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Utilizing a Dynamic Voltage Restorer to Reduce Voltage Sag and Swell in a Power System During Fault Conditions

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ABSTRACT

Modern power systems are become increasingly attuned to the utility company's power quality. Power quality issues include voltage sag and swell, harmonics, flicker, interruptions, and disruption of the sinusoidal waveform. These issues mostly affect industrial users with a variety of sensitive devices. These issues could cause them to lose a great deal of money. If the voltage drop is greater than the equipment's sensitivity threshold, the apparatus will break or sustain damage. In order to address this issue among consumers, gadgets like the Uninterruptible Power Supply (UPS), Static Synchronous Compensator (STATCOM), Active Voltage Restorer (AVR), and Dynamic Voltage Restorer (DVR) have been developed. A DVR is the most efficient and productive bespoke power device available. Thus, the goal of this work is to investigate how the DVR functions while voltage swell and sag are being compensated for. A sample of the distribution network will be used to investigate the DVR system. There are two feeders in this network, and each feeder is linked to the balanced load. One of the feeds has experienced a number of problems, including LG, LLG, and LLLG, which have caused voltage to sag and swell. To simulate the system, MATLAB/Simulink is selected as the software. By generating an output voltage with the least amount of distortion and harmonic distortion possible, the SVPWM-based approach can regulate the circuit with greater accuracy and enhance the DVR's reaction. The parameters, various circuit topologies, and the effects of power devices of components are discussed. The result of the simulation was recorded and discussed.

Keywords : Dynamic Voltage Restorer (DVR), Power Quality (PQ), Voltage Sag and Swell, Space Vector Pulse Width Modulation (SVPWM)

I. INTRODUCTION

In the competitive and deregulated power market of today, the quality of electrical power is crucial. Like power system service quality, it's similar. Power quality problems and their remediation are a top priority for electrical power utilities. Power system malfunctions are the primary source of most PQ issues. PQ problems include a broad spectrum of anomalies, including flickers, harmonic distortion, voltage sags and swellings, impulse transients, and interruptions. Sensitive loads are readily interfered with by voltage sags.

These days, a wide range of electronic devices are susceptible to voltage dips. Variable speed drives, robotics, controls, motor starting contactors, PLCs, controlled power supply, control relays, and many more are a few examples. A specialized power tool called the Dynamic Voltage Restorer (DVR) is used to remove supply-side voltage disturbances. Static Series Compensator is an alternate term for DVR. When voltage sags or swells are detected, a DVR's fundamental function is to inject the proper voltage in series with the supply via an injection transformer. Both at the distribution and transmission levels, DVR can reduce voltage. It was often put at the feeder for the crucial load. In standby mode, DVR doesn't do any switching. The sensitive loads are impacted by voltage changes brought on by symmetrical three-phase faults (LLL), unsymmetrical line-to-line (LL), line-to-ground (LG), and double-line-to-ground (LLG) failures. To lessen this issue, a dynamic voltage controller, a type of power electronic device, is employed. To make up for this and keep the voltages at their nominal value, the DVR injects the independent voltages. Controlling the proper phasor amplitude and angle will allow the DVR to inject power with null or little power for mitigating reasons. On the other hand, the DVR begins to add the lost voltage to the system when the system's voltage falls or rises. Given the speed at which the events happen, the DVR must be able to respond quickly enough to restore the lost voltage to the systems and shield the delicate load from harm. Applications ranging from low to medium voltage can use DVR. The DVR system combines the functions of a power circuit and a control unit because it is a specialized power device. The power circuit unit's DC link, or storage unit, and the control unit's SVPWM control will be the main subjects of the study. In order to reduce voltage sag and swell, the DVR's operation will be simulated using MATLAB/Simulink software. Two feeder and balancing loads make up the distribution system, which is the subject of the simulations. At feeder A, faults such LG, LLG, and LLLG have been used in order to look at the sags event. After then, feeder B will automatically experience a voltage sag or swell. As a result, we looked at the use of DVR for SVPWM-based voltage sag and swell control and mitigation under various failure scenarios.

