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# Voltage Sag Mitigation using DVR and Ultra Capacitor

Manoj Baliram Ambhore<sup>1</sup>, Dr. Nitin J. Phadkule<sup>2</sup>,

PG Student, Department of Electrical Engineering, Government College of Engineering, Aurangabad (MS), India.<sup>1</sup>

Professor, Department of Electrical Engineering, Government College of Engineering, Aurangabad (MS), India.<sup>2</sup>

**ABSTRACT** - Due to the rising integration of renewable energy sources into the power system, power quality issues have recently become more significant. One of the main problems with a power system is voltage sags and swells, and numerous studies have been conducted to try to find solutions. Equipment for power conditioning can raise the power's quality. Sensitive loads are protected from the effects of voltage disturbance on the distribution feeder by the use of dynamic voltage restorers (DVR). Energy storage with a high voltage rating is required in the DVR control procedures due to the absence of a buck-boost converter in some of the present DVR systems. Ultra capacitors (UCAP) have typical characteristics including low energy density and high power density in order to reduce volt sag and swell. In this study, a better DVR structure is presented that can provide extended voltage sag mitigation. Since an ultra-capacitor has many advantages over a traditional battery and generates excessive power quickly, it is used as an energy storage device in the recommended DVR. The DVR's active source has been this ultra-capacitor. This study presents a DVR's modelling and simulation for power quality problems. All simulation activities are performed using MATLAB.

**KEYWORDS:** Voltage sag/swell; Dynamic Voltage Restorer (DVR); Ultra-capacitor (UCAP); DC-DC Converter; MATLAB/Simulink;

**ABBREVIATIONS-** UCAP- Ultracapacitor, DVR- Dynamic Voltage restorer

## I. INTRODUCTION

Many power quality challenges are brought on by the expanding use of non-linear and power electronic loads[1]. Harmonics and voltage distortion are caused by these loads. Power quality problems can result in faults of relay systems, protective devices, and sensitive equipment. Power quality issues caused by voltage sag and swell largely impact the distribution system. Short circuits, lightning strikes, faults, and inrush currents are the causes of voltage sags[2]. Heavy loads being started and stopped, inadequately scaled power supplies, incorrectly controlled transformers, and single lines going to the ground are all factors that contribute to voltage swells[3]. Voltage sag, which can last anywhere from 0.5 cycles per minute, is the phrase used to describe a drop in the normal voltage level that happens between 10 and 90% of the nominal RMS voltage at the power frequency[4]. Voltage swells are transient voltage rises outside of the normal tolerances that happen at the power frequency. Although they typically last more than one cycle, they are typically not longer than a few seconds[5]. The use of specialised power devices is one of the best strategies to reduce voltage sag and swells. There are various unusual forms of power. Each of which has particular benefits and limitations. The custom power device (CPD), based on the idea of semiconductor switches[6], is a powerful tool to protect fragile loads from power line disturbances[7]. Industry is increasingly using the Dynamic Voltage Restorer (DVR)[8], one of many modern CPDs, more frequently to mitigate[16] the negative impacts of voltage disturbances on sensitive loads[9]. The power quality of the distribution system can be enhanced by using a custom power device DVR for voltage disturbances including voltage sags, swells, harmonics, imbalanced voltage, and others. In order to keep the load voltage within the defined tolerance limits, the Dynamic Voltage Restorer (DVR) is a device that detects sags or swells and links a voltage source in series with the supply voltage. It is frequently installed in a distribution system between the supply and the primary load feeder at the point of common coupling (PCC). DVR provides characteristics such as fault current limitations, line voltage harmonics compensation, and decreasing voltage transients in addition to adjusting for voltage sags and swells[10].

Voltage sags, swells, flicker, voltage notch, harmonic distortions, transients, and abrupt disruptions are some of the most common PQ problems affecting industrial clients. PQ problems affect delicate electronic equipment, critical and

nonlinear loads that are a component of precision production processes, and they can lead to a variety of problems, including financial losses, equipment damage, and a deterioration in product quality. Single line to ground fault (SLGF) fault conditions, the initiation of large motor drives, transformer energization, and animal contact are only a few causes of voltage sags. The size, length, and presence or absence of a phase leap help to detect voltage sags. The position of the fault from the sensitive load, associated impedances of the transformers, conductors, and related equipment, voltage class of the feeder, and speed of response of load protection switchgear all affect how much and how long the sag is felt by the sensitive loads[11].

