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Mitigation of Symmetrical and Nonsymmetrical Deep Voltage Sag, Swell and Phase Jump Using Dynamic Voltage Restorer (DVR) With Pre-Sag Compensation Technique

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Abstract— The voltage sags and swells are important power quality problems and the Dynamic Voltage Restorer ( ), is the effective device to mitigate the large voltage sags and swells. In this paper deals with a DVR with Rectifier Supported dc-dc Boost Converter or a deep voltage-sag or swell compensator, which consists of a set of uncontrolled shunt, dc-dc boost and series converters connected back-to-back with three series injection transformers. The dc-dc boost converter installed for maintaining stabilized DC-link voltage which helps to mitigate deep voltage sag or swell. The DVR is characterized by installing the series converter on the source side and the shunt converter on the load side. Here elucidate the design procedure of the rectifier supported dc-dc boost converter DVR and analysis with emphasize to compensate the deep voltage sags or swells up to 50% and also compensate the phase jump. This control method is enough to protect the sensitive loads from supply disturbances. The DVR is operated in such a fashion that it does not supply or absorbed any active power during the steady-state operation; hence system will not make any additional power loss. The operations of dc-dc boost converter supported DVR are verified through extensive digital computer simulation studies.

Index Terms— Custom Power Devices, deep voltage sags, swells, phase jump , Pre-Sag Compensation ,dc-dc Boost Converter, DVR

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1 INTRODUCTION

Modern machineries, sophisticated loads or critical consumers are not desire the polluted in put supplies due to reduce their performance index. The quality of power supply is a necessary measure in the modern industries. [1] For improving the power quality in the distribution systems, some new methods adopted known as Custom Power Devices, [2] they are classified as Shunt Connected Distribution Static Compensator (DSTSTCOM), and series connected compensator as Dynamic Voltage Restorer (DVR) and Unified Power Quality Conditioner (UPQC) which connects both shunt and series. The series connected compensators can improve the terminal voltage quality from unbalanced or distorted source supply to protect the critical consumers also avoids unwanted trapping and consequence losses. The Dynamic Voltage Restorer (DVR) is a power electronic device - based series converter compensator that can protect critical loads from most common supply side disturbances other than outages [3]–[5]. The basic operating principle of a DVR is to insert a voltage of required magnitude and frequency in series with a distribution feeder. Thereby the DVR can restore the voltage on the load side to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. The DVR is connected in series with a distribution feeder through a series injection transformer through a Voltage Source Converter (VSC). This device employs IGBTs and its functions as [6]–[8]. The VSC converter exchanges the real power between dc-bus to ac system.

Various schemes are adopted for exchanging real power with ac system such as battery supported, capacitor supported, and rectifier supported etc. The battery supported method is simple but in the practical sense, it is not desirable in connection with large maintenance cost and size. Through the capacitor supported scheme, a capacitor provides for dc-bus with VSC supply the sufficient magnitude of mitigation voltage to the system. This topology has an innovative with complicated algorithm, however it ineffective to mitigate the deep voltage sag or swell and supply side harmonics efficiently.

In rectifier supported scheme the power may be drawn from the same ac system through a four–quadrant rectifier using three bridges. During the unbalanced or distorted operated condition the power may be drawn from the ac system and required estimated power must be sent back to the system. The uncontrolled rectifier output maintain the dc-link voltage that's depends the value selection of ripple filters this is a cost effective method because surplus to requirements of external energy storage. The DVR can be operated in such a configuration that it does not supply or absorb any average real power in the steady state [9], [10]. However, in the load was assumed to be balanced and linear. This paper will be focus the design and development of DVR with Rectifier Supported dc-dc Boost Converter for better power quality improvement and postulate the performance of device under deferent study state and transient conditions, also be bring in to a significant corollary.

