

Control Schemes for Improving Power Quality with BESS and Ultra-Capacitor Supported Dynamic Voltage Restorer

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Abstract —Issues related to power quality have become more critical in recent times. Voltage sags and swells are amongst the most important issues associated with a power grid. Dynamic voltage restorer (DVR) is one product that can provide improved voltage sag/swell compensation with energy storage integration. A control technique is proposed with Synchronous Reference Frame (SRF) theory. Another technique is proposed to control the capacitor-supported DVR. To improve the power quality of the distribution grid, an Ultra-Capacitor (UCAP) integrated power conditioner is proposed in this paper. UCAPs are complementary to batteries as they deliver high power density and low energy density. They also possess higher energy density compared to conventional capacitors. The main contribution of this paper lies in the integration of rechargeable UCAP-based energy storage into the DVR topology. The proposed DVR control strategy is validated through simulation using MATLAB software.

Keywords—Dynamic voltage restorer (DVR), energy storage integration, Synchronous Reference Frame theory (SRF), phase locked loop (PLL), sag/swell, Ultra-capacitor (UCAP), Power quality.

I. INTRODUCTION

Power quality refers to the characterization of the quality of power being delivered to the customer's premises in Terms of certain indices like the magnitude, frequency of voltage, waveform shape etc. The power electronic devices can be used to improve quality and reliability of power in a distribution network. These devices could either be connected in series or shunt depending on the compensation strategy. DVR is one such series connected custom power device to mitigate voltage sags and swells harmonics in the supply voltages. The concept of using the DVR as a power quality product has gained significant popularity since its first use. Various types of rechargeable energy storage technologies are superconducting magnets, flywheels, batteries (BESS), and ultra-capacitors (UCAPs) are for integration into advanced power applications such as DVR. The most common energy storage device is batteries. However, the focus in recent research has shifted to the use of UCAPs as energy source. DVR with energy storage at the dc-terminal is to meet the active power requirements of the grid during voltage disturbances. Of all the rechargeable energy storage technologies, UCAPs are ideally suited for applications which need active power support. With the prevalence of renewable energy sources on the distribution grid and the corresponding increase in power quality problems, the need for DVRs on the distribution grid is increasing.

II. DYNAMIC VOLTAGE RESTORER

In order to overcome the Power Quality problems the concept of custom power devices emerged into the distributions system. One of the most efficient and effective modern custom power devices is DVR. It is a series connected device that injects voltage into the system to regulate the load terminal voltage. The primary function is to boost up the load side voltage rapidly during voltage sag/swell in order to avoid any disruption on load side voltage. With various topologies and controlling schemes DVR is used to improve power quality problems.

2.1. Basic principle of DVR operation

A DVR is a solid state power electronics switching device consisting of GTO or IGBT, a capacitor depository as a power storage device and inoculation transformer. It is linked in series between a distribution and a load that shown in figure 1. The basic idea of the DVR is to inject controlled voltage generated by a forced commuted converter in series to bus voltage by means of an injecting transformer. A DC/AC inverter regulates this voltage by SPWM technique. During normal operating condition, the DVR injects small voltage to compensate for the voltage drop of the injection transformer and device losses. When voltage sag occurs, the DVR control system calculates and synthesizes the voltage required to preserve voltage to load by injecting a controlled voltage.

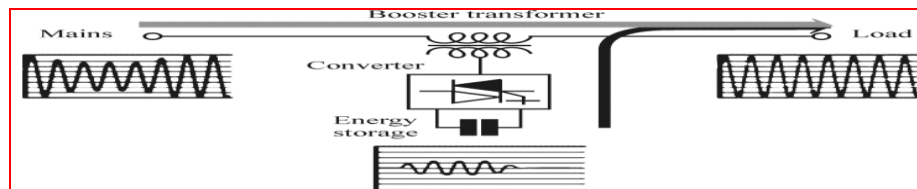


Figure 1. Principle of DVR

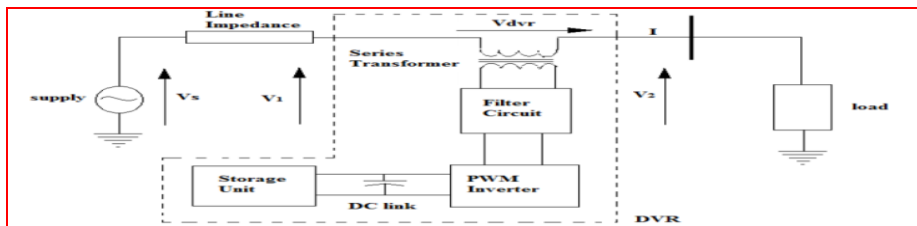


Figure 2. Components of DVR

2.2. Basic arrangement of DVR

There are five important components of DVR as shown in figure 2. The general arrangement of the DVR is composition of Injection transformer, Harmonic filter, Storage Devices, Voltage Source Converter (VSC), and DC charging circuit, Control and Protection system.

