ISSN 2277-2685

IJESR/Apr-Jun. 2024/ Vol-14/Issue-2/144-153

Sanepalle Gopal Reddy *et. al.*, / International Journal of Engineering & Science Research

# POWER QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER WITH SLIDING MODE CONTROL

**Sanepalle Gopal Reddy[1] K. Srinitha[2] Mohammed Furqan Saleem[3], G. Priyanka[4] A. Srinivas[5]**

[1]Associate Professor, Department of EEE, Jyothishmathi Institute of Technology and Science, Nustulapur, Karimnagar, TS, India

[2,3,4,5]UG students, Department of EEE, Jyothismathi Institute of Technology and Science, Nustulapur, Karimnagar, TS, India

**Abstract:** Customers in sensitive industries usually place a higher value on Power Quality (PQ). The potential huge financial losses that vital industrial loads can incur as a result of PQ problems have caught the attention of both consumers and power corporations. Voltage dips and spikes are the most common and severe symptoms of power quality problems in a secondary distribution system. To get rid of voltage dips and spikes, you need a dynamic Custom Power Device (CPD), and one such device is the Dynamic Voltage Restorer (DVR). Quick, flexible, efficient, and ever-changing, it works wonders. Its performance is primarily controlled by preset-type Voltage Source Converters (VSCs). This study develops a fused control mechanism for the DVR's VSC, which is based on Sliding Mode Control (SMC), to mitigate the effects of voltage spikes and dips. While both classic SMC and RTA solve the chattering issue, conventional SMC maintains its other benefits including durability, faster reaction time, and insensitivity to load fluctuations. Using the MATLAB/Simulink SimPowerSystem tool, we tested how well the suggested control approach worked. Every single simulation yielded a Total Harmonic Distortion (THD) value below 5%.

**Keywords:** Power Quality (PQ), Dynamic Voltage Restorer (DVR),Sliding Mode Control (SMC), Total Harmonics Distortion (THD)

## I. INTRODUCTION

An essential challenge for contemporary power systems is power quality (PQ), which may impair sensitive loads and utilities [1-2]. Computers, PLCs, microprocessors, and variable speed drives are electronic components that are crucial to most industrial machinery [3]. Voltage dips/swells and harmonics are examples of variations that could significantly reduce their performance. Distribution system (DS) PQ problems are more common since the DS is the weakest part of the power system [4-5]. Dynamic Voltage or a Custom Power Device (CPD) could solve these issues.

The following are examples of common power devices: Active Filters (AFs), DSTATCOMs, UPQCs, and DVRs [6]. Using a DVR is one of the best solutions to reduce PQ issues because of how well it works. This method is quick, efficient, and dynamic, and it effectively reduces voltage magnitudes [7]. A wide range of control schemes are available for the DVR's VSCs, such as state feedback, reference adaptive models, phase shift control, instantaneous symmetrical components, feedback, feedforward, phase shift control, PI resonant, P + resonant, Artificial Neural Networks (ANNs), Fuzzy Controller (FC), and DC-link with Proportional-Integral (PI) controller [8–11]. While there are benefits and drawbacks to each of these control approaches, they may all be used to produce a clean AC sinusoidal waveform at the DVR's VSC output. The fundamental objective of the design process is to provide a mathematical model of the system that is both accurate and optimal under certain operating circumstances. But these control systems aren't up to snuff when it comes to keeping up with the greatest performance as the system's characteristics change. Therefore, a robust and efficient control system is required, one that can keep running smoothly and precisely regardless of external factors. Because it does not depend on an accurate mathematical description of the system and is not sensitive to parameters, the SMC for DVR is able to avoid these problems. The purpose of this research is to provide a VSC of DVR that uses the SMC control approach to eliminate chattering and reduce the impact of voltage sags and swells in distribution systems., a problem with conventional controllers. The use of SMCs and DVRs in conjunction with the

MATLAB/SIMULINK platform may greatly reduce the frequency of voltage disturbances and total harmonic distortion (THD), as stated in reference [16].

