POWER QUALITY ENHANCEMENT IN DISTRIBUTION SYSTEM USING DVR INTEGRATED WITH ULTRACAPACITOR

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Abstract

This research explores how to improve a Dynamic Voltage Restorer's (DVR) ability to fix voltage problems by integrating a special type of energy storage called a UCAP([1], [2]). This combined system (UCAP-DVR) wouldn't need the main power grid to fix voltage dips and surges (sags and swells) at PCC.The UCAP connects to the DVR using a special converter. It explains how the DVR injects voltage back into the system to counteract sags and swells. This control strategy is relatively simple and works best when the UCAP-DVR can actively provide power. A higher-level control system makes decisions based on real-time conditions and sends instructions to the UCAP and DVR for adjustments. The paper also discusses the design of key components within the UCAP's converter.The researchers tested their UCAP-DVR system using simulations and a real-world setup. The tests confirmed it could dynamically compensate for voltage sags and swells in all three phases of a distribution grid. While not included here, the full paper will detail how the system responds to voltage problems affecting two phases simultaneously. Overall, the research shows that UCAP-based energy storage has promise for future use in distribution grids ([3], [4], [5]). This technology could help automatically respond to voltage fluctuations and protect sensitive equipment from disruptions.

Index terms –
UCAP, DVR, PWM, dc-dc converter, voltage sag/swell, energy storage integration, fault analysis.

I. Introduction

Power systems are prone to voltage sags, sudden drops that can disrupt sensitive equipment. Inverter-based Dynamic Voltage Restorers (DVRs) play a crucial role in stabilizing voltage levels. They react swiftly, detecting sags and generating corrective voltage boosts through their inverters. These boosts are injected into the main supply line, ensuring stable voltage reaches critical loads. DVRs are essential as voltage sags can lead to equipment malfunctions and decrease power system reliability. By safeguarding equipment and preventing outages, inverter-based DVRs provide a cost-effective solution for maintaining a robust power grid. In power systems, inverter-based DVRs and ultracapacitors work together to mitigate voltage sags([3], [5]). DVRs function as voltage regulators, continuously monitoring voltage levels and swiftly providing corrective boosts when sags occur. Ultracapacitors provide the rapid energy required by DVRs ([1]) to counteract sags, thanks to their ability to discharge quickly and endure numerous charge cycles. Together, inverter-based DVRs and ultracapacitors ensure a stable power supply for critical equipment.Various rechargeable energy storage technologies, such as flywheels, batteries, superconducting magnets, and ultra-capacitors, are designed for integration into advanced power applications like DVRs ([1], [3]). Integrating rechargeable energy storage at the DC-terminal of power quality products like STATCOM and DVR has garnered increased interest. Although matrix converter-based DVRs eliminate the need for energy storage devices for emergency grid purposes, they come with drawbacks such as high cost and energy requirements. Another approach involves using H-bridge with cascaded connection in DVR with an inductor controlled by thyristor to minimize the need for energy storage. Among energy storage technologies requiring active power support in milliseconds to seconds range, ultra-capacitors are considered the most suitable. Ultra-capacitors offer various advantages, including no need for cooling or heating, absence of moving parts, and no internal chemical changes during operation. They require minimal maintenance, with reduced lifetime degradation due to deep cycling, and are highly efficient and robust in operation.

II.Literature

In the present paper UCAP based energy storage integration to a DVR into the distribution grid is proposed and the following applications areas are addressed.

- Integration of the UCAP with DVR system gives the system active power capability which is necessary for independently compensating voltage sags and swells.
- Experimental validation pf the UCAP, fault, linear loads, non-linear loads dc-dc converer, inverter their interface and control.
- Development of inverter and dc-dc converter controls to provide sag and swell compensation to the distribution grid.

