ROBUST ANALYSIS OF DYNAMIC VOLTAGE RESTORER UNDER SAG AND SWELL CONDITIONS BY IMPLEMENTATION FOR EMERGENCE CONTROL IN DISTRIBUTION SYSTEM

Mannam Divya1, D. Srinivasarao[2]

[1]M. Tech (Student), Dept of EEE, Universal Engineering College, Guntur, Andhra Pradesh, India.

[2]Associate Professor, Dept of EEE, Universal Engineering College, Guntur, Andhra Pradesh, India

Abstract:

The dynamic voltage restorer (DVR) is one of the modern devices used in distribution systems to protect consumers against sudden changes in voltage amplitude. In this project, emergency control in distribution systems is discussed by using the proposed multifunctional DVR control strategy. In addition, a multi-loop controller based on Posicast and P+ Resonant controllers is suggested to eradicate steady-state inaccuracy in DVR response and enhance transient reaction, respectively. Some load voltage perturbations produced by induction motor starting and a three-phase short circuit failure are addressed by the suggested technique. In addition, the suggested DVR's capacity to minimize the downstream fault current has been tested. The DVR will be protected and the point of common coupling (PCC) voltage will be restored by the current limiter. The PCC is the bus to which all feeders under study are linked. One novel approach is to use the DVR as a virtual impedance, which safeguards the PCC voltage from downstream faults without causing issues with actual power injection into the DVR. The findings of the simulation demonstrate that the DVR can manage the distribution systems in an emergency.

Keywords: DVR, point of common coupling (PCC), P+ Resonant controllers

1.Introduction

Nowadays, modern industrial devices are mostly based on electronic devices such as programmable logic controllers and electronic drives. The electronic devices are very sensitive to disturbances and become less tolerant to power quality problems such as voltage sags, swells and harmonics. Voltage dips are considered to be one of the most severe disturbances to the industrial equipment's. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sags are not corrected within the limited time frame of mechanical switching devices. Transformer taps may be used, but tap changing under load is costly. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

Power Quality Issues

Power quality disputes possess certain side effects and these could be refined as a reduction in the time of a substantial engine begins or it can be as cataclysmic as gear disappointment. However, control quality issues may disturb business activities Today, there is a remote attaining consumption of advanced or microchip-controlled gadgets in every aspect of our client's organizations.

Voltage Sag

A diminishing of the ordinary voltage level somewhere at 10% and 90% of range at the apparent RMS voltage and power frequency with 0.5 cycles to 1 minute as time period is defined as voltage sag. The resultant of a huge current flow in the system or voltage across the system is denoted as the voltage sag or dip. The foremost intention to the dip is the short circuit in the system.

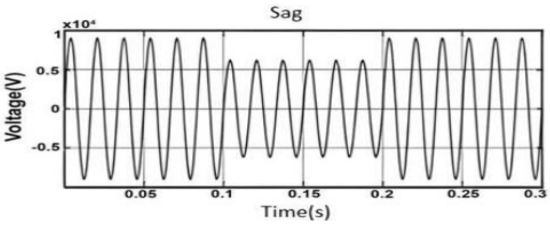

Figure 1. Voltage sag or dip caused by faults

Voltage Swell:

Temporary rise in voltage level at power frequency with duration such that higher than a cycle as well as lesser than few seconds the short duration voltage variation defined as the sudden rise of voltage when the load is switching off. The replacement of load from one source of power to the different source may induce the swell effect.

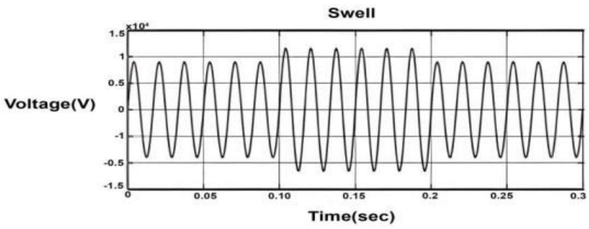

Figure 2. Voltage Swell leading to power quality issues

Interruption

When either the power source or the load current suddenly stops flowing, we say that there has been an interruption. For a visual representation of a pause, see Figure 1.3. This definition distinguishes between different types of interruptions based on their length. A complete loss of supply voltage or load current lasting between 0.1 and 0.2 seconds is a well-known definition of a short interruption.