II. DYNAMIC VOLTAGE RESTORER

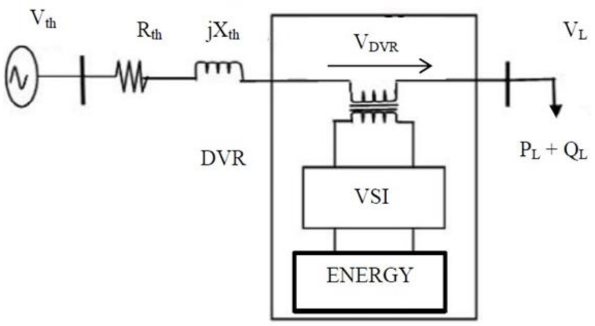

Fig - 1: Schematic of DVR

DVR is a series connected custom power device. Its main function is the protection of sensitive loads from any voltage disturbances except voltage outage. It basically consists of power circuit and control circuit. Four main components of the DVR circuit are: voltage injection/booster transformer, harmonic filter, voltage source inverter (VSI), and storage device or a DC source.

- Voltage injection/booster transformer: The basic function of injection transformer is to increase the voltage supplied by the filtered voltage source inverter (VSI) output to the desired level while isolating the DVR circuit from the distribution networks.

- Harmonic filter: Basically filter unit consists of inductor

(L) and capacitor (C). In DVR, filters are helpful to get a sinusoidal wave out of the inverted wave by SVPWM. This can be achieved by eliminating the unwanted harmonic components generated by the VSI actions.

- Storage devices: The DVR needs real power for compensation purposes during voltage disturbance in the distribution system. In this case the real power of the DVR must be supplied by energy storage when the voltage disturbance exits. The energy storage such as battery is responsible to supply an energy source in DC form.
- DC charging circuit: The DC charging circuit has two main tasks; first task is to charge the energy source after a sag compensation event. And the second task is to maintain dc link voltage at the nominal dc link voltage.

2.1 Voltage injection by DVR

Fig. 1 shows the schematic diagram of DVR systems. The circuit located at the left of DVR represents the Thevenin's equivalent circuit of the system. The system impedance ($Z_{th} = R_{th} + j X_{th}$) depends on the fault level of the load bus. When the system voltage (V_{th}) drops, DVR system will inject a series voltage V_{DVR} using injection transformer. Thus the desired voltage value at the load canbe maintained.

By using KVL,

$$V_{th} - Z_{th}I_L + V_{DVR} = V_L$$

$$V_{DVR} + V_{th} = V_L + Z_{th}I_L$$

Hence, the series injection voltage of DVR is,

$$V_{DVR} = V_L + Z_{th}I_L - V_{th}$$

Where,

$$I_L = [\frac{P_L + jQ_L}{V_L}]^*$$

When V_L is considered as a reference,

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_L I_L \angle\beta - \emptyset - V_{th}\angle\delta$$

Here, α, β and δ are the angle of V_{DVR}, Z_{th} and V_{th} respectively and $\emptyset$ is the load power factor angle with

$$\emptyset = tan^{-1}(\frac{Q_L}{P_L})$$

The complex power injection by DVR is

$$S_{DVR} = V_{DVR} I_L^*$$

2.2. Advantages of using DVR

Dynamic Voltage Restorer is the most efficient and effective modern custom power device used in power distribution network. Besides that, DVR also is lower cost, small size and its fast dynamic response to the disturbance.

2.3. Technical issue of using DVR

To improve PQ conventional compensation methods such as passive filters, synchronous capacitors and phase advancers were used. However the conventional methods have many drawbacks such as resonance, fixed level of compensation, bulky and electro-magnetic interference. These disadvantages forced researchers to undertake adjustable and dynamic methods using custom power devices.

It is observed that the cell voltage and efficiency present higher values for low current densities and power densities. On the other side, for higher power values, the voltage and efficiency have lower values. Therefore, when the designer of the control system wants to find the best operation point for the cell, he/she must take into account efficiency and voltage levels suitable for the application. Operating the system with current at constant current resulting in constant potential and power can be a good start.