2.2.1. Voltage Source Inverter It is a power electronic system consisting of switching devices like MOSFET, GTO, IGBT and IGCT, which can generate sinusoidal voltage at any required frequency, magnitude and phase angle. The VSC is used to either completely replace the supply voltage or to inject the missing voltage which is the difference between the nominal voltage and the actual voltage. Usually VSC is not only used for mitigation of voltages but also for the power quality issues like flickers and harmonics.

2.2.2. Injection Transformer It is used to connect the DVR circuit to the distribution system. Transformer transforms and couples the injected voltages generated by the VSC to the incoming supply voltage. Low voltage windings are connected to the DVR circuit and High voltage windings are connected to the distribution system at the Point of Common Coupling (PCC). In this work three single-phase transformer or three-phase transformer may be used.

2.2.3. Storage Unit It supplies the required energy to the VSC via DC link for the generation of injected voltage in case of sags or swells.

2.2.4. DC charging Circuit The DC charging circuit performs the following tasks. Firstly, it charges the energy source after the compensation of sag/swell event. And secondly, it maintains the DC link voltage at the nominal value.

2.2.5. Filter It is used to maintain the low level harmonic content generated by the VSC to the acceptable level.

III. CONTROL OF DVR

The compensation for voltage sags using a DVR can be performed by injecting or absorbing the reactive power or the real power. When the injected voltage is in-quadrature with the current at the fundamental frequency, the compensation is made by injecting reactive power and the DVR is with a self-supported dc bus. However, if the injected voltage is in-phase with the current, DVR injects real power, and hence, a battery is required at the dc bus of the VSC. The control technique adopted should consider the limitations such as the voltage injection capability (converter and transformer rating) and optimization of the size of energy storage.

3.1. Control of DVR with BESS for voltage sag, swell, and harmonics compensation

Fig. 3 shows a control block of the DVR in which the SRF theory is used for reference signal estimation. The voltages at the PCC V_s and at the load terminal V_L are sensed for deriving the IGBTs' gate signals.

3.2. Control of self-supported DVR for voltage sag, swell, and harmonics compensation

Fig. 4 shows control block of DVR in which SRF theory used for control of self-supported DVR. Voltages at PCC are converted to rotating reference frame using Park's transformation. The harmonics and the oscillatory components of the voltage are eliminated using low-pass filters (LPFs). The compensating strategy for compensation of voltage quality problems considers that the load terminal voltage should be of rated magnitude and undistorted. In order to maintain dc bus voltage of the self-supported capacitor, a PI controller is used at the dc bus voltage of DVR and the output is considered as a voltage V_{cap} for meeting its losses.