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2. PRINCIPLE OF OPERATION OF DVR

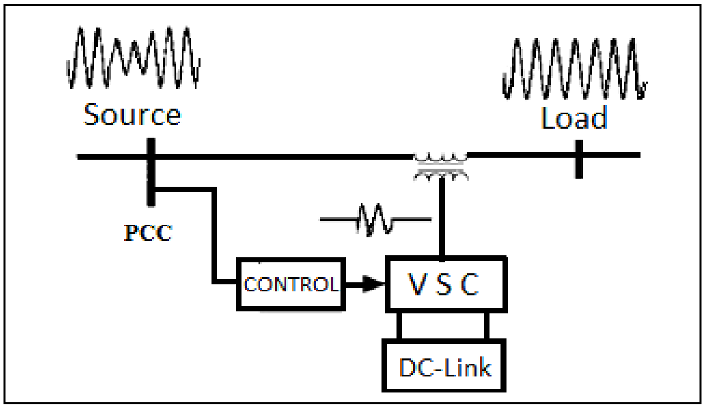

Fig.1. Principle of Operation of Dynamic Voltage Restorer.

The voltage sag or swell is caused due to short circuited in the adjacent feeder(s) or different faults occur in source side. Fig.1. shown Principle of Operation of Dynamic Voltage Restorer. Magnitude and phase of the voltage variation in the source side, is continuously monitoring at the Point of Common Coupling (PCC) by Dynamic Voltage Restorer. Magnitude and phase of the voltage variation in the source side, is continuously monitoring at the Point of Common Coupling (PCC) by means of a control algorithm and distinguish instantaneously the nature of source voltage variation. A fault current somewhere in the grid can lead to a reduced magnitude and, in some cases create a phase jump of the voltage at the PCC. Under this circumstances the DVR generate a compensating voltage corresponding to the estimated magnitude of voltage variation by means of a dc-bus. This compensating voltage injects back to the distribution system via injection transformers and stabilizes the load side voltage.

The phasor diagram indicates with real power injection of DVR, shown in Fig. 2. The Pre- sag voltage, Sag voltage (Vsag) and Load current I_L, Voltage sag angle 'θ_{sag}' and Voltage injection angle 'θ_{inj}'. According to the control logic during the sag period the DVR inject the compensating voltage 'Vinj' in phase with direct axis of sag voltage back to the system.

2.1 Pre-Sag Compensation Technique

In this compensation technique, the DVR supplies the difference between the sagged and pre-sag voltage and restores the voltage magnitude and the phase angle to the nominal pre sag condition. In this technique is it requires a higher capacity energy storage device.

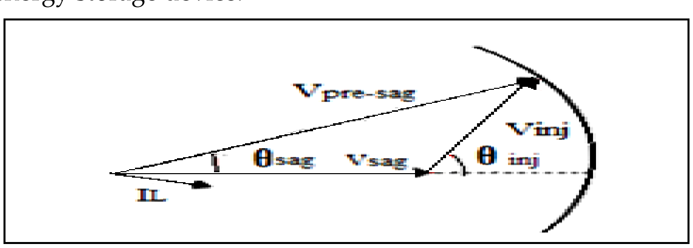

Fig. 2. The phasor diagram of Pre-sag compensation.

Fig. 2, shows the phasor diagram For the pre-sag control strategy. In this diagram, '$V_{pre\text{-}sag}$' and 'V_{Sag}' are voltage at the Point of Common Coupling (PCC), respectively before and during the sag. In this case 'VDVR' is the voltage injected by the DVR, which can be obtained refer to (1), and also θinj is obtained Refer to (2)

$$V_{pre\text{-}sag} = VL, \quad V_{Sag} = V_S \quad \text{and} \quad V_{DVR} = V_{inj} \qquad (1)$$

$$|V_{inj}| = |V_{pre\text{-}sag}| - |V_{Sag}|$$

$$\theta inj = \tan^{-1}\{[V_{pre\text{-}sag}.\mathrm{Sin}(\theta_{pre\text{-}sag})] / [V_{pre\text{-}sag}.\mathrm{Cos}(\theta_{pre\text{-}sag}) - V_{sag}.\mathrm{Cos}(\theta_{sag})]\} \qquad (2)$$

3. CONFIGURATION OF DVR

The DVR with rectifier supported dc-dc boost converter configuration mainly designed for the capability to compensate the deep voltage sag or swell. It consist of uncontrolled rectifier connected to the load side as shunt converter, the uncontrolled rectifier output maintain the dc-link voltage that depends on the value selection of ripple filters. This is a cost effective method because surplus requirements of external energy storage. The Boost converter fed the dc-link voltage and step-up the input voltage level to a pre-defined value. In this configuration the dc-link voltage kept 1000V in connection with the pre-sag compensation based control it requires a higher capacity energy and also the system has designed for mitigating deep voltage sag up to 50% of its nominal voltage. The boost converter switching is realized by MOSFET. The Voltage Source Converter (VSC) used for converting dc voltage into ac voltage is realized by IGBTs. The output voltage of the step up converter is the input dc voltage of the VSC of the DVR. VSC performance is controlled by the gate pulse of the IGBTs that depends up on the control algorithm of the DVR. The output of the VSC, i.e. compensation voltage is injected back to the system via three injection transformer. In this configuration the turn ratio of the injection transformer selected as 1:1.

