Improvement of Voltage Quality in a Distribution System by a Novel Simplified Unit Vector Theory

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Abstract: Nowadays, electrical engineers are increasingly concerned about power quality due to the rising load demand and the utilization of non-linear loads by end users. Power must be supplied continuously and with excellent quality. Voltage variation is a prevalent occurrence in power distribution systems due to the presence of reactance in AC systems and fluctuations in load demand. The dynamic voltage restorer is a compensation device that effectively resolves voltage problems within power distribution systems. The theory of synchronous reference frame is utilized for controlling the DVR components, requiring intricate computations due to the implementation of abc-dq transformation, phase-lock loops, and PI control. The following document introduces an innovative simplified unit vector theory designed to streamline the control of DVR, ultimately minimizing control complexity. The novel streamlined approach underwent testing in scenarios involving distribution systems experiencing sag, swell, or a combination of both. Simulation models were created and outcomes were achieved through the utilization of MATLAB/SIMULINK software.

Keywords: **Dynamic voltage restorer (DVR), sag, swell, control, voltage, quality.**

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1. Introduction

The quality of power reflects how closely a practical system resembles an ideal system. Maintaining voltage, current, frequency and power within nominal values is called power quality. The system voltage fluctuates due to the increase in load demand and the existence of reactance in the power distribution system [1-4]. Day-by-day, load is been increased and the connected loads expect continuous power supply with good quality. When the power is not characterized with quality, the end loads might be affected with inculcating disturbances in the system which demand additional accessories for mitigation.

An abrupt alteration in current flow within a distribution system has the potential to result in voltage sag or swell, thereby elevating concerns regarding power quality. Sag refers to a temporary decrease in the root mean square (rms) value of the supply voltage, ranging from 0.9 pu to 0.1 pu. On the other hand, swell is defined as a brief increase in the rms voltage, ranging from 1.1 pu to 1.8 pu. While they may be temporary in nature, they have the potential to significantly impact both the connected loads and the overall system. The presence of a sag can shorten the lifespan of the connected load, while a swell can cause damage to the load [5,6]. The occurrence of voltage sag can be attributed to the abrupt activation of high-power devices and the existence of inductive reactance components within the system. The occurrence of voltage swell can be attributed to the abrupt deactivation of high-power equipment and the existence of capacitive reactance components within the system. The activation of capacitive banks or loads of the capacitive nature can also lead to voltage surges. It is imperative to promptly eliminate sag and swell in order to prevent any adverse impact on connected loads.

Numerous remedies exist for sag and swell, however, the utilization of FACTS devices can efficiently eliminate the impact of sag and swell. The Dynamic Voltage Restorer (DVR) is a FACTS controller that efficiently mitigates the impact of voltage sags and swells. The DVR functions as a FACTS controller that is installed in series with the distribution system. The DVR injects electrical voltage into the system in the presence of a sag, while it absorbs voltage in the event of a swell being detected. DVR is an electrical converter that operates as a voltage source converter (VSC) by utilizing power electronic switches. By effectively managing the switching between the legs of VSC, the distribution network can either receive or release voltage based on the prevailing conditions. A control circuit is essential for switching the static switches on and off in the DVR to ensure the system's voltage profile [7-9] is maintained. The detection of sag and swell in the distribution system is crucial for compensation. The control circuit plays a crucial role in the functioning of the DVR.

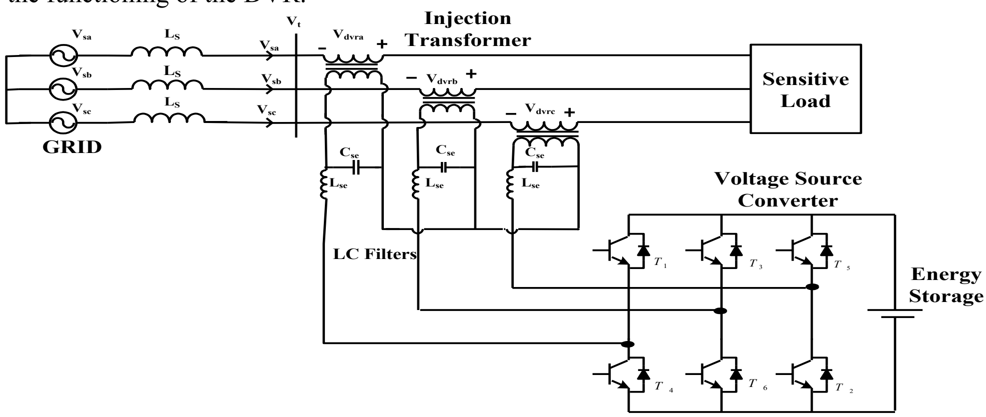

Figure 1: DVR connected to distribution system.