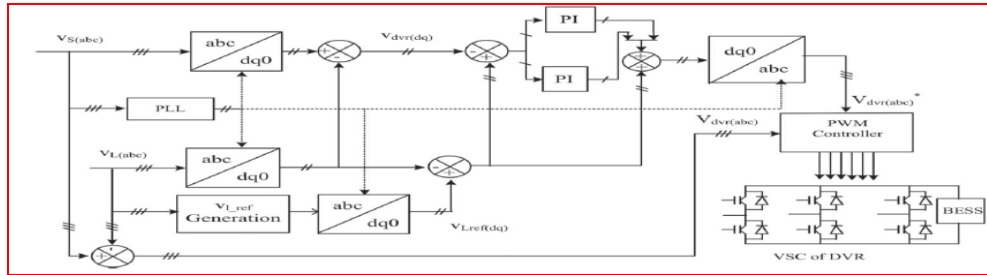


Figure 3. Control of DVR with SRF method

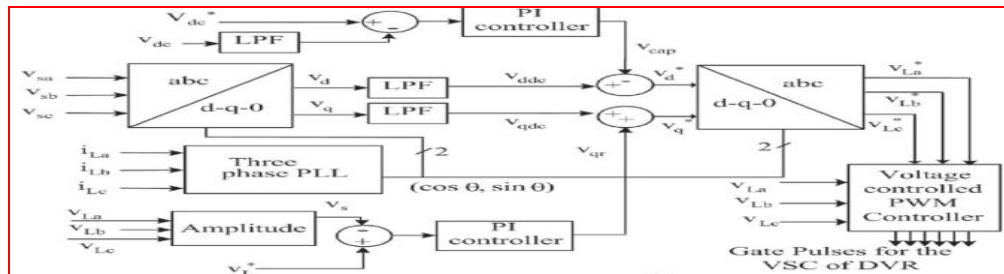


Figure 4. Self-supported DVR SRF method

IV. Control of DVR with UCAP

Of all the rechargeable energy storage technologies, UCAPs are ideally suited for applications which need active power support in the milliseconds to seconds timescale. Fig.5 shows DVR-UCAP. UCAP-based integration into the DVR system is ideal, as the normal duration of momentary voltage sags and swells is in the milliseconds to seconds range. UCAPs have low-energy density and high-power density ideal characteristics for compensating voltage sags and voltage swells, which are both events that require high amount of power for short spans of time. UCAPs also have higher number of charge/discharge cycles when compared to batteries and for the same module size; UCAPs have higher terminal voltage when compared to batteries, which makes the integration easier.

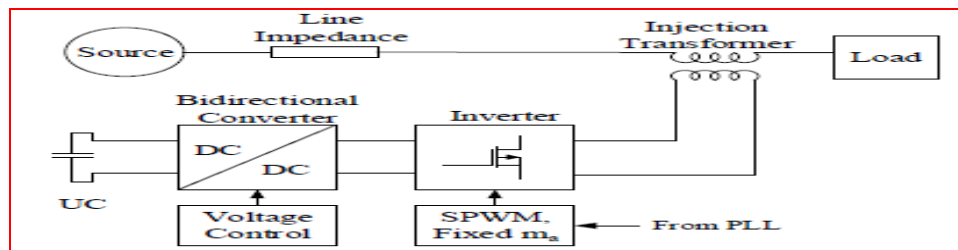


Figure 5. DVR with UCAP control strategy

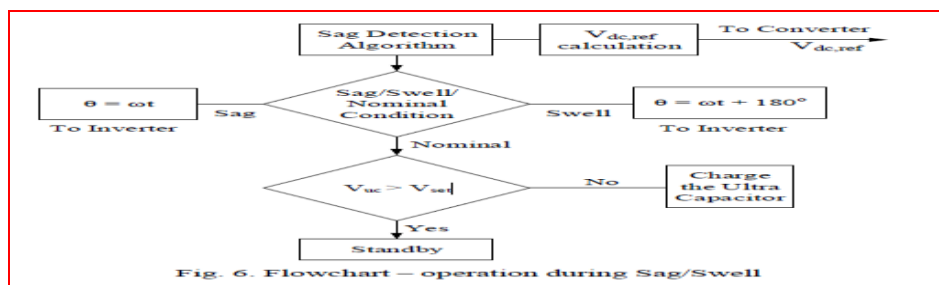


Figure 6. Flowchart – operation during sag/swell

4.1. Sag/Swell detection

The sag detection algorithm is implemented. The source voltage V_{abc} is sensed and transformed into rotating d-q frame by Park's Transformation to obtain DC values V_d and V_q . The magnitude V_s of the supply voltage is obtained from them. This is continuously compared with set reference value through comparator. During healthy condition of supply, the supply voltage magnitude will be same as set reference and comparator outputs a zero value. During sag/swell, comparator outputs a non-zero value that gives peak value of voltage that needs to be injected. During sag, the difference

in magnitude between sensed supply voltage and set reference will be a positive value, whereas during a swell, the difference will be negative. Fig. 6 shows the flowchart of the events that occur once a sag/swell is detected.

4.2. $V_{dc, ref}$ calculation

For SPWM, V_{dc} is calculated and set as reference voltage for the bidirectional converter. The PI controller based voltage loop of the DC/DC converter then adjusts the duty ratio of the switches so that the DC link voltage reaches a steady state value of $V_{dc} = V_{dc, ref}$.