4. CONTROL STRATEGY OF DVR

4.1 DC voltage control of DVR

The duty cycle 'D' by Pulse width modulation technique (PWM) controls and maintain its dc output voltage (V_{dcout}) of the step-up converter. The reference set value ($V_{dcref.}$) decides the output value of the system. This is done by Proportional and Integral controller (PI) as shown in fig. 4. The PI controller compare between V_{dcref}. and V_{dcout} to produce the error e_{vdc}. The voltage e_{vdc} is passed through the PI controller to produce the suitable duty cycle D, which governs switching pulses to the MOSFET. The simulated system parameters are mentioned in TABLE -III

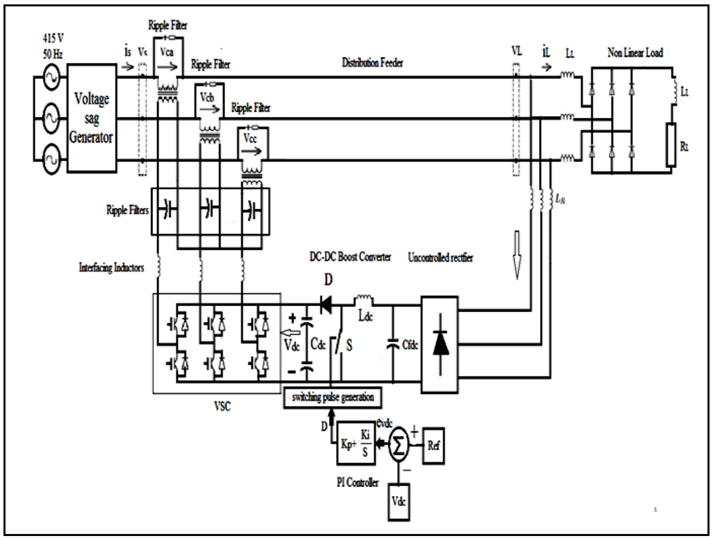

Fig.3. Experimental circuit configuration of the DVR in which the uncontrolled rectifier supported DC-DC Boost converter is installed at the load side.

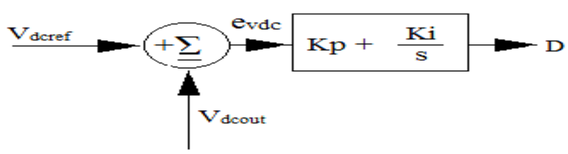

Fig.4. DC voltage control of DVR

4.2 Control method of DVR

Different control strategy may generally be used for DVRs, being either open-loop control [11] or closed-loop control [12]. Closed-loop control was used for this test system incorporating a rotating d-q reference frame with feed forward compensation [5].Fig.5, shows the control loop structure. Complete details can be found in [5]. The phase locked loop (PLL) is used for synchronized to the DVR with grid supply, even during the phase jump. The synchronization function performs a vital role that it can maintain a smooth output voltage. The reference generation controller performs an important role in the DVR control; it determines desired load voltage reference. A software-based phase-locked-loop (PLL) [13] is used to create sinusoidal load voltage references for the coordinate system of the controller. Reference signals for DVR ($V_{DVR,\ ref(d-q)}$) are calculated using the ideal supply reference voltage ($V_{supply,\ ref(d-q)}$) and the actual state of the supply voltage ($V_{supply,(d-q)}$) . The error between the DVR reference voltage ($V_{DVR,\ ref(d-q)}$) and the actual DVR voltage ($V_{DVR,\ (d-q)}$) is minimized by two Proportional plus Integral (PI) controllers. These controllers generate the d-q references to the DVR, which are then transformed to three-phase stationary frame values. These values are in turn PWM modulated using a unipolar switching scheme that takes into account the actual DC-link voltage magnitude (Vdc). The PI controller tuned by assigned the values of Proportional gain and Integral gain. TABLE II