III. SPACE VECTOR PULSE WIDTH MODULATION (SVPWM)

SVPWM helps to produce a vector of voltage that is similar to the reference signal with the help of different inverter switching modes. Fig. 2 is the general view of a three-phase VSI model. Each phase is represented as switch S for three-phase inverter circuit ON-OFF. Here, $SA(t)$; $SB(t)$ and $SC(t)$ are used as the switching functions for the three phases, respectively.

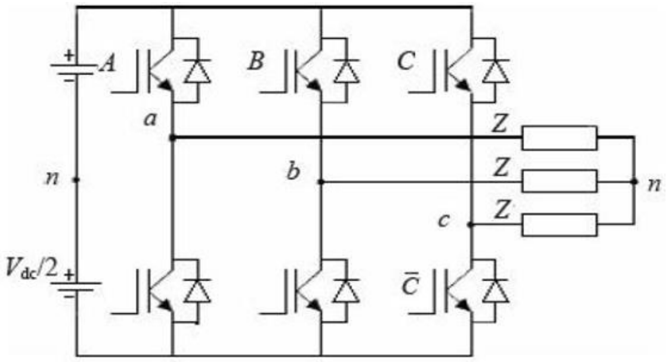

Fig - 2: Three-phase inverter

The space vector of output voltage of inverter can be expressed as V (SA, SB , SC) = 2 V_{dc} (SA + α SB + α^2 SC), where, V_{dc} is voltage of the Dc bus and α =e^{j120}. If we express the on state of the upper-arm with 1 and the off state with 0, the on-off states of three phases have eight combinations, correspondingly forming eight voltage space vectors, as shown in Fig. 3. T refers to the operation times of two adjacent non-zero voltage space vectors in the same zone. Both V_0(000) and V_7(111) are called the zero voltage space vector, and the other six vectors are called the effective vector with a magnitude of $2V_{dc}/3$. For example, when the output voltage vector V is within zone one, it is composed of V_4, V_6, V_0 and V_7 and can be obtained by V_{out} = (T_4V_4)/T + (T_6V_6)/T

ON-OFF states of inverter are as shown in Table 1.

Table - 1: Inverter's ON-OFF states

State	SASB SC	SA-SB-SC	VA/V dc	VB/V dc	VC/V dc
0	000	111	0	0	0
1	001	110	-1/3	-1/3	2/3
2	010	101	-1/3	2/3	-1/3
3	011	100	-2/3	1/3	1/3
4	100	011	2/3	-1/3	-1/3
5	101	010	1/3	-2/3	1/3
6	110	001	1/3	1/3	-2/3
7	111	000	0	0	0

Based on the principle of SVPWM, the Embedded MATLAB functions for generating SVPWM waveforms mainly include the sector selection model, switching time calculator, time switching signal generator, and generation model of SVPWM waveforms.

In the application of SVPWM method, first step is to determine the voltage vector sector. For control purpose α-β coordinate system is used to determine the appropriate sector. When $V\beta > 0$, A = 1; when $3V\alpha + V\beta < 0$, B=1; when $3V\alpha + V\beta < 0$, C = 1. Then, the sector containing the voltage vector can be decided according to N = A+2B+4C, listed in Table 2