4.3. PI controller

The aim of the control scheme is to maintain a constant voltage magnitude at the sensitive load point, under the system disturbance. The control system only measures the RMS voltage at load point. The modulating angle δ or delta is applied to the PWM generators in phase A, whereas the angles for phase B and C are shifted by 240° or -120° and 120° respectively.

4.4. Sequence analyzer

This block outputs the magnitude and segment of positive, negative, zero-progression mechanism of a set of three balanced or unstable signals. Fourier analysis over a sliding window of one cycle of the specified frequency is firstly applied to three input signals. The discrete version of this block allows specifying initial magnitude, phase of output indication.

4.5. LC filter

A three phase series inductance is 2mh and 25 μ F capacitor are connected in LC filter.

V. SIMULATION RESULTS

5.1. Simulink performance and results for BESS supported DVR with SRF

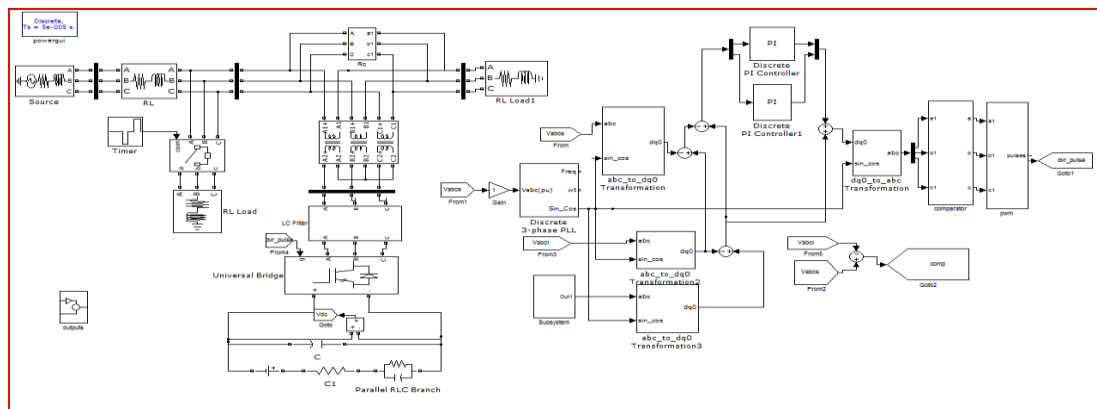


Figure 7. Simulink model for BESS supported DVR with SRF method of control

At 0.2 s, sag in supply voltage and at 0.4 s, a swell in the supply voltages is created.