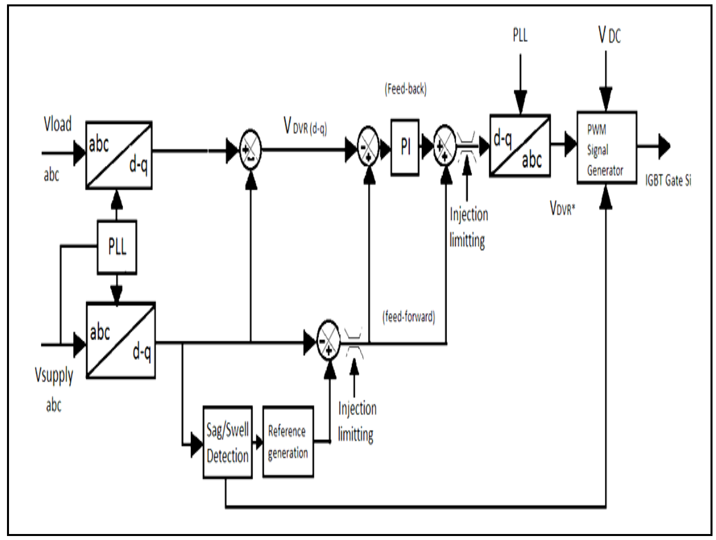

Fig.5. Control of DVR

5.SIGNIFICANCE OF DC-DC BOOST CONVERTER IN PROPOSED TOPOLOGY

The perfect mitigation of voltage sag requires a strong dc-bus support for DVR. For a perfect active power compensation of DVR, a ideal battery is suitable because it maintain the sufficient dc voltage to the system without any variation during the sag compensation period. However it's not suitable in large system due to its high rating, size and cost. Instead of battery supported system, the feedback rectifier supported topology could provide the sufficient dc-bus voltage without providing an external dc source. In the case of deep voltage sag mitigation (consider 50% sag), with the system having continuous disturbance, the dc-bus voltage provided by the uncontrolled rectifier will not be provided sufficient, to mitigate the continuous supply side disturbance due to lack of a strong dc-bus Voltage. The rectifier supported system is enough to mitigate deep voltage sag., however it will not possible to compensate a continuous disturbed system. After mitigation of deep voltage sag at a particular instant, the output of the rectifier voltage will decrease suddenly from the normal dc-bus voltage value, shown in Fig. 7. and take a certain period to normalize to the pre-desired value of the dc-bus voltage. During this period the rectifier could not give the sufficient dc voltage to the DVR. Hence the rectifier supported DVR can't compensate the continuous deep voltage disturbances.To overcome this limitation, instead of uncontrolled rectifier, a rectifier supported dc-dc boost converter realized by MOSFET is used. The dc-dc boost converter provides stabilized dc output voltage with help of a proper controller. Here the boost controller is controlled by means of PI controller.

The PI controller tuning performs vital role in the boost converter to stabilize the stepped up dc output voltage. If a continuous deep voltage disturbances occurs in to the system, the rectifier supported dc-dc boost converter can be mitigate the supply side disturbance sufficiently with help of a approximately constant dc voltage output from the boost converter.

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The effectively tuned PI controller of the boost converter stabilizes output dc voltage at a constant level. In this system topology, boost converter control perform a vital role in the whole system performance. Fig.6. shows the simulink model of the proposed system. The simulated system parameters are mentioned in TABLE –II

TABLE I
DVR controller parameters

Boost controller parameters	
Parameters	Values
Proportional gain	0.1
Integrator gain	0

6.SIMULATION RESULTS AND DISCUSSION

In this section the simulation results and significant performance of DVR are discussed. For obtaining validate results via simulation, a number of tests were performed during normal operation and during abnormal conditions (such as symmetrical and asymmetrical) with different load situations. Both the steady-state effect of the DVR in standby mode and the dynamic sag protection active modes were investigated. While the primary aim of a DVR is to inject voltage during sag events, the majority of the time the unit will remain in standby mode. Therefore, the performance of the DVR in this mode must be investigated to ensure that its affect minimized on the sensitive protected load. Here the performance test conducted only in under nonlinear load condition, however the same system perfectly work in linear loads also. The test was conducted both symmetrical and non symmetrical fault conditions. Fig.7. shows experimental performance of dc-link voltage of rectifier supported DVR. The rectifier supported system can efficiently mitigate the supply voltage disturbances while the however, obviously unable to mitigate during the continuous supply side disturbances due to weak dc link voltage. It clearly shows that, DC-link voltage suddenly decreases during the period from 2 to 2.05s, disturbance in shorter and reached at zero due to heavy disturbance affected in system and it make more time to obtain the normal dc value. Consequently the rectifier supported DVR unable to mitigate the deep voltage with continuous supply side fluctuations. This inefficiency emphasizes the significance of dc-dc boost converter supported system.