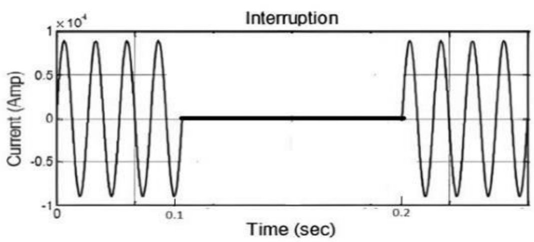

Figure 3. Short interruptions causing power outage at distribution side

A temporary disruption is considered to be blackout for three seconds to one minute, while a blackout that lasts longer than a one minute or a break in service that lasts longer than a minute is considered as an outage. Different things can cause power outages, far too many to list here, but whatever the cause, a system protective device such as a fuse or automatic breaker is typically triggered to shut down the faulty portion of the system. Lightning, animals, trees, car accidents, and broken equipment are all common sources of disruptions.

Harmonics

The harmonic distortion was a major concern for utility engineers in the late 1970s, when electronic power converters were first becoming widespread. While some power quality issues are more pressing, harmonic distortion is still a major concern for some. It is easy to see how an engineer struggling with a complex harmonics issue could come to that conclusion. Many of the established guidelines for designing and operating power systems, which focus on the fundamental frequency alone are challenged by harmonic issues.

Harmonic distortion

It is the nonlinear components of the power system that are the root of the problem with harmonic distortion. If the device's current is not directly proportional to the voltage being applied, we say that it is nonlinear. Even though the input voltage is perfectly sinusoidal, the current that is produced is not. It is possible that a small percentage increase in voltage will cause the current to double and the wave form to shift.

Implementation for Emergence Control In Distribution System

The implementation of emergency control in distribution systems focuses on ensuring that voltage levels remain stable during sudden disturbances, faults, or abnormal operating conditions. In this work, the proposed multifunctional Dynamic Voltage Restorer (DVR) is implemented as a fast-response protective device that actively monitors load voltage and instantly injects a compensating voltage whenever sag, swell, or transient deviations occur. The control strategy integrates a Posicast controller, which minimizes overshoot and transient oscillations, along with a P+Resonant controller to maintain accurate steady-state voltage tracking. To enhance fault tolerance, the DVR is further programmed to operate as a virtual impedance, allowing it to limit downstream fault currents without requiring excessive real power from the energy source. This virtual impedance action helps stabilize the Point of Common Coupling (PCC) during short-circuit faults, preventing voltage collapse and protecting both the DVR and the connected feeders. Through this implementation, the DVR becomes capable of handling emergency conditions such as motor starting surges, short-circuit events, and dynamic load fluctuations ensuring continuous voltage support, improved power quality, and enhanced reliability of the entire distribution network.

Problem Statement

Modern distribution systems frequently encounter voltage disturbances such as sags, swells, and transient fluctuations caused by dynamic loads, induction motor startups, and short-circuit faults. These disturbances severely affect sensitive equipment and compromise the stability of the power network. Existing DVR control strategies struggle to provide fast dynamic compensation, eliminate steady-state errors, and protect the system during downstream faults, where excessive fault current can damage both the DVR and the connected network. Therefore, there is a need for a robust and multifunctional DVR control approach that can simultaneously enhance transient performance, ensure accurate voltage restoration, and limit downstream fault currents without excessive real-power injection. The problem addressed in this work is to design and implement an improved DVR control strategy capable of maintaining stable PCC voltage, mitigating voltage disturbances effectively, and providing reliable emergency control in modern distribution systems.

Objectives of the Study

The primary objectives of this study are:

- To design and implement a robust multifunctional DVR control strategy capable of mitigating voltage sag, swell, and transient disturbances in distribution systems.
- To develop a multilayer control approach using Posicast control to improve transient response and a P+Resonant controller to eliminate steady-state errors in DVR operation.
- To enable the DVR to function as a virtual impedance for effective downstream fault current limitation and enhanced PCC voltage protection.
- To analyze and evaluate DVR performance under various disturbance scenarios, including induction motor starting, short-circuit faults, and dynamic load variations.
- To validate the proposed DVR strategy through simulation results**,** demonstrating improved voltage compensation, reduced transient oscillations, and increased system reliability during emergency conditions.

