RMS voltage of load component during sag and swell.

**Case 2: DVR with Unit vector theory Control**



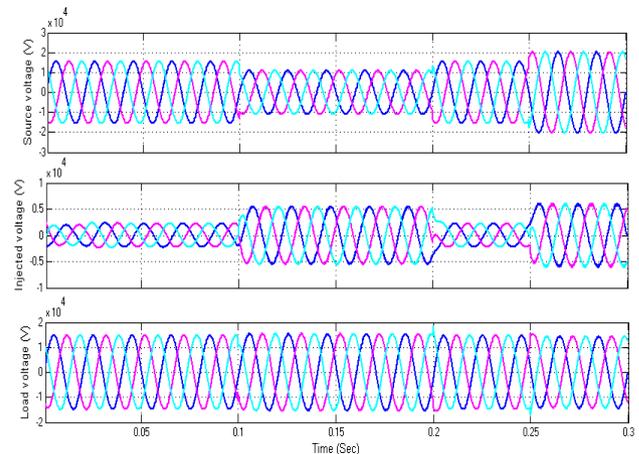
**Figure-15.** Source voltage, Injected voltage and Load voltages for Sag compensation.

Figure-15 shows the Source voltage, Injected voltage and Load voltages for Sag in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude.



**Figure-16.** Source voltage, Injected voltage and Load voltage for Swell.

Figure-16 shows the Source voltage, Injected voltage and Load voltages for Swell in power system. Swell is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude.

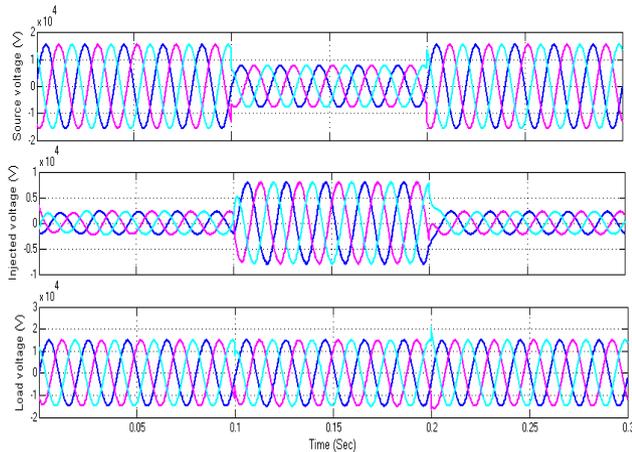


**Figure-17.** Source voltage, Injected voltage and Load voltage for Sag and Swell.

Figure-17 shows the Source voltage, Injected voltage and Load voltages for Sag and swell in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec and swell is observed during 0.25 sec to 0.3 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude compensating sag and swell in power system.

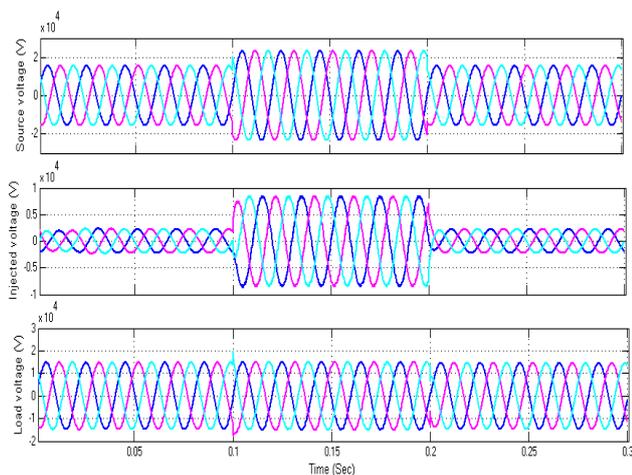


### Case 3: DVR with SRF theory Control



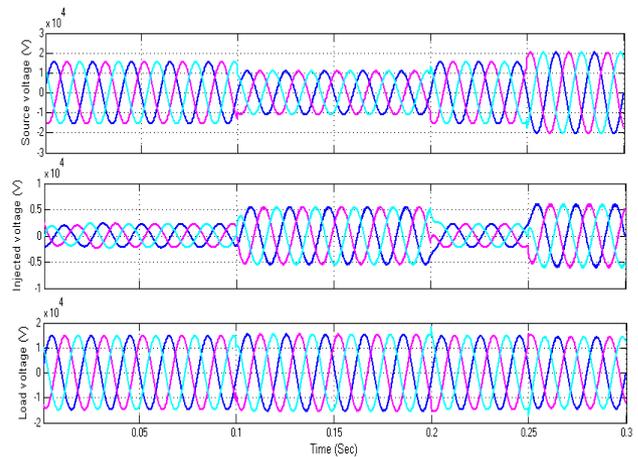
**Figure-18.** Source voltage, Injected voltage and Load voltages for Sag compensation.

Figure-18 shows the Source voltage, Injected voltage and Load voltages for Sag in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude.



**Figure-19.** Source voltage, Injected voltage and Load voltage for Swell.

Figure-19 shows the Source voltage, Injected voltage and Load voltages for Swell in power system. Swell is observed in source voltage during 0.1 sec to 0.2 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude.



**Figure-20.** Source voltage, Injected voltage and Load voltage for Sag and Swell

Figure-20 shows the Source voltage, Injected voltage and Load voltages for Sag and swell in power system. Sag is observed in source voltage during 0.1 sec to 0.2 sec and swell is observed during 0.25 sec to 0.3 sec. DVR injects corresponding voltage compensating signals to power system and thus the load voltage is maintained with constant amplitude compensating sag and swell in power system.

### CONCLUSIONS

Power quality is certainly a major concern in the present era; it becomes especially important with the introduction of sophisticated devices, whose performance is very sensitive to the quality of power supply. DVR is one of the custom power devices to clear-out voltage quality issues. In this paper a brief review is done on DVR configurations and its control strategies. 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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