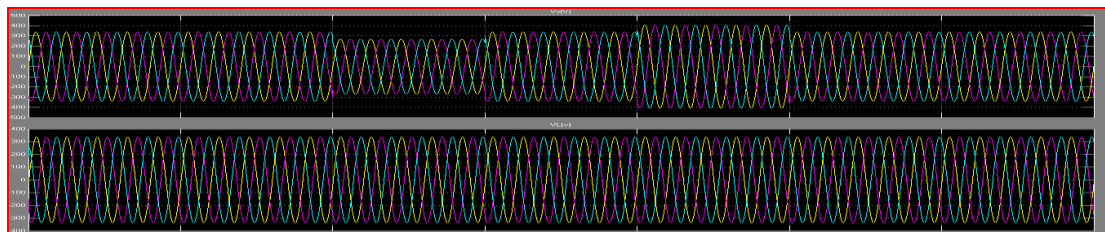


Figure 8. Sag and swell at v_s and v_L waveforms

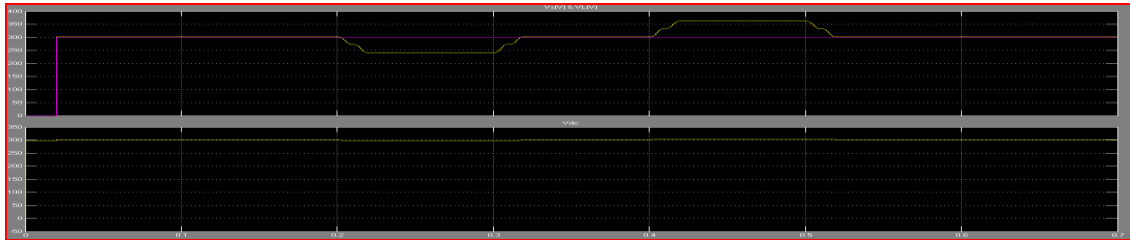


Figure 9. V_s and V_L , V_{dc} Waveforms

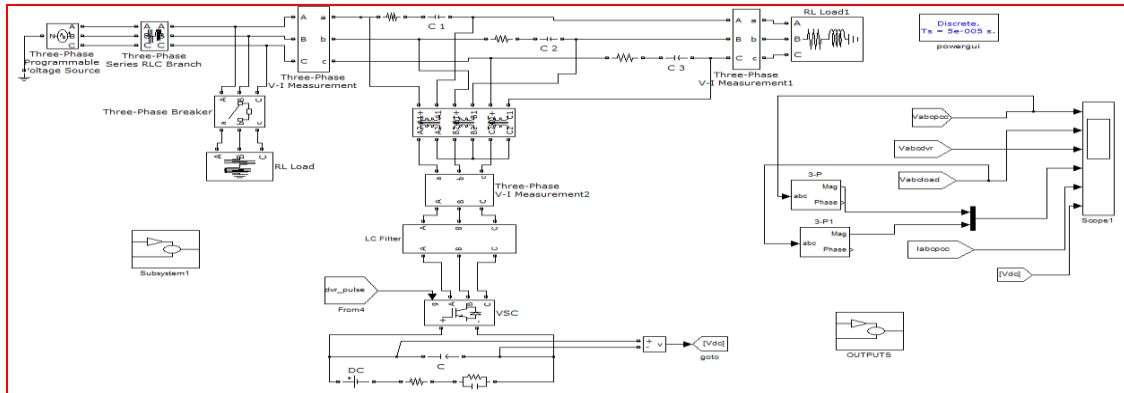


Figure 10. Simulink model for BESS supported DVR with SRF method of control

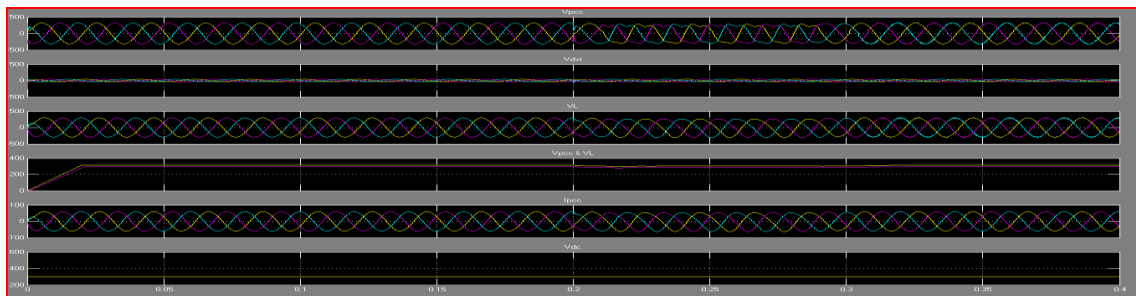


Figure 11. Performance of DVR during harmonics

5.2. Simulink performance of capacitor supported DVR with SRF

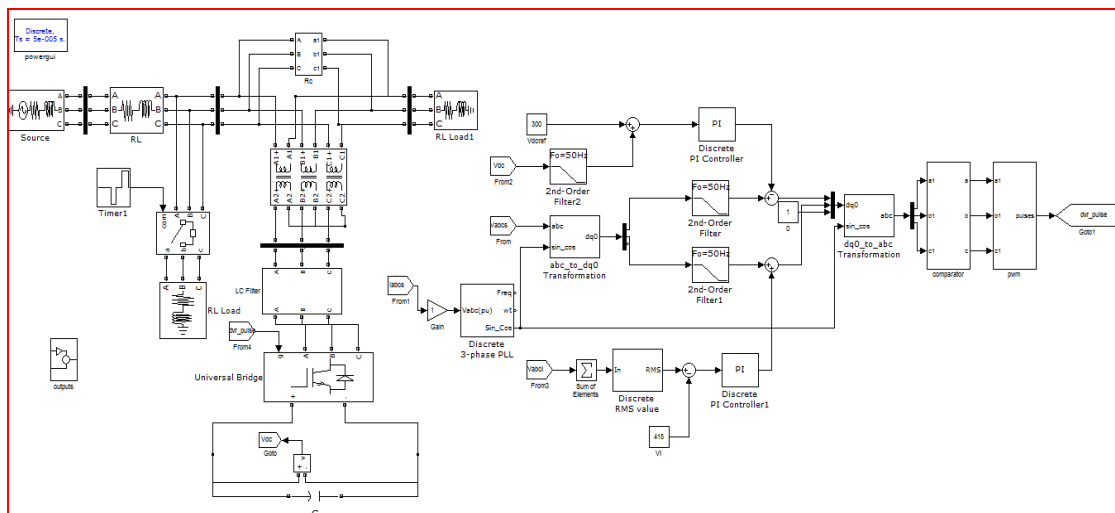


Figure 12. Simulink model for capacitor supported DVR with SRF method of control

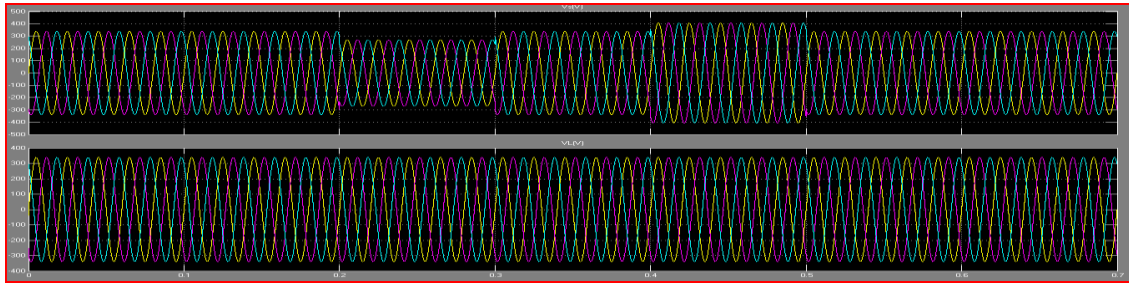


Figure 13. Performances of DVR during voltage sag and swell

5.3. Simulink Performance of UCAP supported DVR

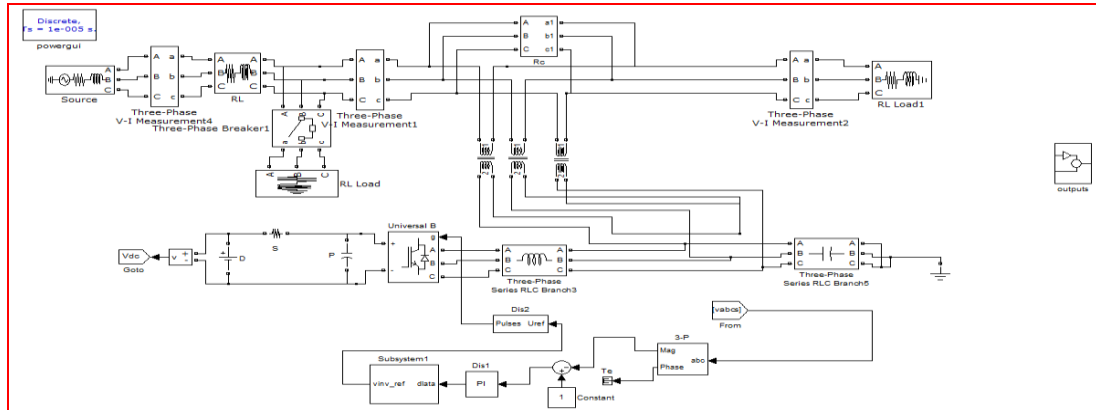


Figure 14. Simulink model for UCAP supported DVR

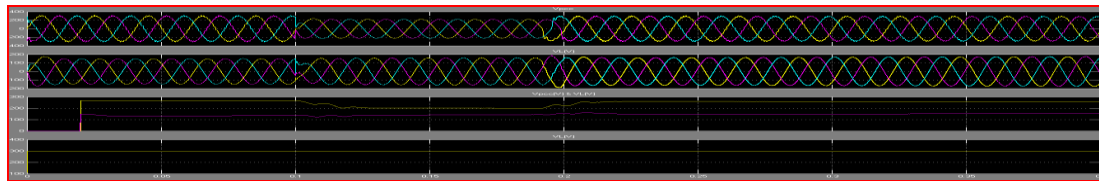


Figure 15. V_{pcc} , V_L and V_{dc} during Sag

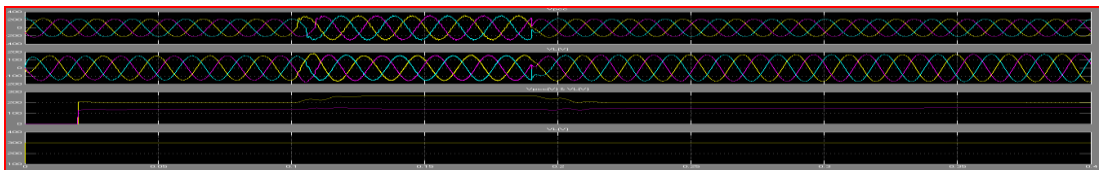


Figure 16. V_{pcc} , V_L and V_{dc} during Swell

5.4. Simulink performance of UCAP supported DVR with two feeder system

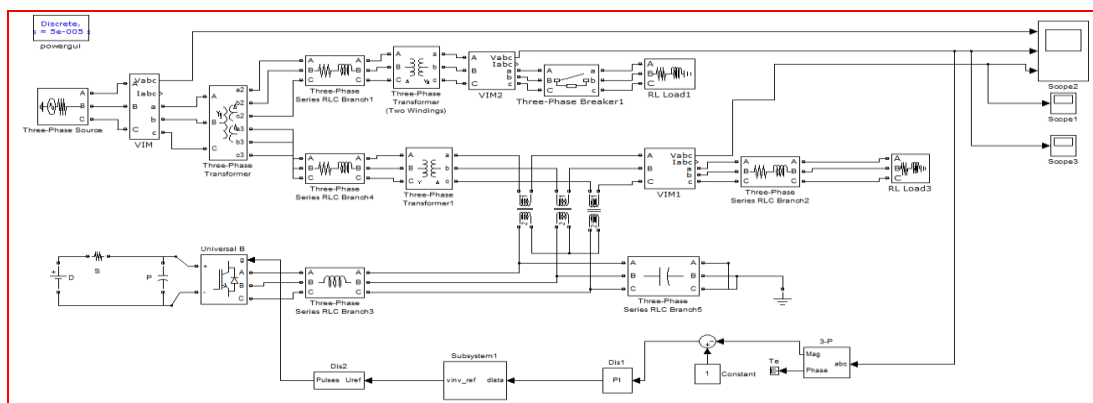