2. Literature Review

Hingorani (2000), widely regarded as the pioneer of Custom Power Devices, emphasized the need for fast and intelligent compensation systems in modern distribution networks. His work highlighted that conventional devices such as OLTCs and capacitor banks were too slow to handle sudden voltage disturbances. Hingorani introduced the DVR as an advanced solution capable of restoring voltage within a few milliseconds, laying the foundational concept for its application in emergency control. **Benachaiba (2009)** further strengthened DVR research by experimentally demonstrating its ability to protect critical loads during voltage sags and swells. His findings showed that DVRs could maintain stable voltage even during severe disturbances caused by motor starting and switching operations. **Ghosh (2012)** contributed significantly by analyzing the performance of DVRs under nonlinear and fast-changing load conditions. He highlighted that conventional PI controllers often failed to maintain accurate voltage injection during distorted grid conditions. Ghosh introduced improved control techniques and recommended multiloop controllers for better stability. **Nguyen (2016)** advanced DVR technology by developing a Posicast-based control strategy designed specifically to reduce transient oscillations. His work showed that Posicast controllers effectively dampened overshoot and improved the DVR's response time during sudden voltage dips. Nguyen demonstrated that this method offered a smoother compensation profile compared to standard PI controllers. **Kaviani (2018)** introduced a major innovation by enabling the DVR to operate as a virtual impedance, a feature essential for limiting downstream fault currents. His study showed that virtual impedance can protect both the DVR and the distribution system during short-circuit faults without causing excessive real-power injection. **Hingorani (2000)** was the first to introduce the concept of Custom Power Devices, highlighting the growing need for fast-acting voltage compensation in distribution networks. He identified that traditional devices such as capacitor banks, voltage regulators, and OLTCs were too slow to react to sudden voltage deviations. **Gyugyi (2001)** expanded on this work by explaining the functional architecture of custom power devices and their capability to handle complex power quality problems. He emphasized the DVR's unique ability to inject a controllable series voltage to correct sags, swells, and waveform distortions. Gyugyi also outlined the limitations of earlier control methods, which lacked precision during high-speed voltage recoveries, thereby motivating further advancements in DVR control strategies. **Benachaiba (2009)** contributed significantly through practical demonstrations of DVR performance under real-world conditions. His experiments illustrated that DVRs could effectively restore voltage during deep sags caused by motor starting and switching disturbances. **Ferdi (2010)** focused on improving DVR reliability under nonlinear loads. His work highlighted that harmonic-rich environments impose additional challenges on compensation accuracy. Ferdi proposed enhanced voltage injection algorithms and stressed the importance of maintaining both amplitude and phase accuracy during compensation. **Ghosh (2012)** examined DVR behavior under unbalanced and distorted grid conditions. He proved that traditional PI controllers were insufficient in maintaining steady-state accuracy when voltage distortions were present. Ghosh recommended the use of multiloop structures, predictive controllers, and feedforward terms to reduce steady-state error. **Nguyen (2016)** introduced the application of Posicast controllers in DVR systems to improve transient response. His studies showed that Posicast control could effectively eliminate overshoot, reduce oscillations, and ensure a smoother voltage recovery during sudden disturbances. **Song (2017)** extended the DVR's accuracy by proposing the Proportional + Resonant (P+R) controller, which eliminates steady-state error even in the presence of low-frequency disturbances. His work demonstrated that resonant controllers achieve better harmonic compensation compared to PI-based systems. Song's contributions advanced the trend toward hybrid and multilayer control structures for DVR accuracy and stability. **Karimi (2017)** focused on the DVR's performance during symmetrical and asymmetrical fault conditions. He highlighted that during downstream faults, excessive fault current could flow through the DVR, risking damage to its components. Karimi proposed improved protection mechanisms and faster detection methods to ensure the DVR remains operational during high-impact disturbances. **Kaviani (2018)** introduced the concept of the DVR acting as a virtual impedance, allowing the device to limit downstream fault currents without requiring high real-power injection. His findings showed that virtual impedance helps maintain PCC voltage stability during short circuits and prevents unnecessary stress on the DVR itself. This innovation transformed the DVR from a purely compensatory device into a multifunctional system capable of both voltage restoration and fault-current limitation. **Li (2020**) further refined DVR control by integrating adaptive and intelligent control techniques, such as fuzzy logic and neural networks, to improve performance during rapidly varying disturbances. His work demonstrated that adaptive DVR control can adjust parameters in real time based on the severity of the voltage dip or swell. Li's approach enhances both accuracy and robustness, reinforcing the DVR's role in emergency distribution system control.