Many control techniques are available to control DVR [10-12] out of one simple strategy is synchronous reference frame theory (SRF). But SRF theory suffers from complex calculations as SRF theory involves abc-dq transformations. Presence of phase locked loop (PLL) and PI control also increases the complexity in control methodology. This paper presents a novel control methodology to control DVR which does not involve complex calculations. A simplified control methodology unit vector theory was used to control DVR for improving voltage quality in distribution system. Detailed explanation of said control strategy will be explained in subsequent sections. System models with DVR for voltage sag and swell were developed and results were obtained using MATLAB/SIMULINK software. Results were explained considering cases for system with SRF controlled DVR and novel unit vector controlled DVR. Compensation for voltage sag and swell were depicted in results.

2. Distribution system with DVR

Dynamic voltage restorer (DVR) is a series FACTS device which compensates voltage in distribution system. DVR connected to distribution system was shown in figure 1. DVR is placed in series to the distribution system and so called series controller. DVR is simply a voltage source converter (VSC) consisting of static power electronic switches with a DC link voltage. The DC voltage from the DC link is converted and supplied to distribution system thus maintaining nominal voltage in distribution system such that the loads connected are not affected due to voltage disturbance. DC link voltage is very important, generally a capacitor is used as DC link but instead a DC sources like batteries, distributed generation can also be employed. The converter supplies voltage to the distribution system via injection transformer placed in the distribution system. Power electronic switches in DVR are controlled by pulses from control circuit. A filter can be inculcated at the output of DVR to smoothen the output of DVR.

3. Control of DVR for voltage compensation

3.1. DVR with SRF theory

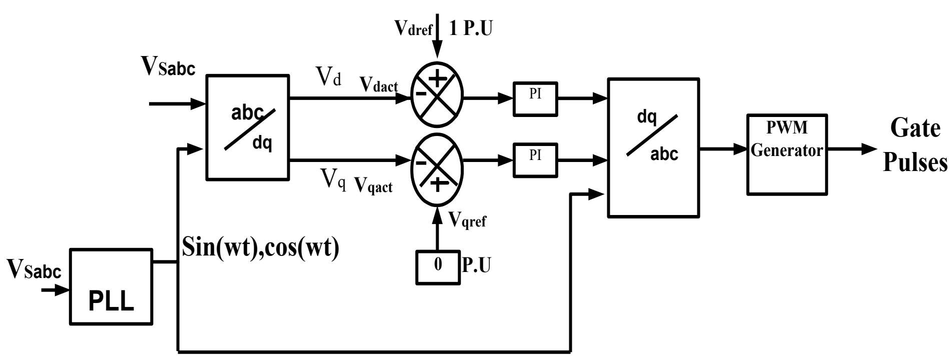

Figure 2: SRF theory of controlling DVR

DVR with SRF theory involves PLL, PI blocks along with abc-dq and dq-abc transformations thus producing gate pulses to the DVR. Initially source voltage is sensed and sent to PLL block. PLL block extracts or gives information regarding sine and cosine wave of sensed input voltage. Obtained sine wave information is sent as a first signal for abc-dq transformation and the other signal is obtained from source voltage. The transformation gives direct component of voltage and quadrature component of voltage. These direct and quadrature components of voltages are compared with their respective reference signals and the error signal is sent to PI controller which gives output to dq-abc transformation. The information of sine and cosine wave is also sent along with the output of PI controller to dq-abc transformation, thus transforming and sends signal to PWM generator. PWM generator produces gate pulses and power electronic switches in DVR acts accordingly. SRF theory involves many calculations and makes the control theory a bit complex. Block diagram of SRF theory was shown in figure 2 and figure 3 shows DVR with SRF theory.