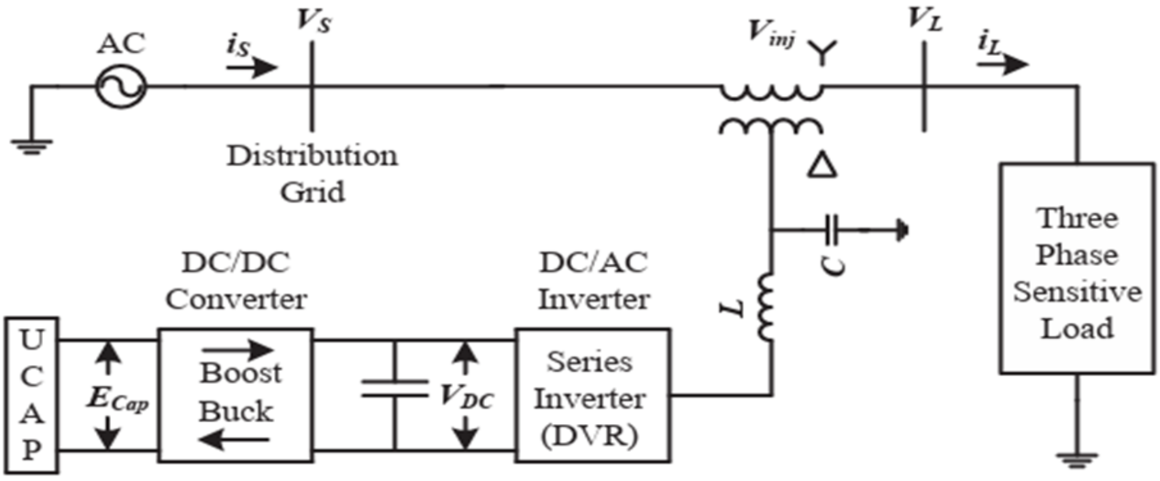

Fig. 1 One line diagram of DVR with UCAP Energy Storage

- The text describes a system illustrated in Figure 3.This system uses a special type of converter, called a 3-phase voltage source inverter, to improve the stability of the electrical grid. The three phase inverter[6] is connected directly to the power lines and helps to smooth out voltage fluctuations, preventing both voltage drops (sags) and surges (swells). The inverter itself is madeup of several components: an IGBT module (which does the main power conversion), a driver circuit that controls the IGBT, a filter that cleans up the inverter's output, and an isolation transformer that separates the inverter's circuit from the grid. In this section, construction and control scheme of components are discussed as

2.1 Pulse Width Modulation Technique

Inverter circuits use a technique called Pulse Width Modulation (PWM) to regulate their output voltage. A key parameter in PWM is the modulation index (m). It essentially controls the amount of power delivered by the inverter.The modulation index plays a crucial role. A low m leads to a lower output voltage, which might limit the inverter's ability to compensate for voltage sags. On the other hand, a very high m (over-modulation) can damage the inverter and create unwanted harmonics in the output voltage. Typically, the modulation index is chosen to be between 0 and 1 to ensure optimal performance and avoid these issues.

$$m = \frac{2\sqrt{2}}{\sqrt{3}V_{dc*n}} V_{ab(rms)} \qquad (1)$$

2.2 Controller Implementation

Traditionally, Dynamic Voltage Restoration (DVR) systems use complex control methods to minimize the need for large energy storage. These methods inject voltage at an angle to the main power line, focusing on reactive power instead of active power. However, with the decreasing cost of energy storage, simpler control techniques are becoming viable. This project explores a method that injects voltage directly in phase with the power line during voltage sags or swells. This approach utilizes the active power capacity of the UCAP-DVR system for more straightforward voltage restoration. It relies on a device called a PLL to synchronize with the grid's voltage.

The system injects voltage directly in line with the grid's voltage (in-phase). To achieve this, a device called a Phase-Locked Loop (PLL) estimates an important grid parameter, denoted by "θ" (theta). This PLL uses the "fictitious power method" described in a separate reference . Since the system operates with a delta connection (a specific type of three-phase grid connection), the line-to-line voltages are readily available. Using the estimated "θ" and these voltages, the controller transforms them into a mathematical framework (d-q domain) to extract the line-to-neutral voltage components the system needs (Vsa, Vsb, Vsc).