A comparative study about dc-link voltages between boost converter output and rectifier output, obviously the strength of dc- link voltage of the boost converter, it behave like a battery output (approx) with unlimited storage capacity. Fig.8. shows experimental performance of dc-link voltage of boost converter output. The wave form explain that, a small variation occur during the period from 2 to 2.1s. For mitigating deep voltage sag due to injection of active power supply for compensating deep voltage sag during this period. Then the dc voltage profile is reach at rated voltage level. The damping period of the system can be reduced by means of proper tuning of PI controller.

TABLE II
System parameters.

Parameters	Values	Units
System voltage	415	Volts
System frequency	50	Hz
System inductance	$1e^{-3}$	H
Resistance	0.001	R
Ripple filter inductance	$1.5e^{-3}$	H
Ripple filter resistance	3	R
Dc-link voltage	1000	Ohm
Interfacing inductor	$0.8e^{-3}$	Volts
Interfacing resistance	0.001	H
Filter capacitor	$1e^{-6}$	F

TABLE III
Boost converter controller parameters.

Boost controller parameters	
Parameters	Values
Proportional gain	1
Integrator gain	15

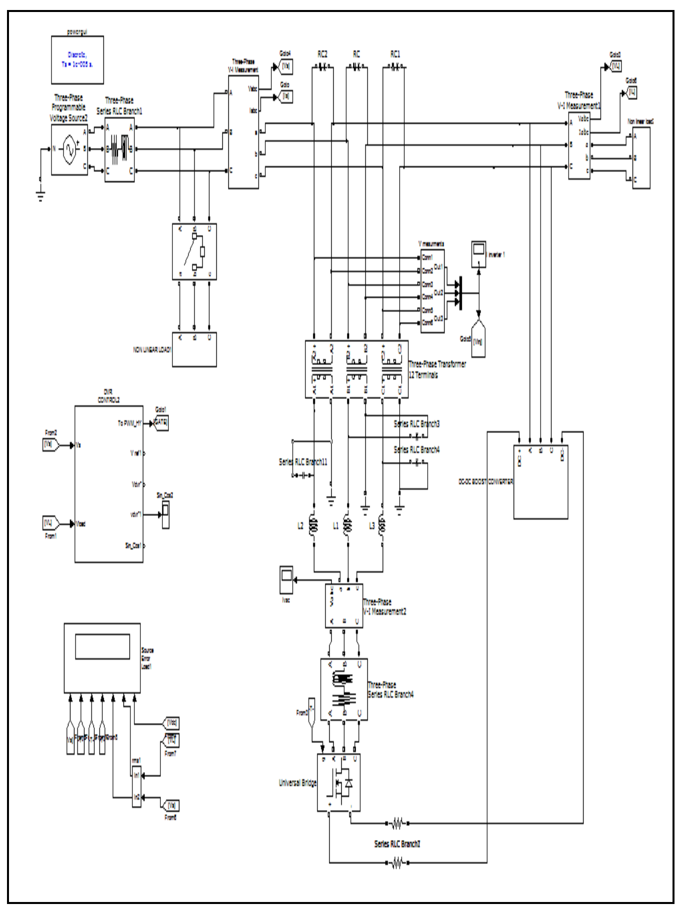

Fig. 6. Simulink modeling of DVR

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Analyzed the experimental performance, of the supply voltage unbalanced condition and compensation using the installed DVR. With Rectifier Supported dc-dc Boost-Converter system, for creating a continuous unbalanced situation, 0.5 p.u. Symmetrical voltage dip generated during the period from 2.0 to 2.1s, as well as an unbalanced condition created during the period from 2.15 to 2.25s. A 5 kW, non linear load is used for conducting the following analysis. Fig.9. and Fig.10 shows the experimental performance results of deep voltage Sag and swell up to 50% with unbalanced conditions. The following simulated waveform of the proposed system, done under nonlinear load condition