## II. LITERATURE SURVEY

*[1]* "A novel dual slope delta modulation technique for a current source inverter based dynamic voltage restorer for mitigation of voltage sags," by S. Hasan, K. Muttaqi, D. Sutanto, and M. A. Rahman Publication date: September 20, 2021, volume 57, issue 5, pages 5437–5447, doi: 10.1109/TIA.2021.3089984.

This study delves into the use of a DSDM approach to the management of a DVR in order to tackle voltage sag issues in the power system. For a long period, the DVR has controlled the VSI's power electrical switches via pulsewidth modulation. But there are a number of issues with the VSI, including total harmonic distortion, high dv/dt, and output voltage ripples. To overcome these obstacles, this study presented a new DSDM method for a DVR that uses a current source inverter (CSI). After a In the event of a power loss, the proposed DSDM technique may get the load voltage back up to normal by turning on the CSI's power electronic switches. This causes the CSI to generate voltage waveforms without the necessary jumping in phase. In order to keep the system voltage stable when the power goes out, a storage-energy-supplied (SES) DVR is usually required. However, the energy storage component adds weight and expense to the DVR. A line-energy-supplied (LES) DVR has been proposed in the literature as a means to reduce DVR expenses via the elimination of energy storage.

To test the DSDM approach, we simulate different voltage drops due to radial distribution system failures. The proposed DSDM approach is used to control the CSI-based SES-DVR and LES-DVR such that voltage sag is reduced. The results of the simulation show that the proposed DSDM method successfully reduces voltage losses by precisely injecting the necessary amount and phase angle of missing voltage.

*[2]* "New method for detecting sag in line interactive dynamic voltage restorer," B. Bae, J. Jeong, J. Lee, and B. Hen Vol. 25, no. 2, pp. 1210-1211, Apr. 2010, doi: 10.1109/TPWRD.2009.2037520, published in the IEEE Transactions on Power Delivery.

This letter introduces a new approach to voltage drop detection using the line-interactive DVR. Instead of the current 4 milliseconds, the DVR may restore power in around 2 milliseconds using the suggested detection mechanism. Through the use of computer simulations, the practicability of the suggested approach was confirmed. When the DVR is equipped with the suggested detection system, it can efficiently compensate for sensitive loads in the event of a voltage drop or interruption.

*[3]* The paper "Control of energy optimized dynamic voltage restorer" was presented by M. Vilathgamuwa, A. A. D. Ranjith, S. S. Choi, and K. J. Tseng in the Proceedings of the 25th Annual IEEE Industrial Electronics Society Conference (IECON), volume 3, December 1999, pages 873-878.

To protect sensitive loads from voltage variations in the power distribution line, a specialized device called a dynamic voltage restorer (DVR) is used. This article shows a correction procedure by reducing DVR power usage and adjusting for voltage swells and sags. The suggested method outperforms the conventional in-phase boosting approach in fixing a specific disturbance while using less storage energy. To further enhance the DVR's dynamic performance, the article delves into a multiloop feedback control mechanism.

*[4]* "A novel distributed control system for a dynamic voltage restorer using elliptical trajectory compensation," published by P. Li et al., with co-authors L. Xie, J. Han, S. Pang, and P. Li 10.1109/TIE.2017.2682785, published in August 2017 in the IEEE Transactions on Industrial Electronics, volume 64, issue 8, pages 6484–6495.

To improve load voltage quality and free a dynamic voltage restorer from its captivity, this study proposes a new decentralized control method. The suggested approach modifies the amplitude and phase angle of the injected voltage using elliptical correction and instantaneous voltage and current computations to achieve low-voltage ride-through. A system of generalized equations based on symmetric-sequence components is given, and an attempt is made to regulate the active and reactive powers independently by adjusting two parameters. Another possible outcome of this strategy is the provision of several choices inside a theoretical framework by manipulation of the status parameters. Since these parameters represent voltage contributions from outside the system, they are used in the positive and negative sequences, respectively, to raise and level off the phase voltage for injection powers. Improving ride-through capabilities is a further goal of the proposed control system for reference generators that enable simultaneous changing voltages. As seen in the MATLAB simulation, the suggested control methods have the potential to offset voltage drops in a very short time.