3.Distribution System Emergency Control Using A Multi-Functional Dynamic Voltage Restorer

Distribution networks are increasingly exposed to voltage disturbances such as sags, swells, and sudden transient events caused by motor starting, switching operations, and short-circuit faults. These disturbances can severely affect sensitive equipment and compromise system reliability if not addressed promptly. Almost 80% of power-quality (PQ) issues in distribution systems are caused by voltage sag and voltage swell, two of the most significant PQ issues. Voltage sag is defined as a drop of 0.1 to 0.9 p.u. in the rms voltage level at system frequency and duration of half a cycle to 1 minute according to the IEEE 1959–1995 standards. The most common reasons for voltage drops include starting big motors, activating transformers, and short circuits. We can classify the sources of voltage sag as low- or medium-frequency transient events based on its definition and nature, which indicate that it is a transient occurrence. Various techniques for compensating voltage drops have been implemented in recent years, taking into account the usage of delicate electronics in contemporary industries. Using the DVR to compensate the load voltage and improve the PQ is one of these techniques. Diverse control strategies have been identified in prior research on various facets of DVR performance. How you intend to use DVR will dictate which of these approaches you take. Finding the voltage drop and restoring it with as little DVR active power injection as possible is the primary goal of various approaches. Additionally, sag and swell mitigation can be achieved using the in-phase correction method.

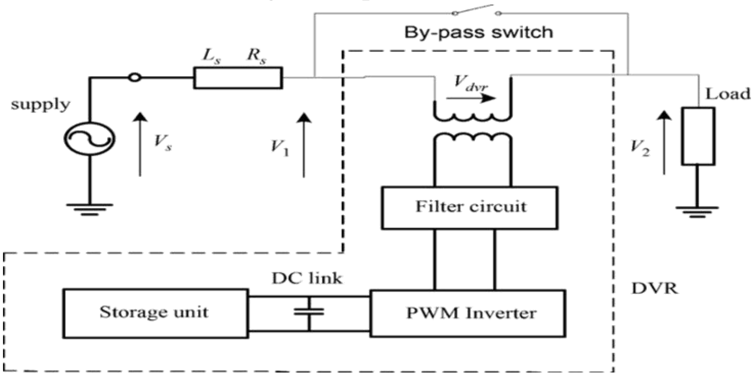

Figure 4. Typical DVR-connected distribution system

DVR Components

Figure depicts a typical distribution system with a DVR connected. The DVR is made up of a voltage-source inverter, an inverter output filter, an injection transformer coupled in series, and a DC-linked energy storage device. It is necessary to filter the inverter output before injecting it into the system in order to remove harmonics caused by the inverter's switching function. For practical purposes, the DVR's injection transformer is typically linked in parallel with a bypass switch.

Basic Operational Principle Of DVR

The DVR system depicted in Figure regulates the load voltage by means of the injection series transformer, which introduces a suitable voltage phasor into the system. The DVR must actively supply power to the system during compensation in the majority of sag compensation methods. Consequently, compensation may be constrained by the storage unit's capacity, particularly in cases of prolonged power drops.

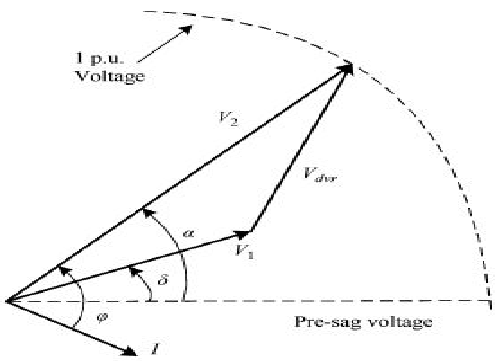

Figure 5. Electrical conditions during a voltage sag

The digital video recorder inverter is nonlinear because it uses semiconductor switches. It is possible, though, to use linearization methods to simplify the state equations. Filter modeling is often a simple LC circuit, but load modeling is more complicated because loads can be either linearly or nonlinearly time-variant.

$$1+G(s)=1+\frac{\delta}{1+\delta}\left(e^{-sT_d/2}-1\right) \qquad (3.1)$$

You can find the period of the damped response signal and the step response overshoot in the given equation. There isn't much sensitivity to noise with the Posicast controller because of its modest high-frequency gain.

Proposed Multifunctional DVR

In addition to its other uses, DVR can safeguard multiple customers at medium voltage levels when the source of disruption is plainly seen in the statistics.

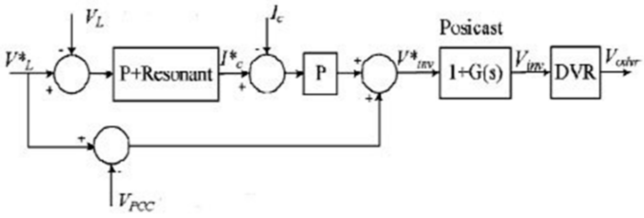

Figure 6: Multi loop control using the Posicast and P+ Resonant controllers

Proposed Method For Using The Flux-Charge Model

Here, we provide a mechanism that the DVR can use to safeguard its components by restoring the PCC voltage and limiting the fault current. Here, we apply the flux-charge model in such a way that the DVR sits in series with the distribution feeder and functions as a variable-valued virtual inductance. This can only be accomplished by adjusting the DVR's settings such that it injects a correct voltage of the opposite polarity from the typical scenario The suggested way for controlling the DVR is shown in Figure.