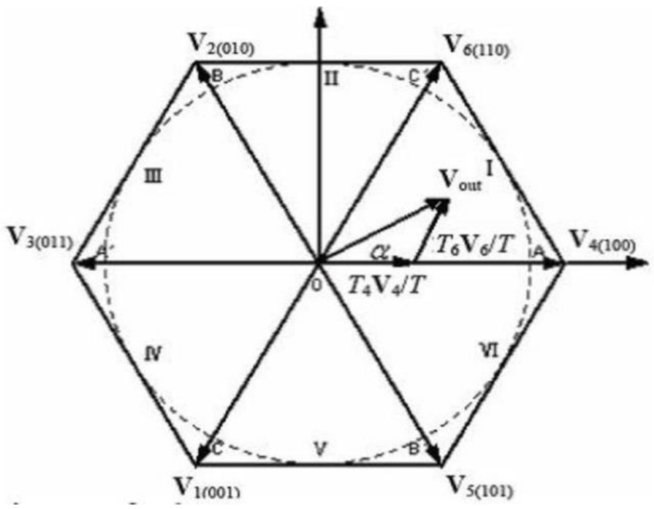

Fig - 3: Voltage space vectors

Table - 2: Sector containing the voltage vector vs N

Sector	I	II	III	IV	V	VI
N	3	1	5	4	6	2

Table 3 lists the operation times of fundamental vectors against N, where $T1$ and Tm refer to the operation times of two adjacent non-zero voltage space vectors in the same zone. Z=T(-3Vα+Vβ)/(2Vdc), Y=T(3Vα+Vβ)/(2Vdc), X=2T[Vβ/2Vdc]. The sum of T1 and Tm must be smaller than or equal to T (PWM modulation period). The over saturation state must be judged: if T1 + Tm > T; take T1 = T1[T/(T1 + Tm)]; Tm = Tm[T/(T1 + Tm)].

Table - 3: Operating time of fundamental vector

N	1	2	3	4	5	6
T1	Z	Y	-Z	-X	X	-Y
Tm	Y	-X	X	Z	-Y	-Z

The relation between N and operating time of switches is presented in Table 4. Ta = (T - T1 - Tm)/4, Tb = Ta + T1/2, and Tc = Tb + Tm/2, Tcm1, Tcm2 and Tcm3 are the operation times of the three phases respectively.

Table - 4: Relation between N, Tcm, Ta, Tb and Tc

N	1	2	3	4	5	6
Tcm1	Tb	Ta	Ta	Tc	Tc	Tb
Tcm2	Ta	Tc	Tb	Tb	Ta	Tc
Tcm3	Tc	Tb	Tc	Ta	Tb	Ta

By comparing the computed Tcm1, Tcm2 and Tcm3 with the equilateral triangle diagram, a symmetrical space vector PWM waveform can be generated. The waveforms of PWM2, PWM4 and PWM6 are obtained by reversing those of PWM1, PWM3 and PWM5, respectively.

The SVPWM waveform in a sampling period is shown in Fig. 4, Ts refers to sampling time, $T0$ refers to the time of zero vector operation, Tk and $Tk+1$ refer to the operation times of two adjacent non-zero voltage space vectors in the same zone, then the resultant torque increases to 3 times. The phase is switched to the next in every 60 electrical degrees. The duration of operation for each power electronic part is 120 electrical degrees. The exciting duration of each winding is 240 electrical degrees: including 120 degrees for positive direction and 120 degrees for negative direction.

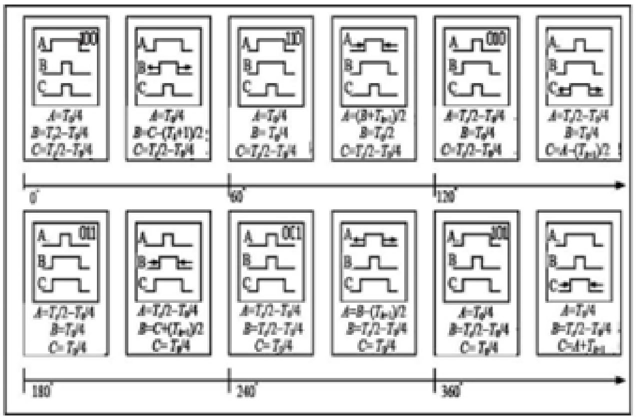

Fig – 4 : SVPWM waveform in a single sampling period

IV. SIMULATION RESULTS

Fig. 5 shows the main circuit of distribution network with installation of DVR systems. The load connected to the system is balanced loads. The three phase fault generator was placed at feeder A.