*[5]* Mater. Today, Proc., vol. 10, Feb. 2022, doi: 10.1016/j.matpr.2021.07.053, "Control strategies for power quality enrichment in distribution network using UPQC," N. C. S. Sarita, S. S. Reddy, and P. Sujatha.

A UPQC, a state-of-the-art power quality conditioner, is now being utilized to enhance distribution network power quality. By mitigating power quality problems brought on by variations in voltage and current, power quality control (UPQC) is of great assistance to the distribution network. Investigation into its control mechanism under poor grid settings characterized by imbalance and distortion is much sought after. The ability of UPQC to continue operating in the presence of non-linear harmonic loads and imbalances is crucial if the goal power quality is to be maintained. In order to enhance power quality (PQ), this study investigates UPQC control algorithms and methodologies and suggests a flexible control strategy to make UPQC more efficient. A mission-critical distribution network may benefit from the suggested dynamic control method's enhancements to both steady-state performance and dynamic responsiveness. As a precaution, we put the suggested control method through its paces using MATLAB/SIMULINK models.

## III. PROPOSED SYSTEM

Connected in series with the distribution line, power electronics switching devices known as distributed voltage regulators (DVRs) inject the required controlled voltage. Figure 1 displays the grid together with the generalized DVR model. A portable digital recorder (DVR) has a power supply and a management system. A boosting injection transformer is used to connect a VSC in series with the grid.

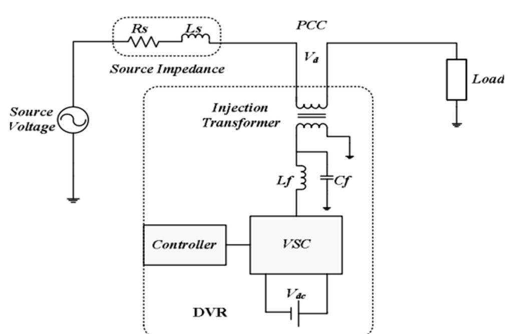


**Fig 1 Generalized single line model of DVR in the distribution network.**

One or more converters linked in series make up the voltage source converter, which is used to provide the necessary voltage rating. Based on the magnitude and phase, the DVR may inject a voltage into each phase at a fundamental frequency. The digital video recorder (DVR) has two modes of operation; one of them is standby mode, which is also known as short circuit operation (SCO) mode. When this mode is engaged, no electricity is injected.

2. This is called a "boost" the load bus voltage is restored when the DVR injects a voltage with the right magnitude and phase. to its pre-fault condition.

The four components illustrated in Figure 5.1 make up the power circuit of the DVR.

**a)Voltage Source Converter (VSC)**

Here you may choose between a three-wire or four-wire VSC, depending on your needs. The second one may be used to inject a voltage with no sequencing at all. There are two types of converters used: three-level and the more common two-level (Graetz Bridge) kind.

**b)Transformers**

For Boost or Injection

It is possible to bridge the voltage loss between the VSC and distribution voltage by connecting the distribution feeder in series with three single-phase transformers. All three transformers are versatile enough to handle windings of different kinds, such as open star, delta, star, and open star. You can't insert the zero sequence voltage into the second one. The connections of the load-supplying step-down transformer must be considered while selecting the winding of the injection transformer.

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**c)Passive Filters**

Both the converter side and the high voltage side are viable options for where to locate the boost transformers' passive filters. The converter side filters block the VSC-generated higher-order harmonic currents from entering the transformer windings. Better still, these parts can withstand lower voltages. One drawback is that the injected voltage experiences voltage loss and phase shift due to the filter inductor. Hopefully, this will be anticipated by the DVR's management software. While a transformer's windings may boost its rating owing to high-frequency current flow, this impact can be mitigated by employing the transformer's leakage reactance as a filter inductor and placing the filter on the high-voltage side of the device.