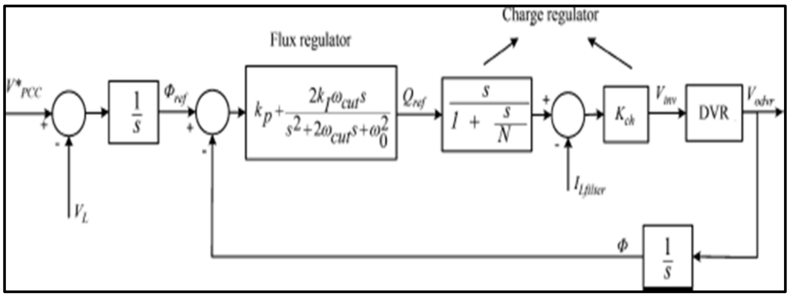

Figure 7: Proposed method

Consequently, an inner charge model is contemplated as a means to stabilize the system. Here, the charge of the filter inductor as determined by integrating its current follows the flux regulator's reference charge output.

3.5 MATLAB IMPLIMENTATION

The performance of the proposed multifunctional Dynamic Voltage Restorer (DVR) is examined in this paper using MATLAB/Simulink models and implementations under different distribution system sag, swell, and failure scenarios. Voltage source inverter, sensitive load, distribution feeder, supply system, series injection transformer, and dc-link with energy storage are all components of the model for simulation. By comparing the reference load voltage with the measured load voltage and processing the resulting error through the Posicast and P+Resonant controllers, the correct modulation signals for the PWM inverter are generated as part of the closed-loop control strategy that is implemented using Simulink control blocks.

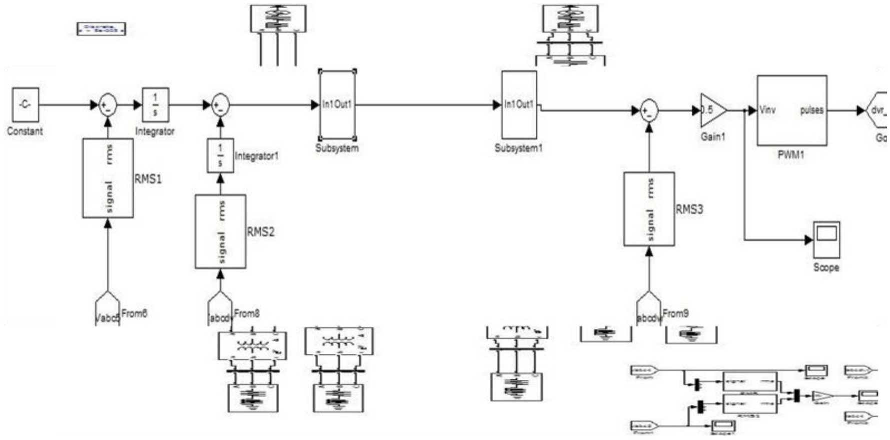

Figure 8: implementation module

4. RESULT AND DISCUSSIONS

The IEEE standard 13-bus balanced industrial system will be used as the test system. The test system is modeled in PSCAD/EMTDC software. Control methods of Figures were applied to control the DVR, and the voltage, current, flux, and charge errors were included as the Figures shows. Also, the DVR was modeled by its components (instead of its transfer functions) in the PSCAD/EMTDC software to make more real simulation results. A 12-pulse inverter was used so that each phase could be controlled separately. The plant is fed from a utility supply at 69 kV and the local plant distribution system operates at 13.8 kV. The plant power factor correction capacitors are rated at 6000 kvar.

Three-Phase Short Circuit

The simulation results are shown in Figures. As can be seen in the Figure, the rms voltage of PCC drops to about0.25 p.u. during the fault. It is obvious that this remaining voltage is due to the impedances in the system. The DVR will start the compensation just after the detection of sag. As can be seen in the enlarged figure, the DVR has restored the voltage to normal form with attenuation of the oscillations at the start of the compensation in less than half a cycle. It is worth noting that the amount and shape of the oscillations depends also on the time of applying the fault. As can be seen in the enlarged figure, the voltage value of phase B is nearly zero; this phase has minimum oscillation when the fault starts

Three-Phase Fault Compensation By DVR

This research also makes use of a multipurpose DVR that, when switched to virtual impedance mode, restricts the downstream fault current and stops the converter from receiving an excessive amount of real power. By working in tandem, these measures prove that the DVR is a cutting-edge emergency control device for distribution networks, protecting loads and keeping systems stable in the event of three-phase short-circuit faults.