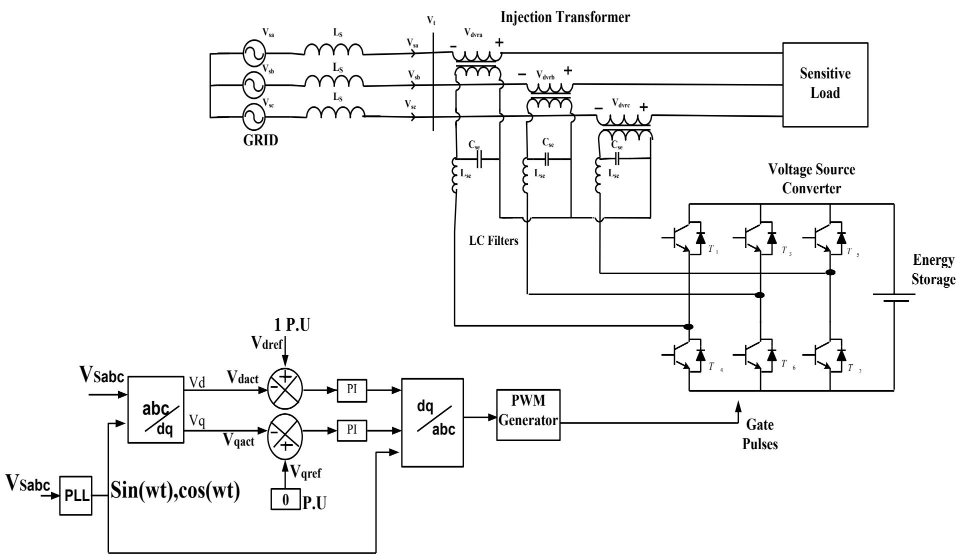

Figure 3: DVR with SRF theory

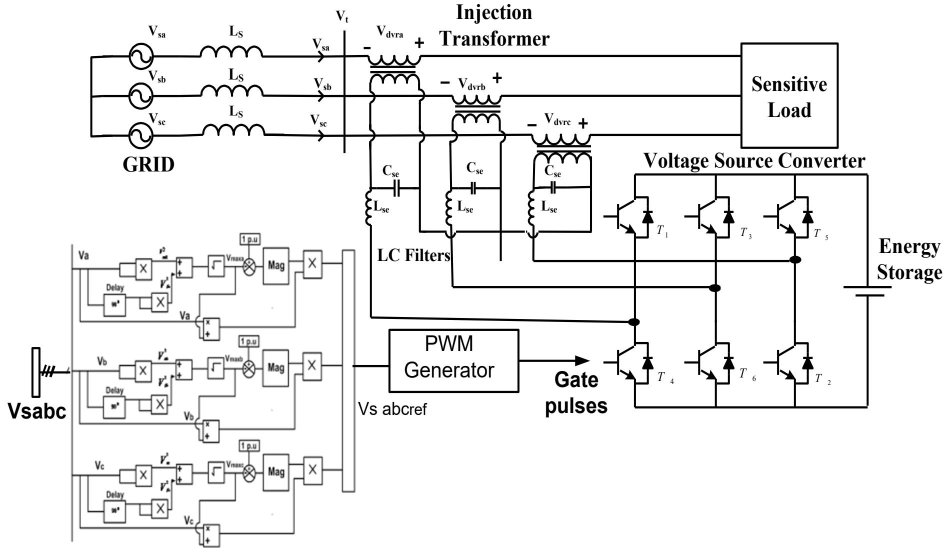

Figure 4: DVR with simplified unit vector control theory

3.2. DVR with proposed unit vector control theory

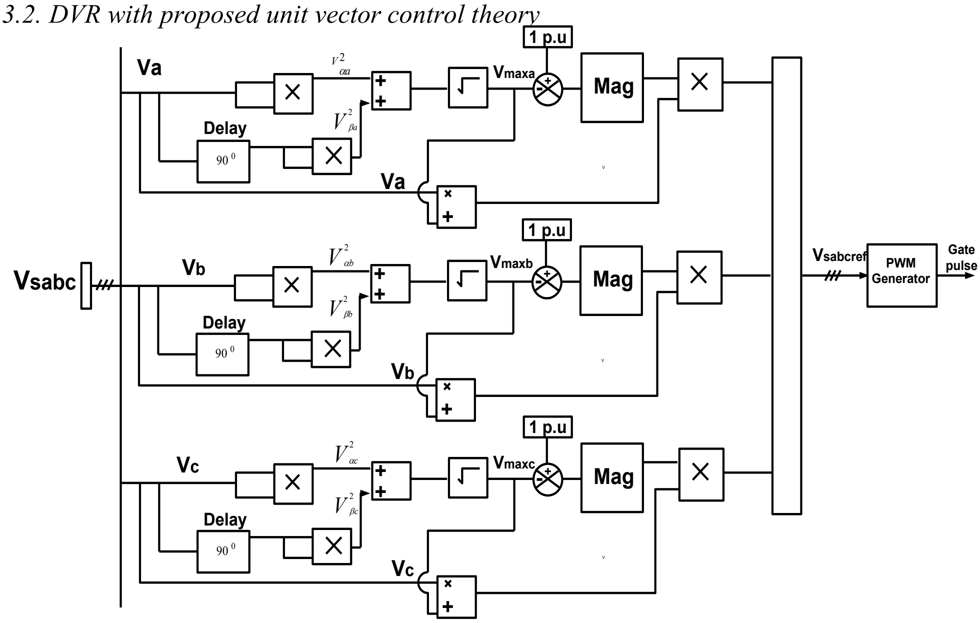

Figure 5: Control block diagram of proposed unit vector theory

DVR with simplified unit vector theory is depicted in Figure 4, while Figure 5 illustrates the block diagram of the proposed control theory. In this control technique for managing DVR, there is no requirement for information on sine or cosine, and transformations are unnecessary too. Complex calculations are circumvented, simplifying the control method. The initial data on Va, Vb, and Vc is sourced from the voltage origin. Va multiplying with Va gives $V\alpha a^2$. The signal $V\beta a^2$ is obtained by adding a delay of 90^0 to Va and then adding it to the original signal. The signal obtained is subsequently subjected to a square root operation, and the highest value is ascertained. The obtained maximum value is compared with a value of 1 pu, and the magnitude is determined. The signal obtained by performing an arithmetic operation on Va and the maximum value was multiplied by this magnitude. The acquired signal represents the reference value. The