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \cos\left(\theta - \frac{\pi}{6}\right) & \sin\left(\theta - \frac{\pi}{6}\right) \\ -\sin\left(\theta - \frac{\pi}{6}\right) & \cos\left(\theta - \frac{\pi}{6}\right) \end{bmatrix} \begin{bmatrix} \frac{V_d}{\sqrt{3}} \\ \frac{V_q}{\sqrt{3}} \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} V_{refa} \\ V_{refb} \\ V_{refc} \end{bmatrix} = m * \begin{bmatrix} (sin\theta - \frac{V_{sa}}{169.7}) \\ (sin(\theta - \frac{2\pi}{3}) - \frac{V_{sb}}{169.7}) \\ (sin(\theta + \frac{2\pi}{3}) - \frac{V_{sc}}{169.7}) \end{bmatrix} \qquad (3)$$

$$P_{inv} = 3V_{inj2a(rms)} I_{La(rms)} \mathrm{COS}\, \varphi \qquad (4)$$

$$Q_{inv} = 3V_{inj2a(rms)} I_{La(rms)} \mathrm{Sin}\, \varphi \qquad (5)$$

The system acts like a shield against voltage fluctuations. If the voltage on the power line (source side) drops (sag) or increases (swell), the DVR and UCAP system injects a corresponding voltage (V_{inj2}) in phase with the line voltage. This injected voltage counteracts the fluctuation and maintains a steady voltage (V_L) for the devices connected at the end (load).The actual amount of active and reactive power the inverter supplies depends on the strength of the voltage injection (measured by the root mean square value of V_{inj2a}) and the current drawn by the devices (load current, I_{La}). The phase difference between these two waveforms (represented by φ) also plays a role in determining the power flow.

2.3 Bi-directional dc-dc converter

Unlike batteries, Ultracapacitors (UCAPs) can't directly connect to the inverter's DC link. This is because the UCAP's voltage drops as it releases energy (discharges). To address this, a bi-directional DC-DC converter is needed. This converter acts like a voltage stabilizer, ensuring a constant voltage for the DC link even as the UCAP voltage fluctuates. During a voltage sag, the grid needs extra power from the UCAP system. The DC-DC converter operates in "boost" mode, essentially stepping up the UCAP's voltage to meet the grid's requirements. Conversely, during a voltage swell, the UCAP needs to absorb excess power from the grid. Here, the converter switches to "buck" mode, effectively lowering the grid voltage to charge the UCAP. In essence, the bi-directional DC-DC converter acts like a gear system, adjusting power flow between the UCAP and the grid based on the situation.

The UCAP's voltage changes as it supplies or stores energy, unlike a DC link which needs a steady voltage. To bridge this gap, a bi-directional DC-DC converter acts as an intermediary. This converter plays a crucial role.The control method chosen for this converter is "average current mode control" - a well-established technique. This method is used in both "buck" mode (when charging the UCAP) and "boost" mode (when discharging the UCAP). Compared to other control methods like voltage mode control or peak current mode control, average current mode control offers better stability for this application.

2.4 Unbalanced Load

In power distribution networks, a situation known as "voltage unbalance" occurs when the currents or voltage magnitudes on the three phases aren't equal. This is like a three-legged stool where one leg carries more weight than the others. The Institute of Electrical and Electronics Engineers (IEEE) has a technical definition for this unbalance, but simply put, it's any deviation from a perfect sine wave in voltage or current. This deviation can be a difference in size (magnitude) or timing (phase shift) between the three phases.

While perfectly balanced voltages are rare in three-phase systems, excessive unbalance can cause problems. Unequal loads on the distribution lines create "negative or zero sequence voltages" which in turn cause currents of the same type to flow. This further disrupts the balance in the system.