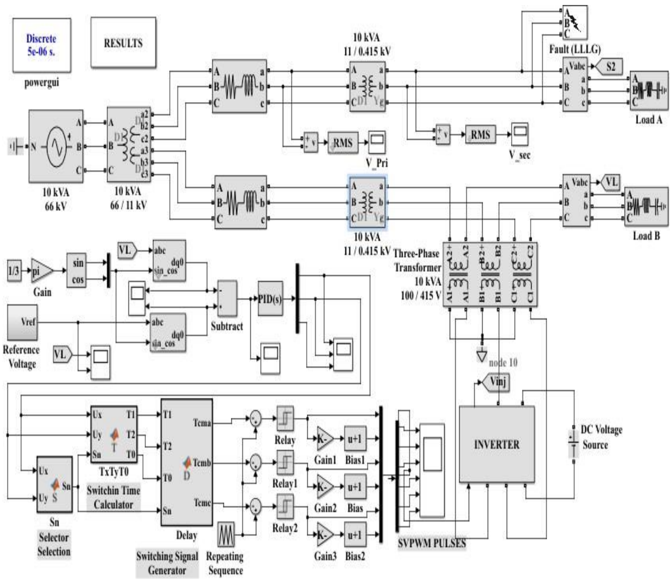

Fig - 5: MATLAB/ Simulink model of distribution networkwith DVR

Fig. 6 shows the result of the simulation without installation of the DVR system. When, a LLLG fault applied at feeder A, the voltage sags occurred on feeder B between 0.1-0.2 second. The event occurred during the interval of time can be considered as voltage sag because the periodof the voltage sag is between 0.5 cycles until 1minute. From this result, it means the next simulation of distribution network installed with DVR system can be proceeds by using the same value and configuration of the fault occurred in the simulation.

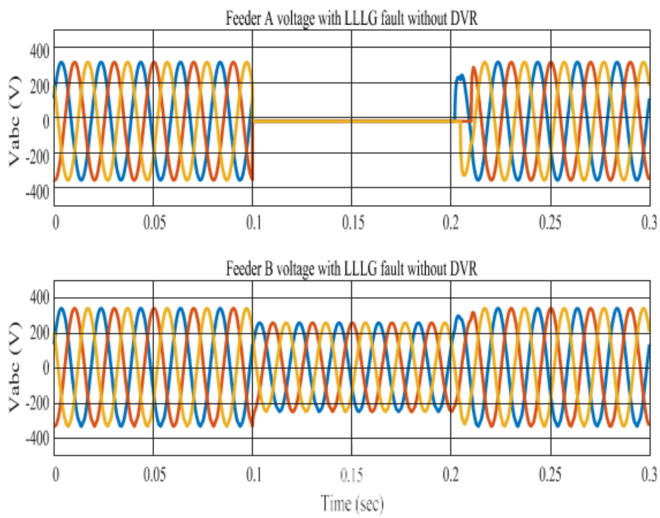

Fig - 6: Load voltage for feeder A and B respectively without DVR (LLLG fault)

Fig. 7 shows that the DVR successfully compensated the voltage sag at feeder B produced due to a LLLG fault onfeeder A. Voltage during the 0.1-0.2 second restored back to the nominal value and voltage injected by DVR is also observed.

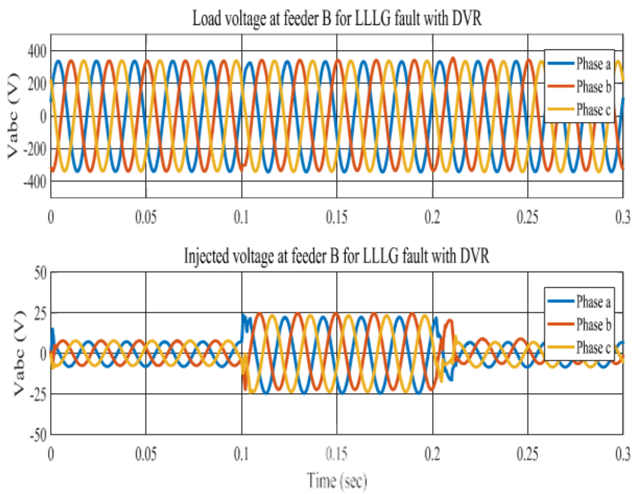

Fig - 7: Load and injected voltage at feeder B with compensation by DVR (LLLG fault)

Fig. 8 shows load voltage at feeder A and B when a LLG fault occurred at feeder A, the voltage sag is observed on feeder B.