DVR has been found to be effective at reducing voltage sag and swell when various control mechanisms are used. The core architecture of the DVR, its operation, compensation schemes, and control paradigms are thoroughly discussed. The advantages of DVR over alternative systems include being less expensive, needing less computational effort, and being simpler to operate. DVR provides a less complex way to enhance voltage profile. In comparison to other systems, linear controllers are simpler to use and require less computation[12]. The term "power quality" refers to how well the power delivered to customers' locations satisfies specific requirements, such as the voltage's amplitude and frequency, the waveform's shape, etc. These indices can deviate from their nominal values for a number of reasons, both inside the utility's control and outside of it. Power quality issues include harmonics, long-term voltage disruptions, voltage sags and swells, and others. Switching loads and capacitor banks, power system defects or short circuits, high machine starting currents, among other things, can all lead to power quality issues[13].

*i. Voltage Sags -*

Any defects wherever in the network will have some effect on other voltages since the electrical system is continuous circuit. Sites near the faulted area will naturally experience a bigger voltage drop as a result of the fault than other, (electrically) remote areas. Although sags can occur anywhere in a system, utility distribution systems exhibit them more visibly because low-voltage systems are more vulnerable to circumstances that could result in short circuits. The majority of utility companies perform distribution system protection using a technique known as "fuse saving." The diagram below (Fig 1) shows a typical overhead distribution system, with two feeders using the same substation transformer to supply power. Each major circuit has one fused tap and an automatic circuit recloser (ACR)[14].

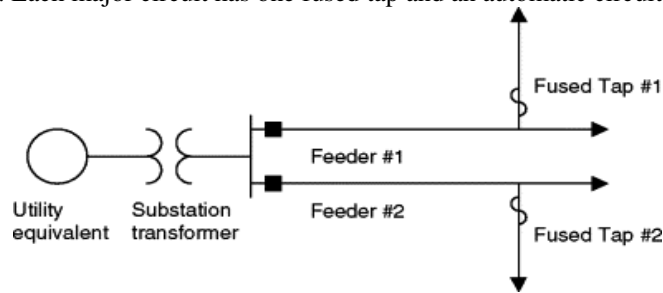


Figure 1– Overhead distribution system

Under a protection system based on fuse-saving technology, any fault downstream of a fault will first be corrected by the substation recloser, followed by a reclosing operation (re-energizing the circuit) ½ to later. If the problem is still there, the nearest fuse should blow to totally isolate it. The voltage sag's waveform is presented in the picture below(fig 2), and the bottom image displays the disruption in the RMS voltage trend.



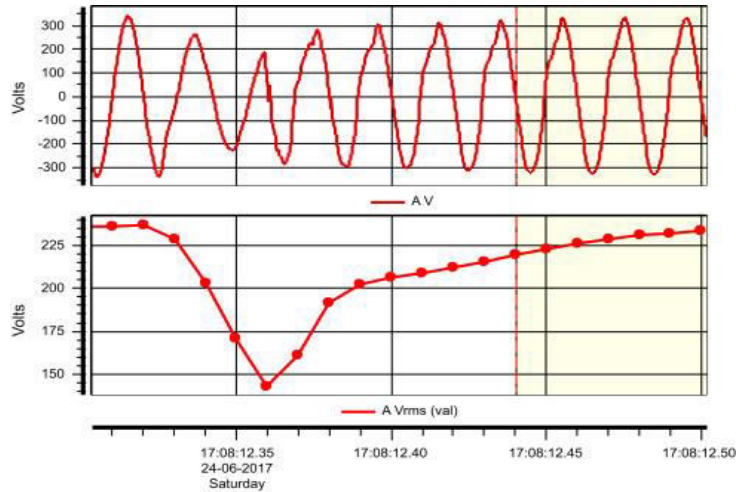


Figure 2- Wave shape of voltage sag.