The consequences of voltage unbalance can be nasty: overheating of equipment, unwanted harmonics in the power grid, and more. To prevent these issues, engineers employ various techniques like load balancing and using three-phase motors whenever possible.

Voltage unbalance occurs when the voltages or currents on the three phases of a power system are unequal. This can be caused by several factors:

Unequal Loads: This is the main culprit, especially single-phase loads that are not evenly distributed across the phases.

Faulty Equipment: Malfunctioning transformers, blown fuses, or open circuits can also contribute to unbalance.

Motors: Induction motors can create unbalance due to differences in their internal impedance between phases.

The consequences of voltage unbalance are significant. It leads to current unbalance, which translates to heat generation. This heat can damage electrical devices, transformers, and motors, potentially causing fires and permanent breakdowns.

2.5 Fault Analysis

In a functioning power grid, electricity typically flows smoothly at regular voltage and current levels. However, issues arise when a "fault" disrupts this flow, leading to a surge in current that can harm equipment.

To prevent such damage, engineers rely on fault detection and analysis to select appropriate protective measures like circuit breakers and relays. These devices act as safeguards, identifying and halting faults before they cause significant harm.

Open-circuit faults, which occur due to malfunctions in one or more conductors in the power system, are a common type, affecting single-phase, two-phase, and three-phase circuits. These faults often result from issues such as joint failures in overhead lines, cable malfunctions, or melting of conductors or fuses. They are also referred to as series faults and can cause unbalanced or unsymmetrical conditions apart from three-phase faults.

For example, in a transmission line, if one phase fails before an open-circuit fault occurs, the load on the alternator may decrease, causing it to accelerate beyond its synchronous speed, potentially leading to overvoltages in other transmission cables.

Consequently, one-phase and two-phase open conditions can produce currents and voltages in the power system that can cause significant damage to equipment.

III.Simulation Results

The simulation of the proposed UCAP integrated DVR system is carried out in MATLAB for a 400V, 50Hz system. The system response for a three-phase voltage sag which lasts for 0.25s and is shown in Fig. 6.4 & 6.5. It can be observed from Figs 6.5 & 6.9. that during voltage sag the source voltage V_{srms} is reduced while the load voltage V_{Lrms} is maintained constant due to voltages injected in-phase by the series inverter.

The system response for a three-phase voltage swell which lasts for 0.25s and is shown in Fig. 6.7 & 6.8. It can be observed from Figs 6.8 to 6.9 that during voltage sag the source voltage V_{srms} is reduced while the load voltage V_{Lrms} is maintained constant due to voltages injected in-phase by the series inverter.

SOC is described because the ratio of the contemporary to be had capability of t he battery to the most to be had capability. State of charge (SOC) of ultracapacitor performs an crucial position withinside the strength control optimization of hybrid strength garage device for electric powered vehicles.In addition to the perfection of the version and the SOC estimation algorithm, the parameter identity approach and temperature component need to additionally be considered.In each events %SOC remains constant as shown in Fig. 6.3

Graphs related to DVR injecting in phase voltage and source voltage are shown in Figs 6.1 and 6.2.