**d) Energy Storage**

With this setup, power will keep flowing to the load regardless of how much the voltage drops. Acid batteries made of lead material. An additional AC supply may power an auxiliary bridge converter, which supplies DC power to the VSC.

**e)BY-PASS switch**

A network of interrelated devices is what makes up a digital video recorder. In the event of a fault downstream, a fault current is produced and flows via the inverter. We are using the bypass switch to safeguard the inverter. One common method of avoiding the inverter circuit is to utilize a crowbar switch. In the end, the crowbar would be used to deactivate the inverter if the current reached a particular threshold. The inverter's components might be bypassed, however, if the current is large enough.

**IV. Control Strategy**

The three basic ways of control are as follows:

a) **Pre-Sag Compensation**

Constant monitoring of the supply voltage allows for the adjustment of the load voltage to the pre-sag condition. This method generates (nearly) continuous load voltage, although it usually need a higher DVR rating. Before a sag occurs, VS = VL = Vo. The magnitude of the supplied voltage to VS1 drops due to the voltage sag. Additionally, as shown in Figure 5.2, the phase angle of the supply could fluctuate. In order to maintain the magnitude and phase of the load voltage (VL = VS1 + VC1) at Vo, the DVR injects a voltage VC1. Some loads supposedly have a higher susceptibility to phase jumps, thus it's crucial to account for both voltage spikes and dips.

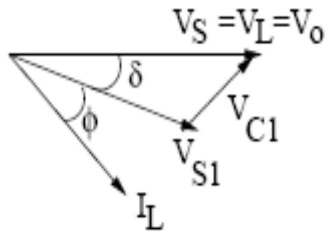


**Fig 2 pre sag phaser diagram**

**b) In-phase Compensation**

The DVR will continuously inject a voltage that is in phase with the supply voltage, regardless of the load current or the pre-sag voltage (Vo). This control mechanism reduces the magnitude of the injected voltage to a minimum. However, there is an issue with the phase of the load voltage. For non-phase jump sensitive loads, this control method optimizes the voltage rating of the DVR. No matter what you do, the DVR will still drain the battery.

**5. 8 control system for DVR**

As seen in Figure 5.3, the DVR includes a reference signal estimate that adheres to SRF theory as one of its control blocks. Voltages applied to the PCC and load terminals, respectively, generate the ground and supply voltages of the IGBTs. The produced unit vector may be used to find the reference load voltage V*L [23]. According to the abc−dqo conversion, the voltages at the load points (VLa, VLb, VLc) are converted into the rotating reference frame using Park’s transformation. This transformation is applied using unit vectors (sin, θ, cos, θ) generated by a phase-locked loop.

$$\begin{bmatrix} v_{Lq} \\ v_{Ld} \\ v_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_{Laref} \\ v_{Lbref} \\ v_{Lcref} \end{bmatrix}. \quad (1)$$

Similarly, reference load voltages

$$v_{Dd} = v_{Sd} - v_{Ld}$$
$$v_{Dq} = v_{Sq} - v_{Lq}.$$

Additionally, voltages were converted at the PCC vSare to the rotating reference frame. Next, the reference frame, which is in a perpetual state of motion, is used to compute the DVR voltages.

$$vDd = vSd - vLd \quad (2)$$
$$vDq = vSq - vLq \quad (3)$$

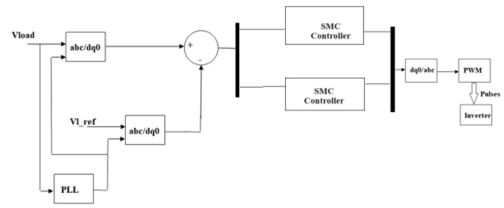


**Fig. 3. Control block of the DVR that uses the SMC controller.**

## V. PROPOSED SMC CONTROLLER

The sliding mode controller (SMC) is one method of switching control. With this kind of control, the sliding surface provides an excellent goal for the system states to be steered towards. Maintaining system states is the job of a well-designed control rule. Basic sliding mode control has been published for quadrotors and has been successfully implemented on many occasions. To stabilize the under-actuated subsystem of the quadrotor, R. Xu and U. Ozguner proposed a sliding mode control using a PID controller. They tested the controller's robustness by dealing with parametric uncertainty. In order to maintain the quadrotor's stability, Swamp (2016) implemented a second-order sliding mode control based on Lyapunov theory. This second-order model proved to be more resilient and showed promise than the conventional sliding mode controller. Figure 2 shows a simple SMC.