Figure 17. Simulink model for UCAP supported DVR with two feeder system

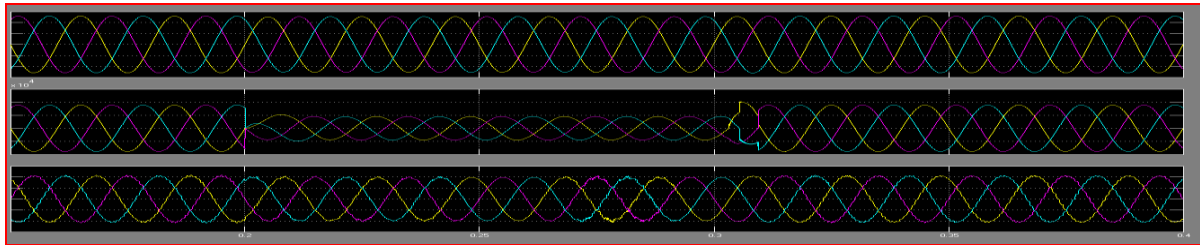


Figure 18. DVR during voltage Sag

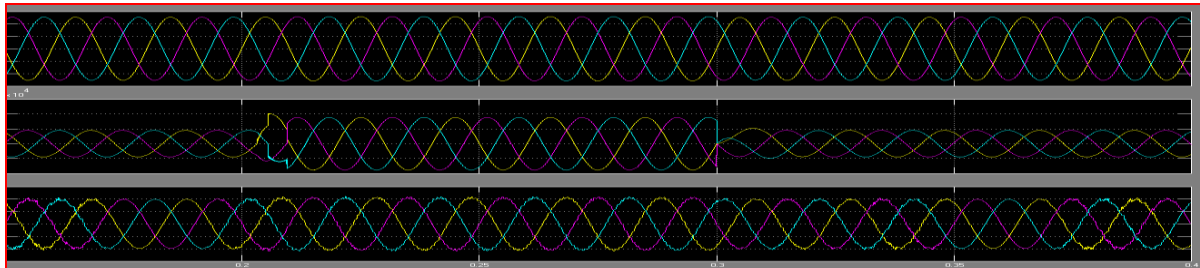


Figure 19. DVR during voltage Swell

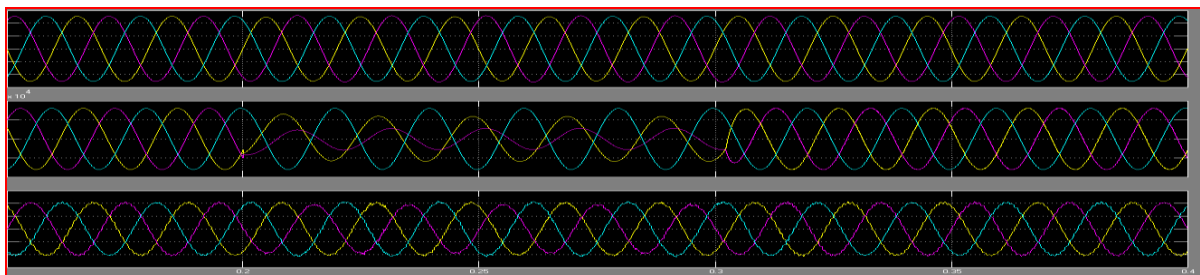


Figure 20. Performance of DVR during Faults

VI. CONCLUSION

In this paper, the concept of SRF Theory is proposed with BESS and Capacitor supported DVR and main contribution on integrating UCAP-based rechargeable energy storage to the DVR system to improve its voltage restoration capabilities is explored. With this integration, the DVR will be able to independently compensate voltage sags and swells without relying on the grid to compensate for faults on the grid. The UCAP integration through a bidirectional dc–dc converter at the dc-link of the DVR is proposed. Similar UCAP based energy storages can be deployed in the future on the distribution grid to respond to dynamic changes in the voltage profiles of the grid and prevent sensitive loads from voltage disturbances. The simulation shows that the DVR performance