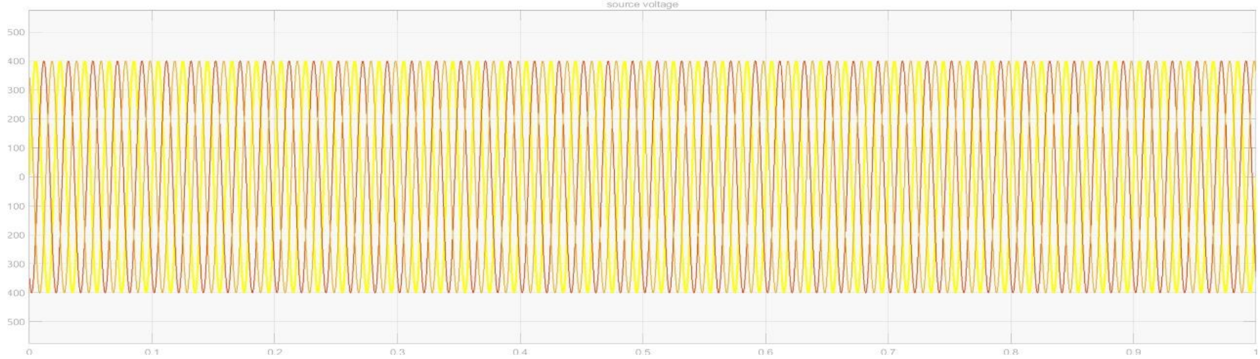

Fig 6.1 Source Voltage

This DVR voltage will be injected in phase where the sag / swell occurred.

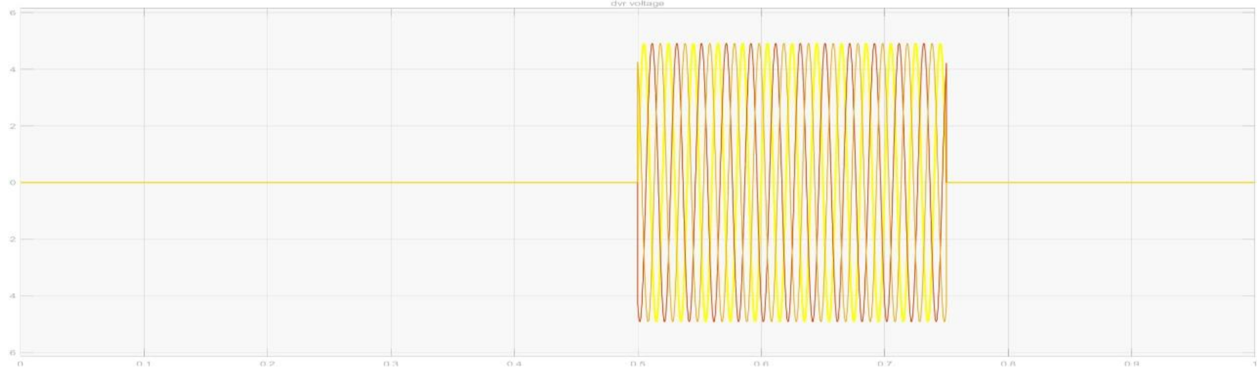

Fig 6.2 DVR Voltage

State of Charge (%SOC) of the ultracapacitor remained constant in bothe events.

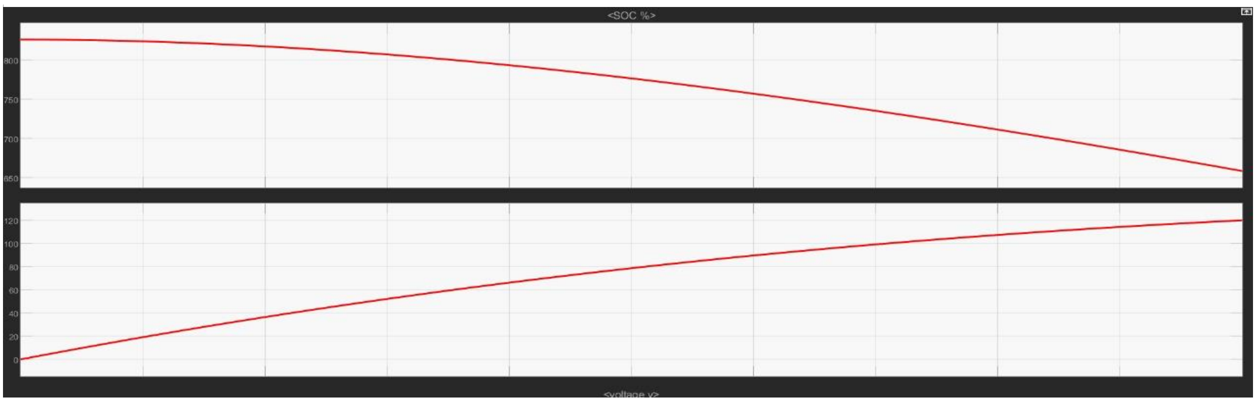

Fig 6.3 %SOC of the Ultracapacitor

Change in fault resistance results in voltage sag and swell . During voltage sag, the amplitude of voltage is decreased from 1 and during swell, it is increased above . Changes in fault resistance is explained as follows.