explained procedure is for Va. The same process is employed to acquire the reference signal for Vb and Vc. The aggregated reference signal is transmitted to the PWM generator which generates gate pulses for the static switches in the DVR. The control design becomes simplified as this control method eliminates the need for intricate calculations involving transformations and other complex processes.

4. MATLAB results and illustrations

Results were obtained and discussed for two cases. One is DVR driven with conventional SRF theory and the other is for DVR driven from proposed unit vector control theory. For both the cases, distribution system consisting sag, swell individually were discussed and the system containing both sag and swell were also discussed. For all the cases source voltage, DVR voltage and load voltage were shown. All the voltage values are considered to be in per unit values.

4.1. DVR with SRF theory

Figure 6 shows the results pertaining to source voltage, DVR injected voltage and load voltage for DVR driven with conventional SRF theory. At instant 0.1 sec, sag was observed in voltage of distribution system and persists till

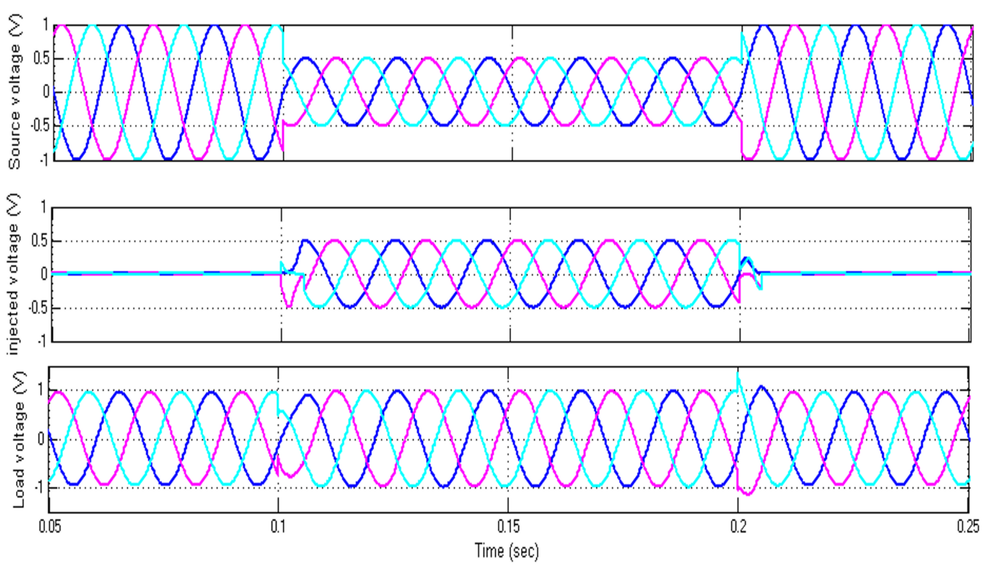

Figure 6: Result showing source voltage, DVR injected voltage and load voltage with sag