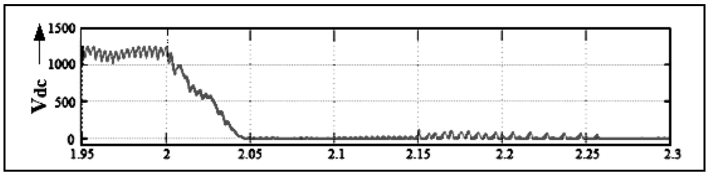


Fig.7. shows experimental performance of dc-link voltage of rectifier output of DVR.

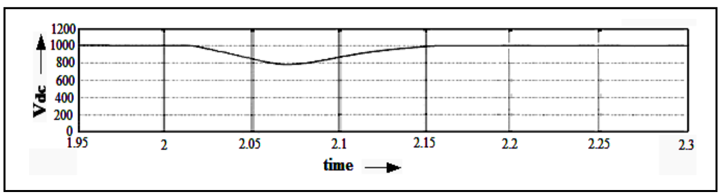
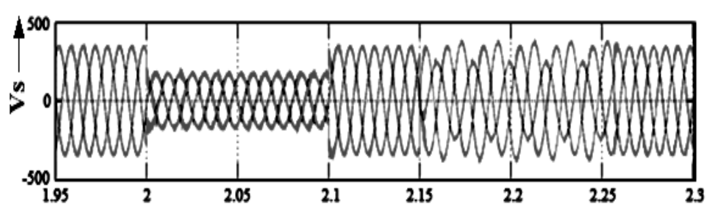
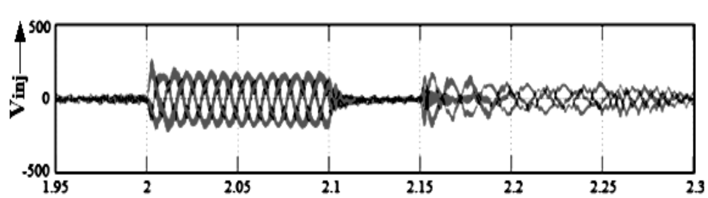


Fig.8. shows experimental performance of dc-link voltage of boost converter output of DVR.

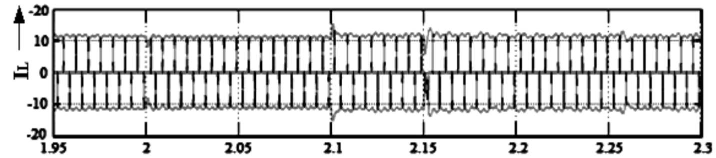
The results Postulated that performance of rectifier supported dc-dc boost-converter system has the perfect mitigation capability of 50% sag or swell with continuous supply side disturbances and also shows that the DVR maintained a constant load voltage magnitude and phase throughout the event. The importance of rectifier supported dc-dc boost-converter in the DVR system; it has a capability to compensate the continuous supply voltage disturbances in the system and also capable to compensate phase jump.



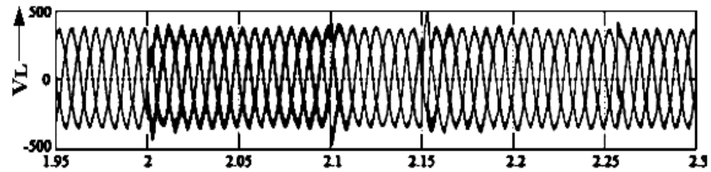
(a)



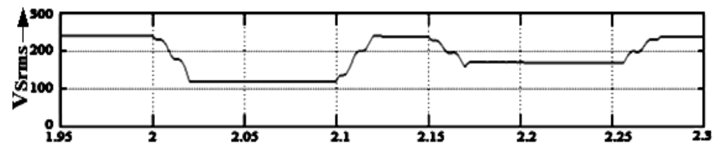
(b)



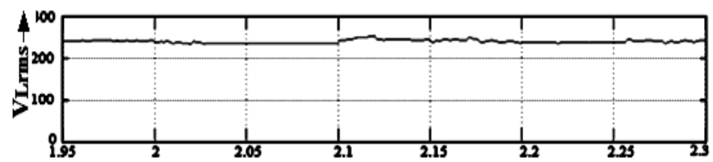
(c)