**ii. Area Of Vulnerability-**

The concept of an area of vulnerability has been devised to evaluate the likelihood of sensitive equipment being exposed to voltage below its minimal voltage sag ride-through capability. The lower voltage level that a piece of equipment can withstand without breaking down or malfunctioning is referred to by the latter term. Another name for this is the equipment voltage sag immunity or susceptibility limit. The total circuit miles exposed to faults that could potentially drop voltage magnitudes at an end-user facility below the necessary minimum voltage sag ride-through capacity make up the region of vulnerability[15]. The region of vulnerability for motor contactor and variable-speed drive loads at an end-user facility supplied by a distribution system is depicted in the diagram below(fig 3).

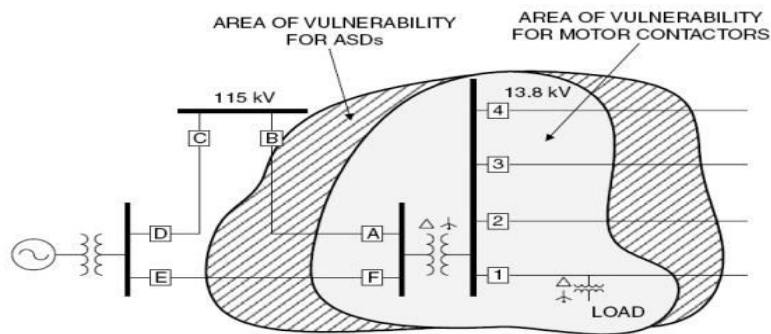


Figure 3 - Illustration of area of Vulnerability

**iii. Mitigation Of Voltage Sags**

Different power quality problems would require different fixes. It would be extremely expensive to decide to implement mitigation strategies that do not fully or adequately address the problem. These costs consist of lost production, human costs for cleanup and restarting, product damage, lowered product quality, delivery delays, and lower customer satisfaction[16]. When a client or installation has voltage sag, there are a number of mitigation measures available to deal with the problem. The manufacturer of the equipment, the utility, and the customer are the three groups that fall under these obligations. Some mitigating techniques include —

- Dynamic voltage restorer Active series Compensators Distribution static compensator (DSTATCOM)
- Solid state transfer switch (SSTS) Static UPS with energy storage Backup storage energy supply (BSES)
- Ferro resonant transformer Flywheel and Motor Generator set Static Var Compensator (SVC)

**iv. Dynamic Voltage Restorer (DVR):**

During voltage sag, complicated static devices known as Dynamic Voltage Restorers (DVR) add the "missing" voltage. In essence, this means that in order to restore the voltage to the required level for the load, the device injects voltage

into the system. In order to inject voltage, a switching mechanism and a transformer connected in series with the load are used.

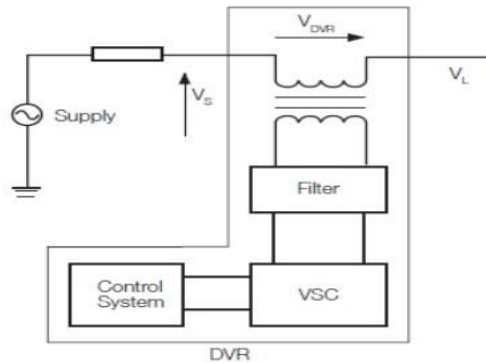


Figure 4- Basic DVR Structure

There are two types of DVRs: those with and those without energy storage. Devices without energy storage can change the voltage waveform by drawing more current from the source. With devices with energy storage, the voltage waveform is adjusted utilising the energy that has been saved. In contrast to a UPS, a DVR with storage only transmits the section of the waveform that has been reduced by voltage sag. It does not transmit the complete waveform. DVRs frequently become inoperable when there are outages. A DVR diagram is displayed in Figure below (fig 4 ,5). The voltage source converter (VSC), harmonic filter, injection/booster transformer, and control system make up the basic components of a DVR. For those who are interested in learning more about DVR systems, the article includes a detailed description of the architecture and operation of DVRs. DVR systems have the advantage of being very quick and efficient. The DVR is claimed to be the best practical choice for decreasing voltage sags based on its size and capabilities. Systems without storage are not affected by any of the current storage-related issues. The use of DVR systems for purposes other than minimising voltage sag is another advantage [12,13,14].