0.2 sec. During this period of time, the system voltage was dropped from 1pu to 0.5pu. Since DVR is connected to the system, DVR now injects required voltage of 0.5pu from 0.1 sec to 0.2 sec in to the system as seen in the results. The load voltage was maintained constant as a result of DVR presence nullifying the effect of sag on load, compensating source voltage.

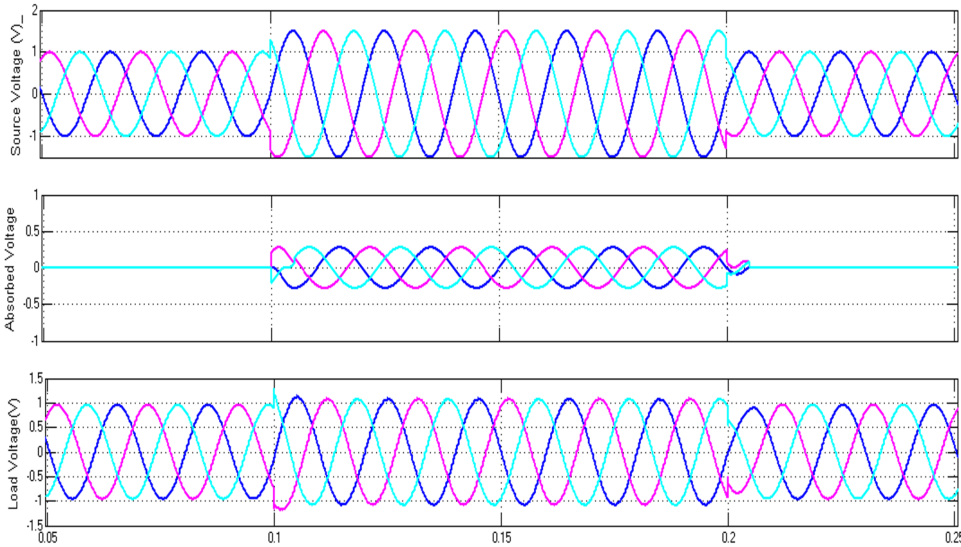

Figure 7: Result showing source voltage, DVR voltage and load voltage with swell

Similarly, at instant 0.1 sec, swell was observed in voltage of distribution system and persists till 0.2 sec which can be observed from figure 7. During this period of time, the system voltage was raised above 1pu. Since DVR is connected to the system, DVR now absorbs excess voltage from 0.1 sec to 0.2 sec from the system as seen in the results. The load voltage was maintained constant as a result of DVR presence nullifying the effect of swell on load, compensating source voltage.