When the fault resistance is 2 i.e., below 6, voltage sag is occurred during time interval 0.5 to 0.75 is shown below

Fig 6.4 Voltage when Fault Resistance is 2

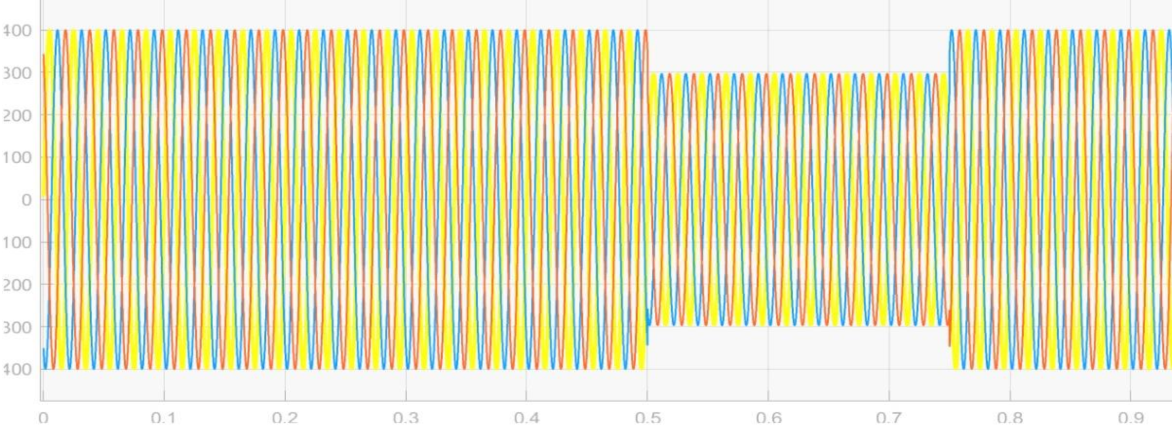

Fig 6.5 Voltage Sag

When fault resistance is 6, voltage remains constant a shown in below graph

Fig 6.6 Voltage when fault resistance is 6

When fault resistance is above 6, voltage swell occurs during time interval 0.5 to 0.75 as shown in below graph.