v. **Ultra Capacitor-**

A device used to store electrical energy is an electrochemical capacitor, also known as an ultracapacitor, supercapacitor, or electrochemical capacitor. The design and functioning mechanism, which lies between that of a normal capacitor and a battery, enables a number of interesting and practical applications. Similar to a battery, an ultracapacitor cell consists of positive and negative electrodes that are separated by an electrolyte. Ultracapacitors, on the other hand, store energy electrostatically, as opposed to batteries, which do so chemically. The electrolyte of an ultracapacitor (fig 5) is divided by a dielectric separator, which works similarly to a capacitor. This construction has a far higher energy storage density than a conventional capacitor because it can accommodate a short electrode separation. Yet, because an ultracapacitor's discharge is not dependent on a chemical reaction, it can release its stored energy far more quickly than a battery of the same size. Because no physical or chemical changes occur when charge is maintained, ultracapacitors can be used again without degrading [15].

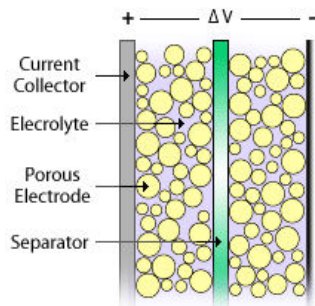


Figure 5- Schematic of an Ultracapacitor cell. (Image Credits NREL.gov)

## II. RELATED WORK

A voltage feedback PI-controller was developed by G Siva Rama Krishna et al to generate the gate pulses for the inverter. The buck boost converter is also controlled by an average current mode controller, a dependable controller for boosting and bucking DC voltage levels. R offers a rechargeable UCAP and DVR combination that uses an in phase injection technique to account for voltage peaks and valleys. N. RathinaPrabha et al, Its UCAP-modular, DVR's adaptive system design provides active power capability and deep, extended mitigation for power quality issues. In addition to providing a constant dc-link voltage for the DVR, the bidirectional DC-DC converter that connects the DVR to UCAP also makes adjustments for transient voltage sag and swell. The functionality of UCAPDVR is improved while using the FUZZY LOGIC Controller. The suggested system's simulation model was created in MATLAB, and the results were compared to those attained using traditional DVR.

The DVR's power circuit and a super capacitor make up K. D. Joshi's suggested technology. DVR protects that load as a result from any power failures. This study shows how to use a proportional integral (PI) controller to control a super capacitor-based DVR. The PSCAD/EMTDC application is used to simulate the system. This software's graphic features make it easier to execute various model implementation and simulation outcomes. Dr. M. Kalyanasundaram et al proposed a thorough fuzzy-based DVR that was effective in three areas. A voltage supply inverter-based DVR with a fuzzy controller is installed in the distribution system to provide the required load aspect correction.

If you want to show the sample how to recognise the indication of serious trouble in real-time, you may use the BP-based manipulation method to extract the basic weighted pricing of the active and reactive power components of load currents. Pravin G. Bhende et al propose an enhanced DVR architecture to provide more comprehensive PQ mitigation. The suggested DVR uses an ultra-capacitor as an energy storage device because of its capacity to deliver a sizable amount of power in a short period of time and the several advantages it offers over a traditional battery.

Rechargeable energy storage is integrated, according to C. Subbaraju et al., to control the current active power. Rechargeable ultra capacitors (UCAP) should be used in conjunction with a digital video recorder for this type of application (DVR). For active power supply in the millisecond to second range, this configuration works best. As ultra-capacitors can have both low and high energy densities, they can be used in a variety of applications.

According to S. Preetha et al., UCAP is utilised as energy storage since it produces a large amount of electricity in a short period of time. Delivering a steady dc-link voltage while also adjusting for brief voltage changes is made possible by a bidirectional DC-DC converter that incorporates the DVR within the ultra-capacitor.