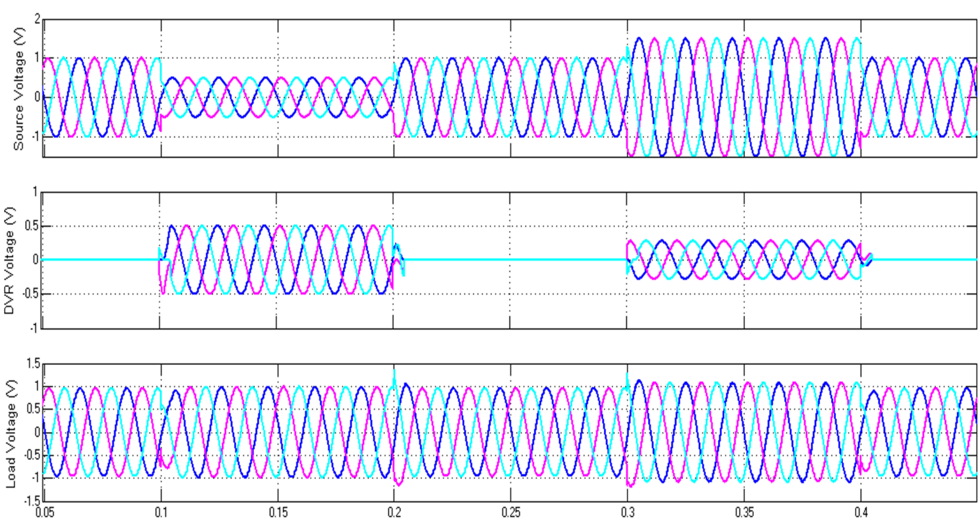

Figure 8: Result showing source voltage, DVR injected voltage and load voltage with sag and swell

In figure 8, the system containing both sag and swell can be observed. Now DVR is suppose to compensate both sag and swell effect. From 0.1 sec to 0.2 sec the effect of sag can be observed where voltage drops to 0.5pu from 1pu and from 0.3 sec to 0.4 sec, the effect of swell can be observed in which voltage raises above 1pu. DVR compensating voltages are observed compensating the source voltage by injecting/absorbing source voltage thus maintaining the system voltage constant. Constant voltage profile was observed in the results even when system contains both sag and swell.

4.2. DVR with proposed unit vector control theory

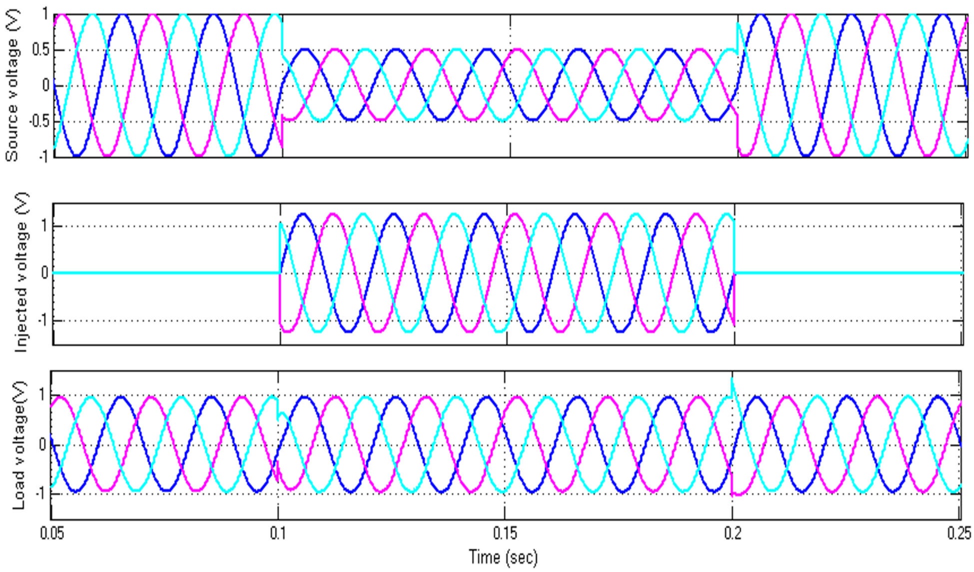

Figure 9: Result showing source voltage, DVR injected voltage and load voltage with sag

Figure 9 shows the results pertaining to source voltage, DVR injected voltage and load voltage for DVR driven with proposed simple unit vector control theory. At instant 0.1 sec, sag was observed in voltage of distribution system and persists till 0.2 sec. During this period of time, the system voltage was dropped from 1pu to 0.5pu. Since DVR is connected to the system, DVR now injects required voltage from 0.1 sec to 0.2 sec in to the system as seen in the results. The load voltage was maintained constant as a result of DVR presence nullifying the effect of sag on load, compensating source voltage.