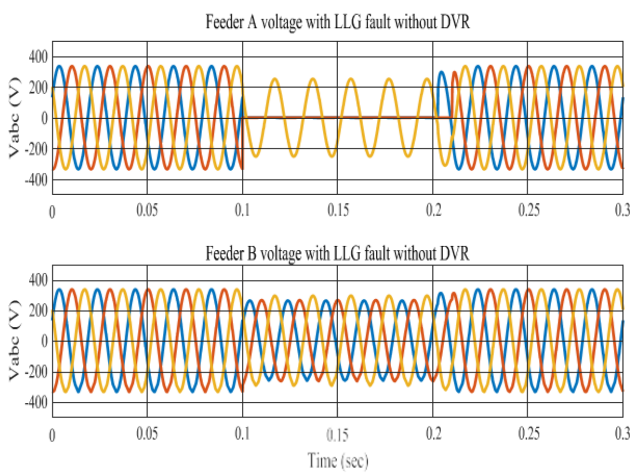

Fig - 8: Load voltage for feeder A and B respectively without DVR (LLG fault)

Fig. 9 shows that the DVR successfully compensated the voltage sag at feeder B produced due to a LLG fault on feeder A.

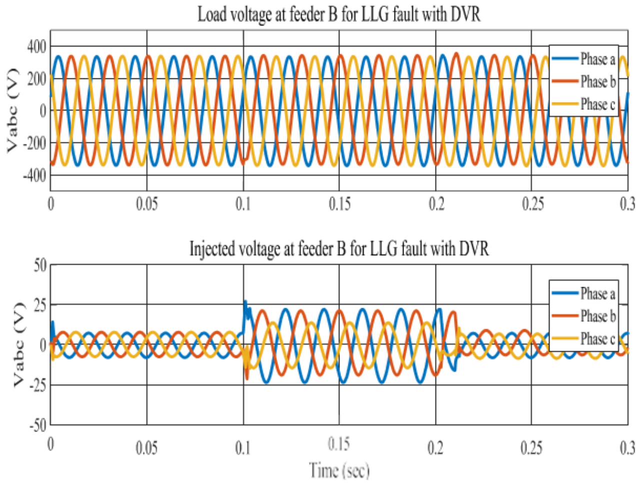

Fig - 9: Load and injected voltage at feeder B after compensation by DVR (LLG)

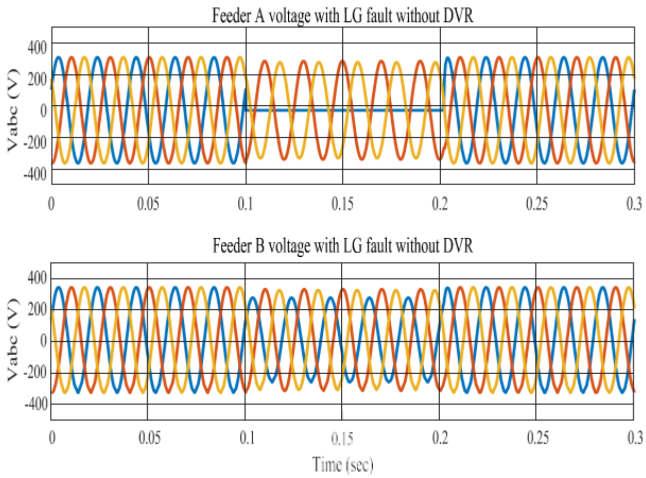

Fig - 10: Load voltage for feeder A and B respectively without DVR (LG fault)

Fig. 11 shows that the DVR successfully compensated the voltage sag at feeder B produced due to a LG fault on feeder A.