## III. METHODOLOGY

Schematic of the proposed control approach incorporating the sag detection algorithm. The source voltage  $V_{abc}$  is measured and transformed into a rotating d-q frame using Park's Transformation to yield the DC values  $V_d$  and  $V_q$ . The magnitude of the supply voltage  $V_s$  is determined from  $V_d$  and  $V_q$  (1). This is continuously compared to the predetermined reference value using a comparator. The supply voltage magnitude will match the predetermined reference value when the supply network is operating properly, and the comparator will output zero. The peak voltage that has to be injected during a sag or swell is indicated by the comparator's non-zero value, which is provided. During a sag and a swell, the size of the difference between the detected supply voltage and the specified reference will be positive, respectively. The sag/swell detection control shifts the phase of the modulating signals used by the inverter by 180 degrees if the difference is negative or when there is a swell. The phase angle is produced by the PLL that has been synchronised to the supply voltage. Figure 6 shows the series of events that occur after a sag or swell.

$$V_s = \sqrt{V_d^2 + V_q^2} \quad \text{-----I}$$

$$\begin{bmatrix} V_d \\ V_q \end{bmatrix} = T \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad \text{-----II}$$

Whereas,

$$T = \frac{2}{3} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - \frac{2}{3}\pi) & \cos(\omega t + \frac{2}{3}\pi) \\ -\sin(\omega t) & -\sin(\omega t - \frac{2}{3}\pi) & -\sin(\omega t + \frac{2}{3}\pi) \end{bmatrix} \quad \text{----III}$$

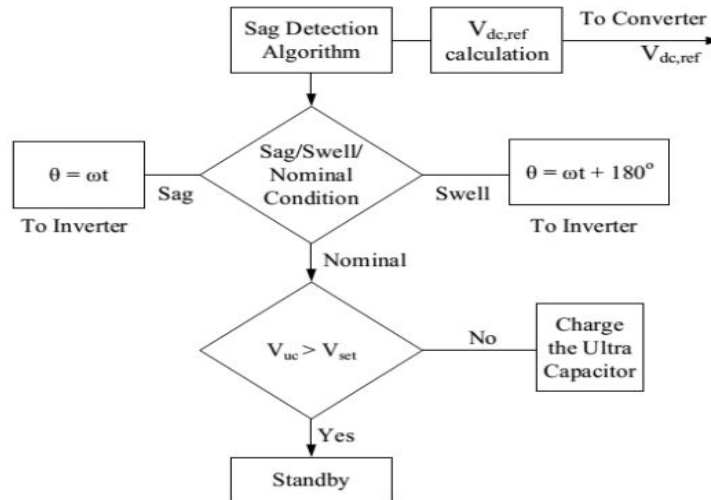


Figure 6 - Flowchart – operations during Sag/Swell.

The integrated UCAP-DVR is modelled in MATLAB/Simulink for a 400 V-RMS system. The proposed integrated dynamic voltage restorer ultra capacitor design and its control circuit are built using MATLAB/SIMULINK to enhance the distribution grid's power quality. Fig. 7, 8, 9 depicts the simulation model for the proposed system. An ultra capacitor-based DVR(fig 8) is used in the system's configuration to lessen voltage sag and swell. The controller architecture of the suggested system is shown in figure 7; demonstrate the output voltage obtained in contrast to the input voltage and the DVR system voltages.