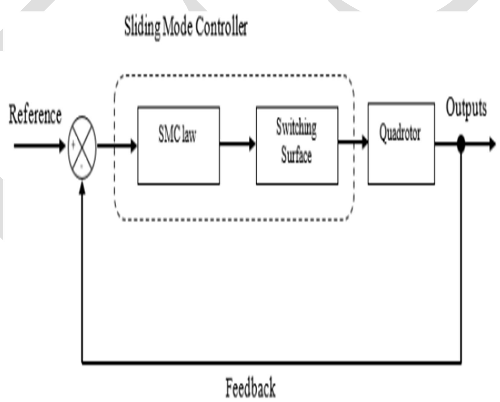


**Figure.4 A block diagram of Sliding Mode Controller**

A number of people are interested in using the SMC technique to cope with uncertainties while designing robust controllers for high-order nonlinear systems. Reducing the impact of disruptions and parametric uncertainties, it may provide resilience to the system. However, the regulated model's continual switching is the root cause of the chattering problem. Energy loss, unmodeled dynamics, and unstable systems are some of the possible negative results that might result from this..

## VI. SIMULATION RESULTS

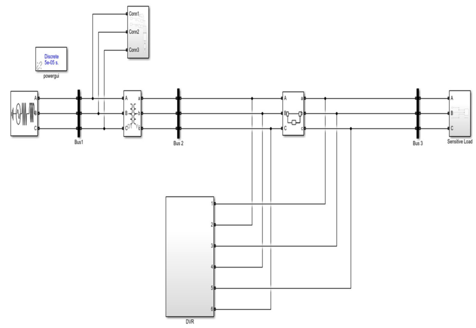

**Fig .5 MATLAB/SIMULINK circuit diagram of the proposed system**

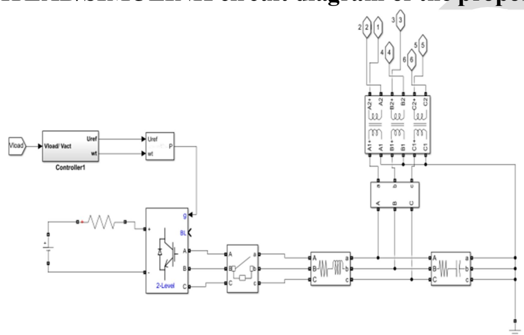

**Fig.6 Subsystem of DVR**

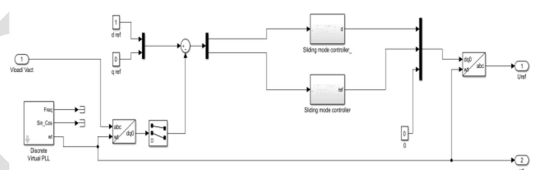

**Fig.7 Subsystem of Controller**

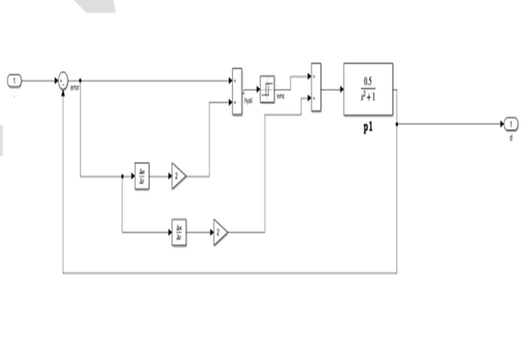

**Fig.8 SMC subsystem**

**CASE-1 UNDER SAG CONDITION**

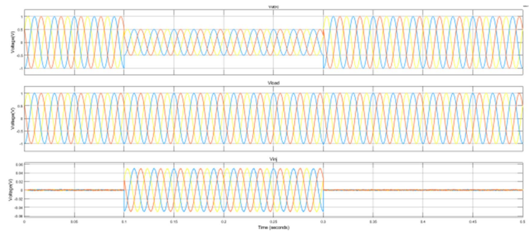

**Fig.9 (a)Source voltage (b)Load voltage (c) injected voltage**

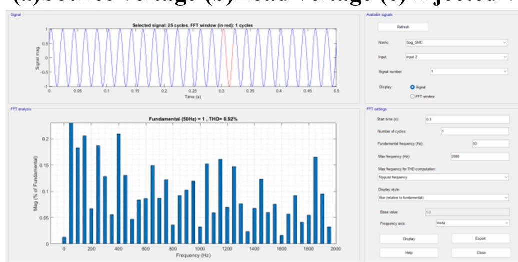

**Fig.10 load voltage THD% = 0.92%**

**CASE-2 UNDER SWELL CONDITION**

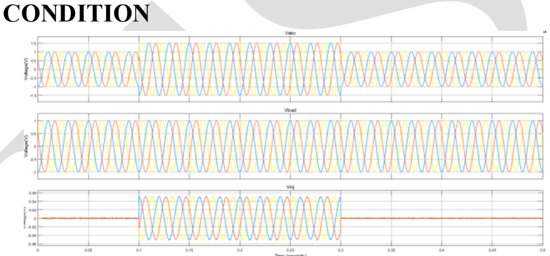

**Fig.11 (a)Source voltage (b)Load voltage (c) injected voltage**

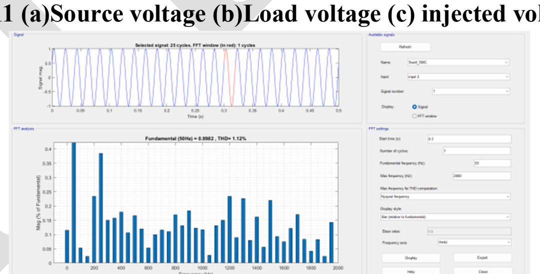