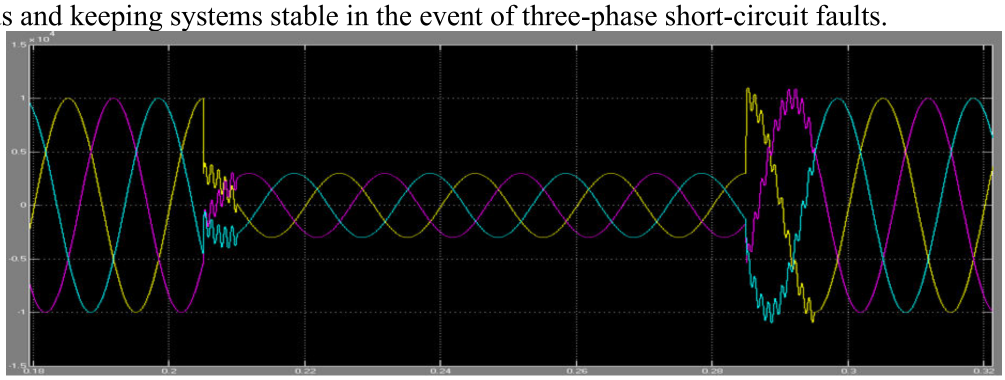

Figure 9: Three-phase PCC voltages

Figure illustrates the three-phase PCC voltages during a disturbance event, showing the system's response before, during, and after the fault. Initially, all three phases exhibit balanced sinusoidal waveforms with equal magnitude and 120° phase separation. At the moment of disturbance, a significant distortion and reduction in voltage amplitude occur, indicating the onset of a fault or sag condition at the PCC.

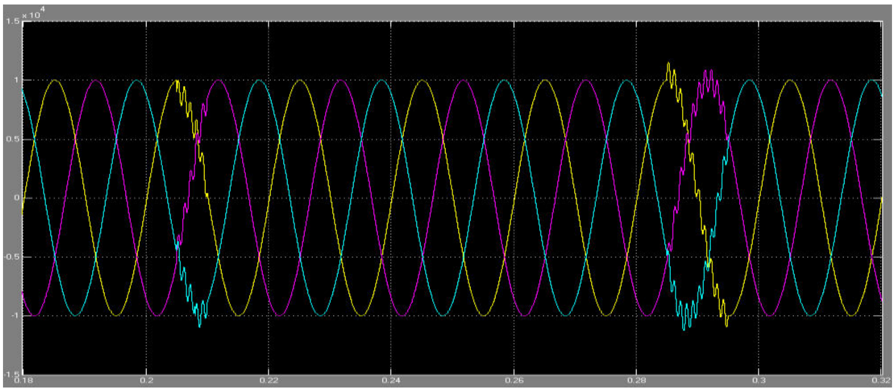

Figure 10: three-phase load voltages

Figure shows the three-phase load voltages during a disturbance event and the subsequent compensation provided by the DVR. Initially, the load voltages remain balanced with uniform sinusoidal waveforms. When the voltage sag occurs, a noticeable drop and distortion appear in all three phases, indicating the impact of the fault on the load side. Once the DVR injects the compensating series voltage, the waveforms quickly recover, returning to their nominal amplitude and balanced condition.

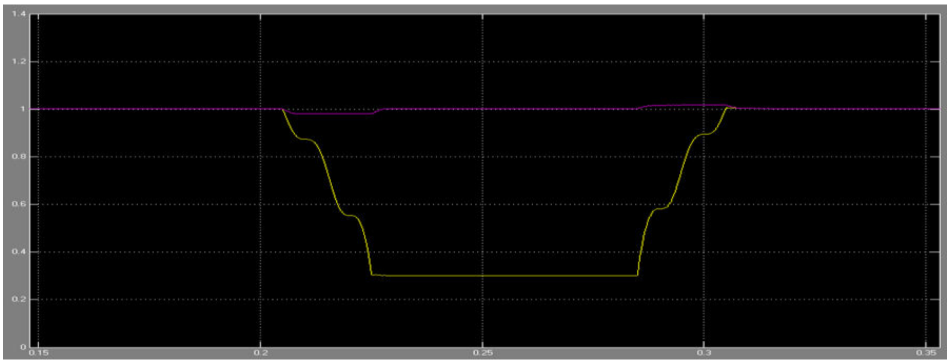

Figure 11: RMS voltages of PCC and load

The figure illustrates the RMS voltage profiles of both the PCC and the load during a voltage sag event. As shown, the PCC voltage (yellow curve) experiences a significant drop when the fault occurs, reaching nearly one-third of its nominal magnitude and remaining depressed throughout the disturbance period. In contrast, the load RMS voltage (purple curve) remains nearly constant and unaffected, demonstrating the fast and effective compensation provided by the DVR.