is efficient in mitigation of voltage sags and swells. The DVR handles both balanced and unbalanced situations without any difficulties. It injects an appropriate voltage component to correct any anomaly rapidly in the supply voltage; in addition, it keeps the load voltage balanced and constant at the nominal value.

REFERENCES

- [1] M. H. J. Bollen, Understanding Power Quality Problems-Voltage Sags and Interruptions. New York, NY, USA: IEEE Press, 2000.
- [2] A. Ghosh and G. Ledwich, Power Quality Enhancement Using Custom Power Devices. London, U.K.: Kluwer, 2002.
- [3] Mohibullah, S.H. Laskar, "Power quality issues and need of intelligent PQ monitoring in the smart grid environment," 47th International Universities Power Engineering Conference (UPEC), pp. 1-6, September 2012, London.
- [4] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, Electric Power Systems Quality, 2nd Ed. New York, NY, USA: McGraw-Hill, 2006.
- [5] A. Moreno-Munoz, Power Quality: Mitigation Technologies in Distributed Environment. London, U.K.: Springer-Verlag, 2007.
- [6] K. R. Padiyar, FACTS Controllers in Transmission and Distribution. New Delhi, India: New Age Int., 2007.
- [7] IEEE Recommended Practices and Recommendations for Harmonics Control in Electric Power Systems, IEEE Std. 519, 1992.

- [8] V. B. Bhavraju and P. N. Enjeti, "An active line conditioner to balance voltages in a three phase system," IEEE Trans. Ind. Appl., vol. 32, no. 2, pp. 287–292, Mar./Apr. 1996.
- [9] I. Hunter, "Power quality issues-a distribution company perspective," Power Engineering Journal, vol. 15, no. 2, pp. 75-80, April 2001.
- [10] O. Ipinnimo, S. Chowdhury, S.P. Chowdhury, J. Mitra, "A review of voltage dip mitigation techniques with distributed generation in electricity networks," Electric Power Systems Research, vol. 103, pp. 28-36, October 2013.
- [11] Hingorani, N.G., "Introducing custom power," Spectrum, IEEE, vol.32, no.6, pp.41-48, June 1995.
- [12] Changjiang Zhan, V.K. Ramachandaramurthy, A. Arulampalam, C. Fitzer, S. Kromlidis, M. Barnes and N. Jenkins, "Dynamic voltage restorer based on voltage space vector PWM control," IEEE Transactions on Industry Applications, vol. 37, no. 6, pp. 1855 - 1863, Nov2001.