Fig 6.7 Voltage when fault resistance above 6

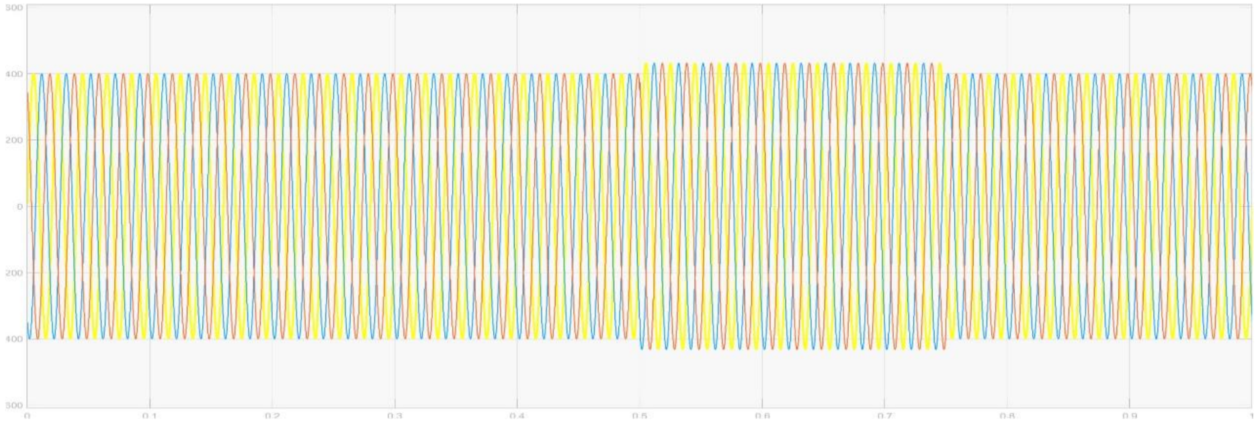

Fig 6.8 Voltage Swell

During voltage sag and swell, voltage across load remianed constant because of injected in-phase voltage from DVR. Voltge across load is shown in below figure

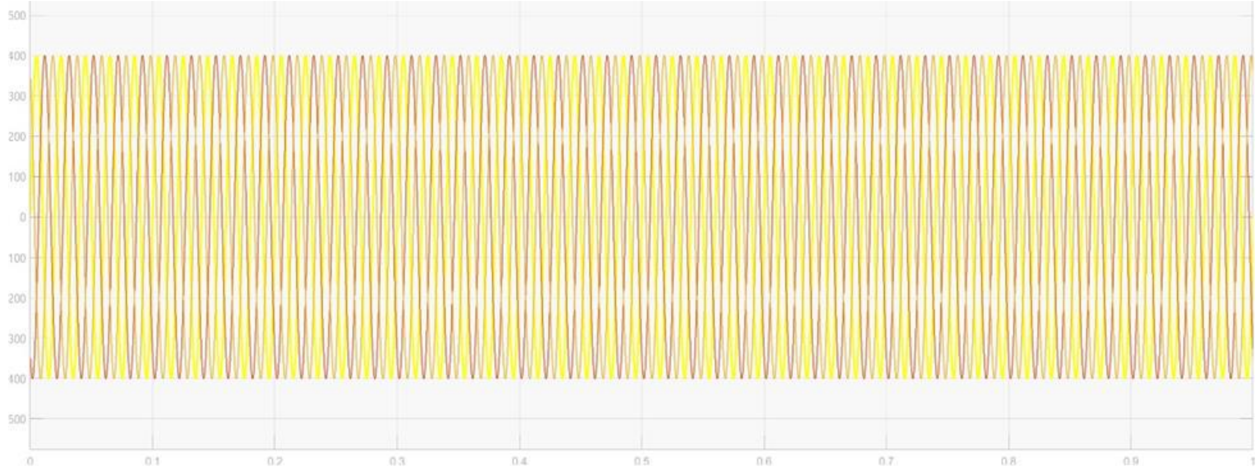

Fig 6.9 Load voltage

IV.Conclusion

This research explores how to improve a Dynamic Voltage Restorer's (DVR) ability to fix voltage problems by integrating a special type of energy storage called a UCAP. This combined system (UCAP-DVR) wouldn't need the main power grid to fix voltage dips and surges (sags and swells).The UCAP connects to the DVR using a special converter. The authors explain how the DVR injects voltage back into the system to counteract sags and swells. This control strategy is relatively simple and works best when the UCAP-DVR can actively provide power.A higher-level control system makes decisions based on real-time conditions and sends instructions to the UCAP and DVR for adjustments. The paper also discusses the design of key components within the UCAP's converter.The researchers tested their UCAP-DVR system using simulations and a real-world setup. The tests confirmed it could dynamically compensate for voltage sags and swells in all three phases of a distribution grid. While not included here, the full paper will detail how the system responds to voltage problems affecting two phases simultaneously.Overall, the research shows that UCAP-based energy storage has promise for future use in distribution grids. This technology could help automatically respond to voltage fluctuations and protect sensitive equipment from disruptions.

V.References

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