(d)

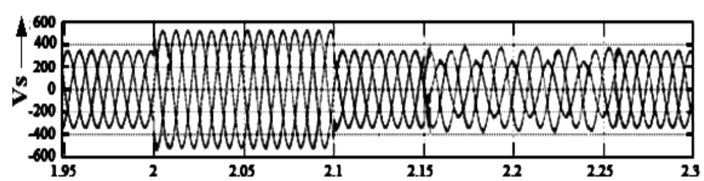


(e)

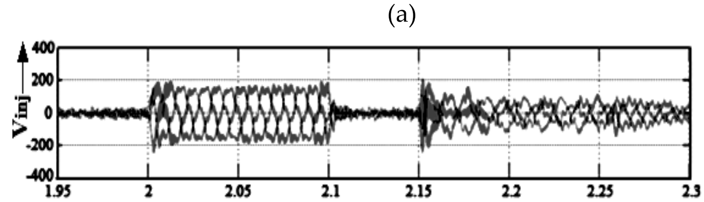


(f) time

Fig.9. (a) Supply voltage with 50% Sag and also unbalanced, (b) Injected or compensating DVR voltage, (c) Load current, (d) Mitigated load voltage, (e) Supply voltage with 50% sag (rms), (f) Mitigated load voltage (rms).



(a)



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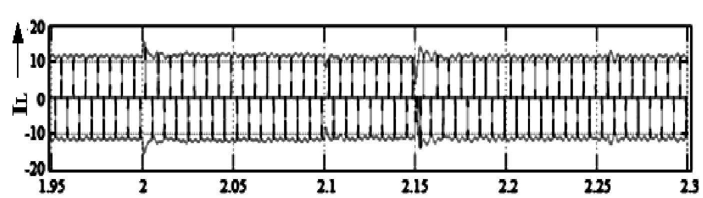

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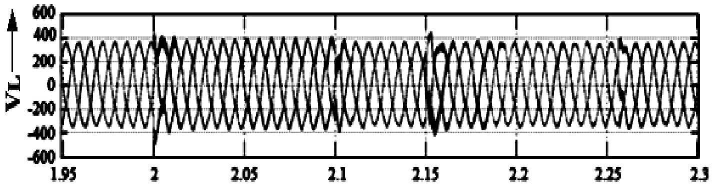

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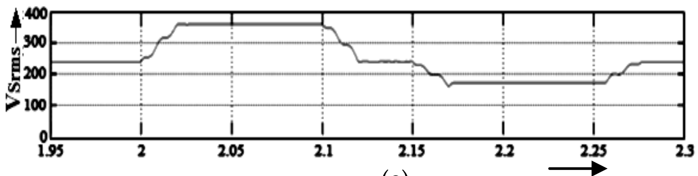

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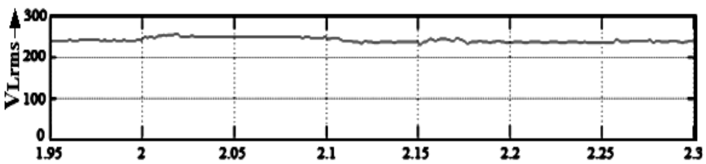

(f) Time

Fig.10. (a) Supply voltage with 50% Swell and also unbalanced, (b) Injected or compensating DVR voltage, (c) Load current, (d) Compensated load voltage, (e) Supply voltage with 50% sag (rms), (f) Mitigated load voltage (r m s)

7. CONCLUSION

This paper has presented the Mitigation of Symmetrical and nonsymmetrical deep voltage sag, swell and phase jump using Dynamic Voltage restorer (DVR) with Pre-sag compensation Technique. Traditional non-controllable series compensation based on series capacitors can create problem due to unwanted resonance with the rest of the power system. A specific problem that often arises in conjunction with series capacitors is Sub Synchronous Resonance (SSR), A VSC-based device will not cause this problem; rather if installed closed the power station; it can change the degree of series compensation in order to move away from the risk for SSR. Moreover this proposed topology is capable to mitigate deep voltage sags or swells up to 50%; with help of a dc-dc boost converter, this features leads to design possibilities of advanced power quality controllers.

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9. BIOGRAPHIES

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