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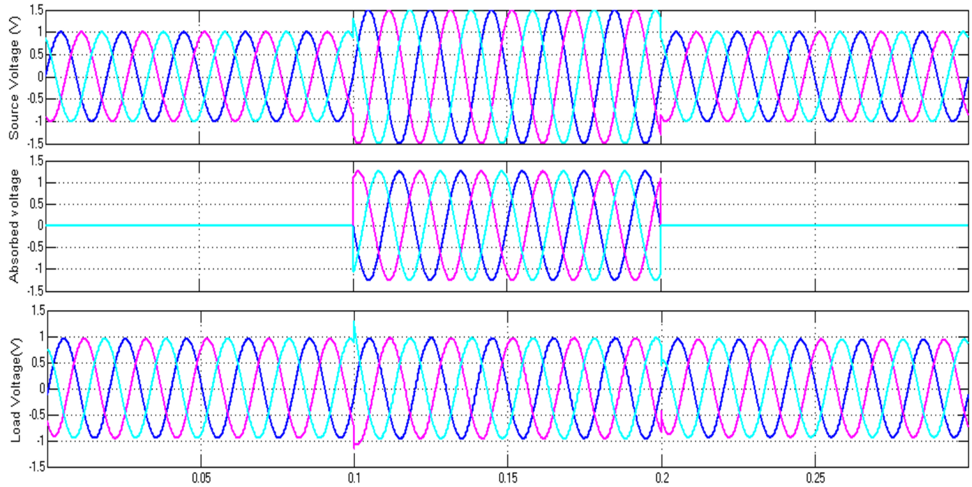

Figure 10: Result showing source voltage, DVR injected voltage and load voltage with swell

Similarly, at instant 0.1 sec, swell was observed in voltage of distribution system and persists till 0.2 sec which can be observed from figure 10. During this period of time, the system voltage was raised above 1pu. Since DVR is connected to the system, DVR now absorbs excess voltage from 0.1 sec to 0.2 sec from the system as seen in the results. The load voltage was maintained constant as a result of DVR presence nullifying the effect of swell on load, compensating source voltage.

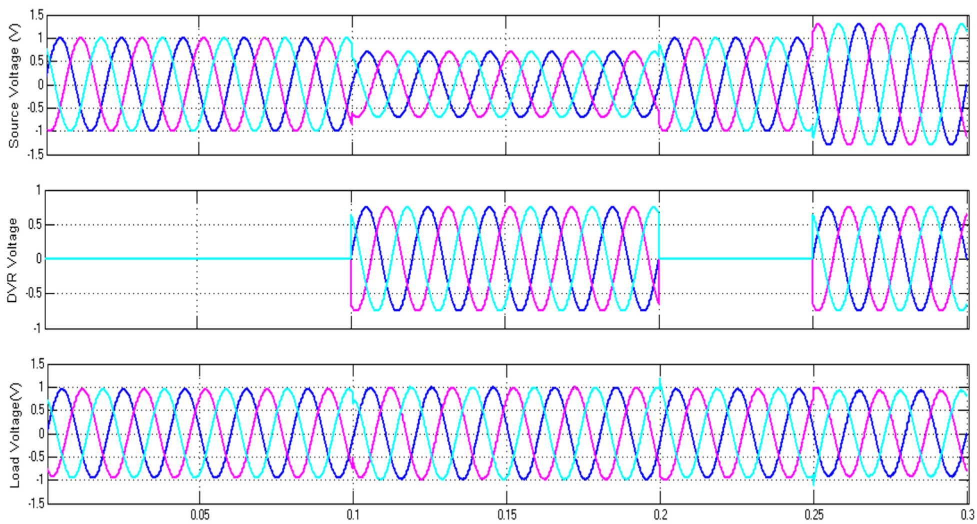

Figure 11: Result showing source voltage, DVR injected voltage and load voltage with sag and swell

In figure 11, the system containing both sag and swell can be observed. Now DVR is suppose to compensate both sag and swell effect. From 0.1 sec to 0.2 sec the effect of sag can be observed where voltage drops to 0.5pu from 1pu and from 0.3 sec to 0.4 sec, the effect of swell can be observed in which voltage raises above 1pu. DVR compensating voltages are observed compensating the source voltage by injecting/absorbing source voltage thus maintaining the system voltage constant. Constant voltage profile was observed in the results even when system contains both sag and swell.

5. Conclusions

SRF theory can effectively control DVR switches for required system compensation but involvement of complex calculations makes SRF a bit tough in design. Simplified unit vector control theory proposed in this paper was simple in operation excluding all complex calculations. Results show the effectiveness of proposed control theory for voltage compensation when sag or swell present in distribution system. Compensation for voltage sag and swell were shown for both cases when DVR driven with SRF theory and proposed unit vector control theory. Proposed control method gives same results as if DVR is driven with SRF but reduction in complexity involved in calculations in proposed theory makes theory simple in design.

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