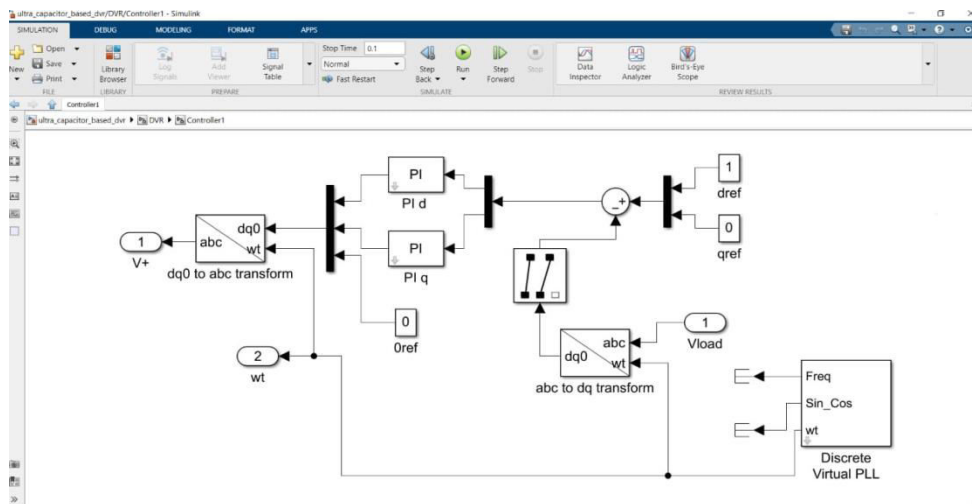


Figure 7: Simulation model for DVR

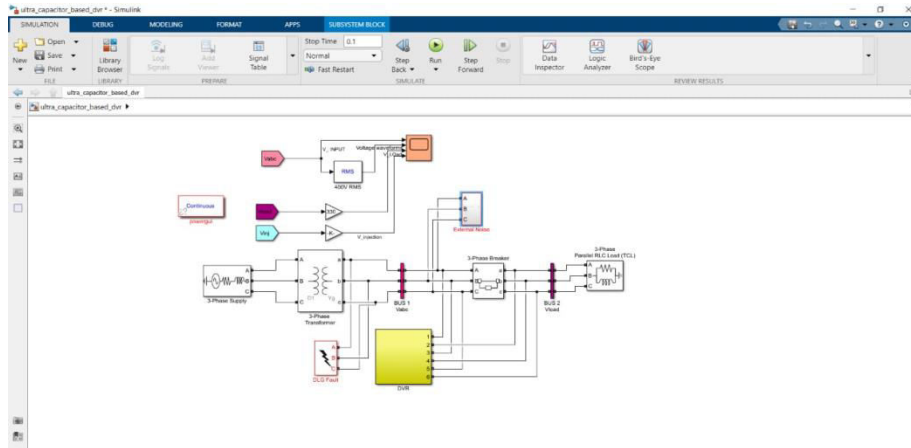


Figure 8 Ultra capacitor based DVR

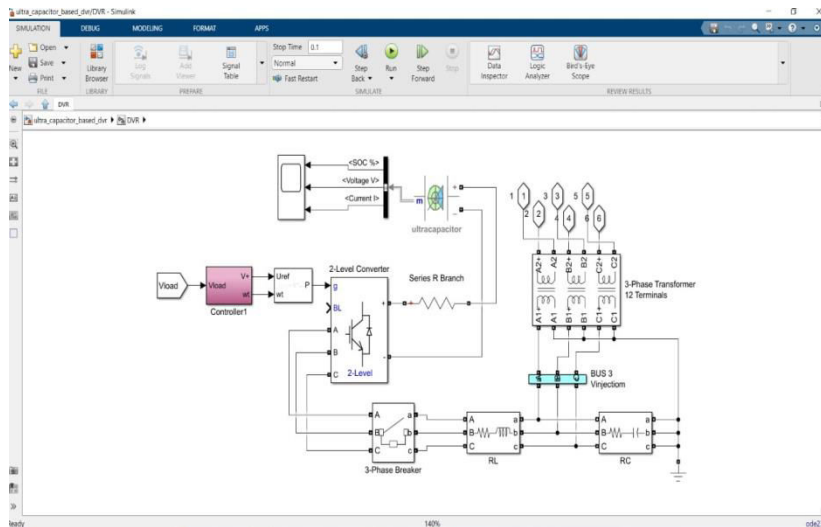


Figure 9: Simulation model for Ultra capacitor

#### IV. EXPERIMENTAL RESULTS

The result of combining UCAP-DVR for the voltage sag and swell occurrence is explained in the paragraphs that follow. Fig 10 explains the signal statistics used for experiments.