Starting The Induction Motor

A large induction motor is started on bus "03: MILL-1." The motor specifications are provided in Appendix. The large motor starting current will cause the PCC voltage (bus "03: MILL-1" voltage) to drop. The simulation results in the case of using the DVR are shown in Figures. In this simulation, the motor is started at t=405 ms. As can be seen in Figure, at this time, the PCC rms voltage drops to about 0.8 p.u. The motor speed reaches the nominal value in about 1s.

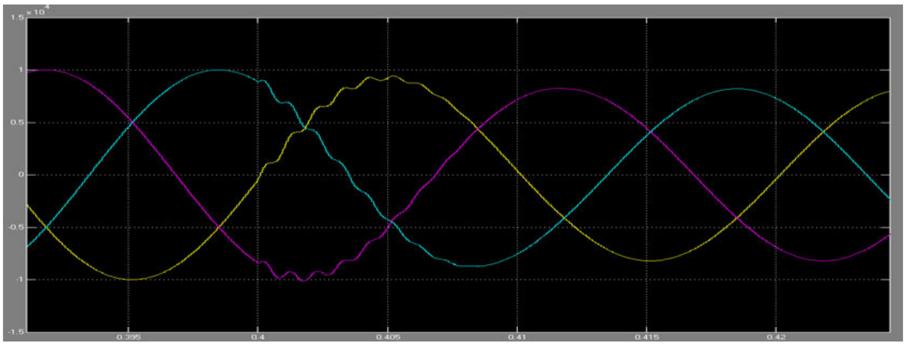

Figure 12: Starting Of An Induction Motor And The DVR Compensation

The figure illustrates the voltage waveforms during the starting of an induction motor and the subsequent compensation provided by the DVR. When the motor starts, a noticeable voltage dip appears across all three phases due to the high inrush current characteristic of induction motor starting. This sag temporarily distorts the waveform and reduces the supply voltage magnitude.

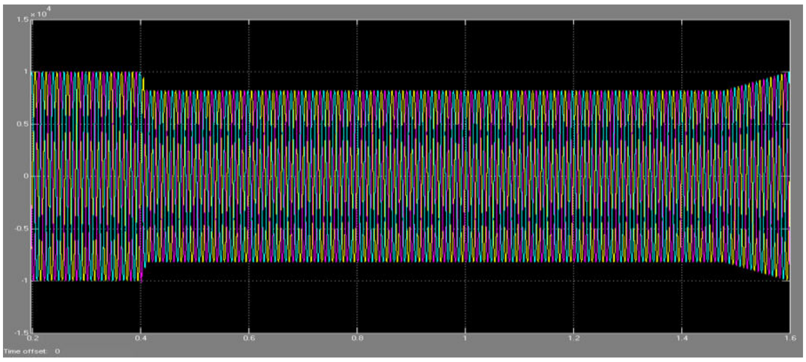

Figure 13: Three phase PCC voltages

The figure presents the three-phase PCC voltages during a disturbance event in the distribution system. Initially, the PCC voltages maintain a balanced sinusoidal pattern with equal magnitude across all three phases. When the voltage sag occurs, a noticeable drop in amplitude can be observed, indicating the impact of the disturbance on the upstream supply. During this interval, the waveform becomes compressed and distorted, reflecting the severity of the fault.

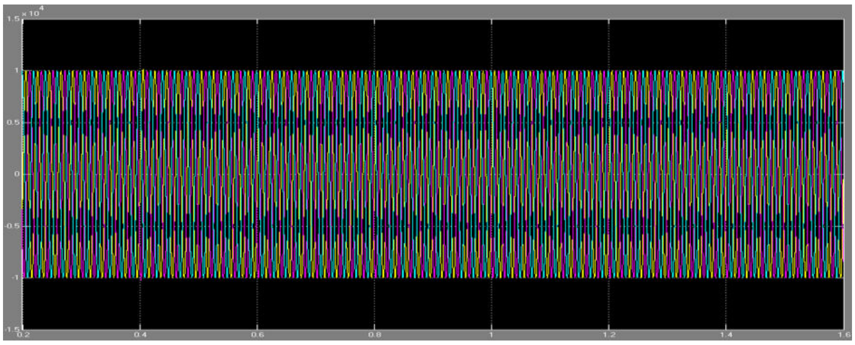

Figure 14: Three-phase load voltages

The figure depicts the three-phase load voltages throughout the disturbance event, clearly showing the effectiveness of the DVR in maintaining voltage quality. Despite upstream voltage variations, the load voltages remain well-balanced and exhibit consistent sinusoidal waveforms across all three phases.