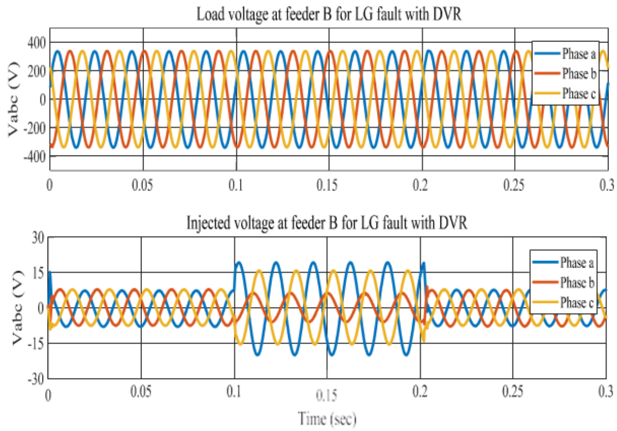

Fig - 11: Load and injected voltage at feeder B after compensation by DVR (LG)

Fig. 12 shows load voltage at feeder A and B when a voltage swell is produced through the source voltage magnitude control.

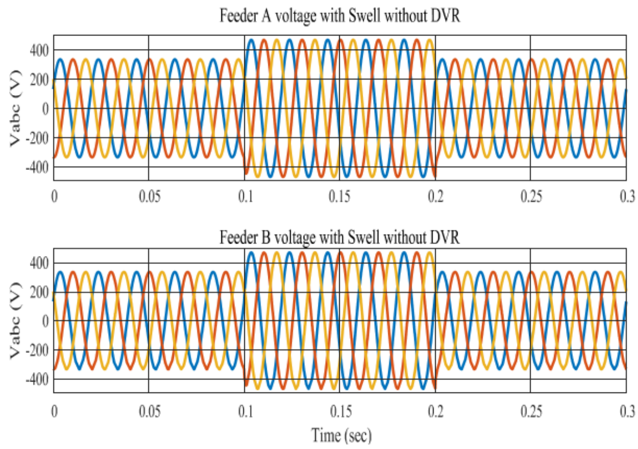

Fig - 12: Load voltage for feeder A and B respectively without DVR (Swell)

Fig. 13 shows that the DVR successfully compensated the voltage swell at feeder B and the voltage injected by DVR is also represented.

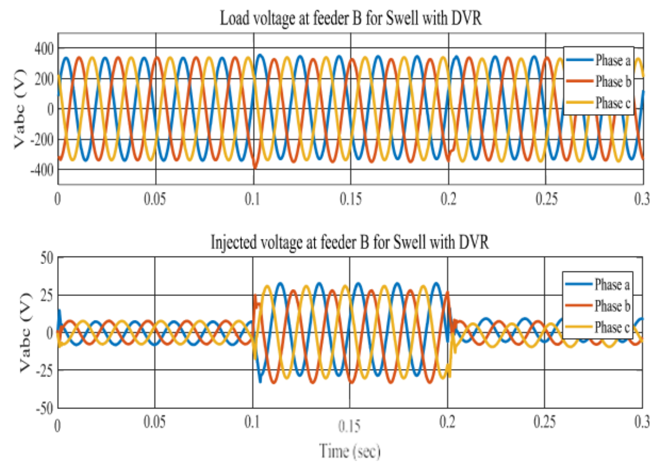

Fig - 13: Load and injected voltage at feeder B after compensation (Swell)

CONCLUSION

In this paper, mitigation of voltage sag and swell using DVR is presented under fault conditions. In order to investigate whether the DVR is able to deal with this problem, MATLAB/Simulink is used to simulate the system and mitigate the voltage sag and swell. Based on the simulation that had been done, it can be proved that DVR is the dynamic fast response devices that able to overcome the issues with the use of SVPWM method. DVR is able to mitigate voltage during sag as well as swell and output voltage after compensation is in range of the nominal value. The simulation was implemented by using the distribution network where the effectiveness of the DVR system is better compared to the transmission network.

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