Signal Statistics		
	Value	Time
Max	2.921e+02	0.050
Min	6.639e+01	0.073
Peak to Peak	2.257e+02	
Mean	1.722e+02	
Median	1.756e+02	
RMS	1.865e+02	

Figure 10- Signal Statistics used in Analysis

The voltage that the series electrical converters [Vabc, Vabc\_RMS, Vload, Vinj] for the voltage sag is shown in Fig 11. As the injected voltage Vinj lags the line-neutral supply voltage V0ab by 300 mV, it can usually be inferred from Fig



11. that they are in phase with one another. For a 400 V RMS (figure 10 shows signal statistics), the integrated UCAP-DVR is simulated in MATLAB/Simulink. The proposed integrated dynamic voltage restorer ultra capacitor design and its control circuit are implemented to improve the power quality of the distribution grid. This broad modelling and its results are constantly contrasted with the conventional and underpaid throughout the analysis. By addressing voltage sag and swell issues without introducing distortions, the integrated UCAP-DVR outperforms the free and conventional systems.

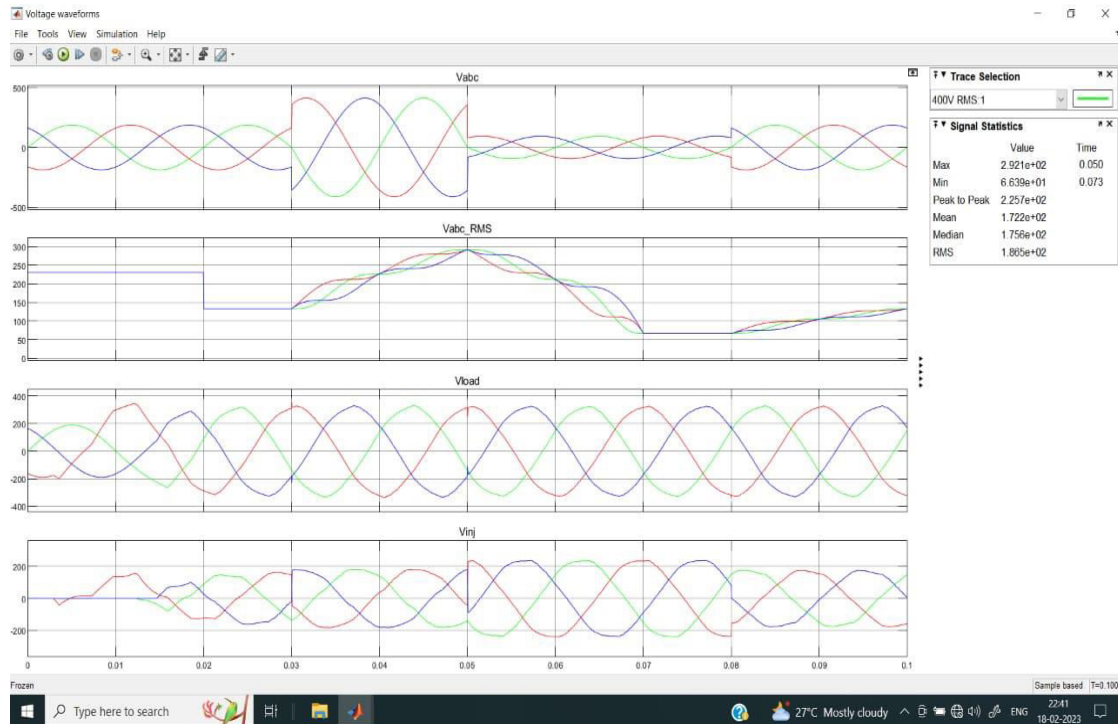


Figure 11 – Voltage waveforms

## V. CONCLUSION

In this work, the notion of integrating UCAP-based rechargeable energy storage is examined to improve the DVR system's capability to restore electricity. Due to its integration, the DVR will be able to independently rectify power sags and swells rather than relying on the grid to do so. It is advised to use a bidirectional dc-dc converter at the DVR's dc link to integrate the UCAP. The power stage and controller architecture of the series inverter, which serves as the DVR, are described. Since the DVR system is able to deliver active power, it is easier to implement the control approach, which is based on injecting voltages that are in phase with the system voltage.

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