**Fig.12 load voltage THD% = 1.12%**

**CASE-3 UNDER FAULT CONDITION**

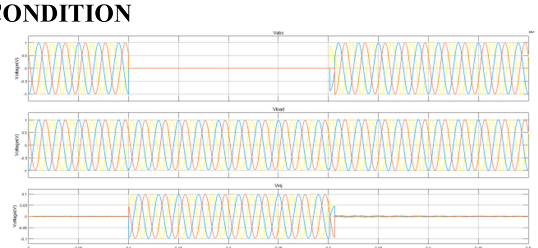

**Fig.13 (a)Source voltage (b)Load voltage (c) injected voltage**

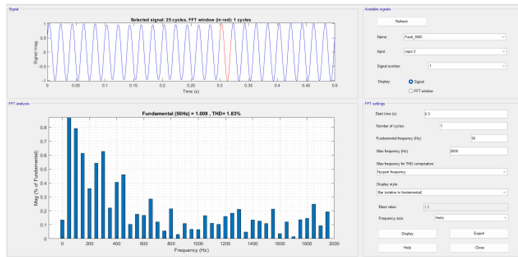

**Fig.14 load voltage THD% = 1.83%**

## CONCLUSION

The digital video recorder (DVR) has been an effective and practical tool for improving power quality, and it has been recommended as the most notable technology for this purpose. An SMC-based DVR with a power circuit may be modelled and simulated using the MATLAB/Simulink platform. The control circuit and power system are subjected to a sensitive load. Under sag, swell, and fault situations, the DVR is tested with the test system. A more stable and smooth voltage profile with little harmonic content was maintained by the suggested DVR using an SMC-based control method, which proved successful in compensating for the distorted load voltage. With the right voltage component injected by the DVR, any voltage supply fault may be corrected, allowing the load voltage to remain normal and constant within the ideal range. An exciting avenue for future study in this area is the use of control strategies based on optimization techniques similar to soft computing in order to enhance power quality.

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