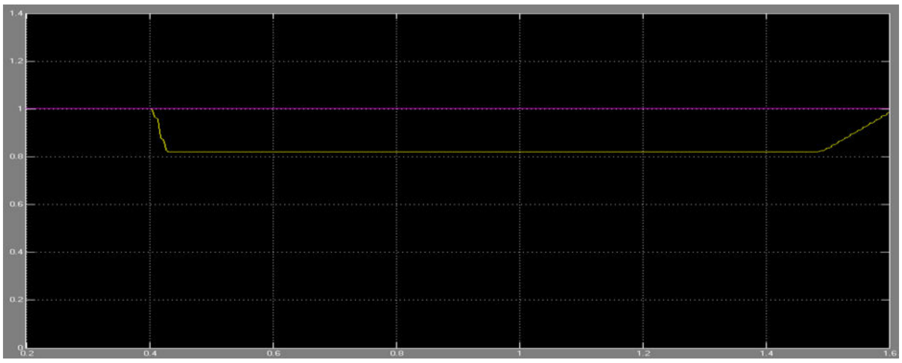

Figure 15: RMS voltages of PCC and load

The figure illustrates the RMS voltage profiles of both the PCC and the load during a sag event. The PCC voltage (yellow curve) experiences a noticeable reduction when the disturbance occurs, dropping to around 80% of its nominal value and remaining depressed until the fault clears. In contrast, the load RMS voltage (purple curve) remains almost constant throughout the entire duration of the disturbance, indicating the effective operation of the DVR. By rapidly injecting the required compensating voltage, the DVR ensures that the load voltage stays close to its rated magnitude despite the significant drop at the PCC.

Current Wave Shape Due Three-Phase Short- Circuit

During a three-phase short-circuit fault, the current waveform experiences a sudden and dramatic increase, creating a high-magnitude fault current that far exceeds normal operating levels. The waveform typically contains both symmetrical AC components and a DC offset, causing the current to rise sharply in the first cycle and gradually settle into a steady-state symmetrical pattern.

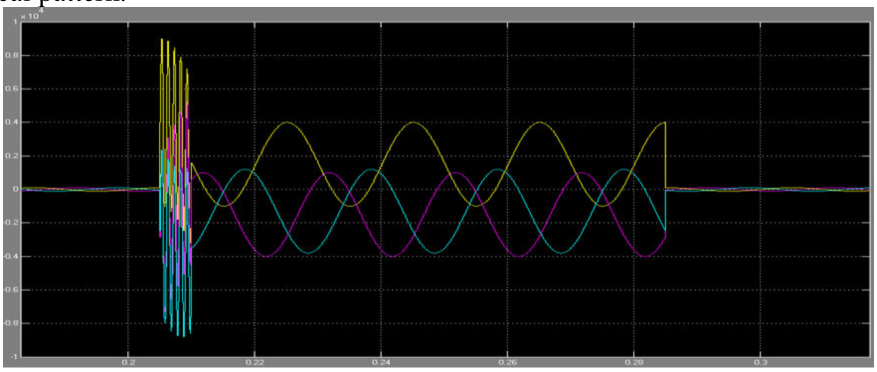

Figure 16: Three-Phase Short- Circuit

The figure illustrates the three-phase voltage waveforms during a short-circuit event in the distribution system. At the instant the fault occurs, the voltages in all three phases experience a sudden and severe collapse, resulting in a highly distorted and irregular waveform. This abrupt drop demonstrates the high-impact nature of a three-phase fault, which produces significant voltage depression and waveform distortion due to the rapid rise in fault current.

Fault Current Limiting

The last simulation is run for a symmetrical downstream fault, and the capability of the DVR to reduce the fault current and restore the PCC voltage is tested. For this purpose, a three-phase short circuit is applied on bus “05: FDR F”. In Figure, the fault Current, without the DVR compensation, is shown. For the simulation with DVR compensation, the three-phase fault is applied at t=205 ms and then removed after t= 0.1. Also a breaker will remove the faulted bus from the entire system at t=300 ms.

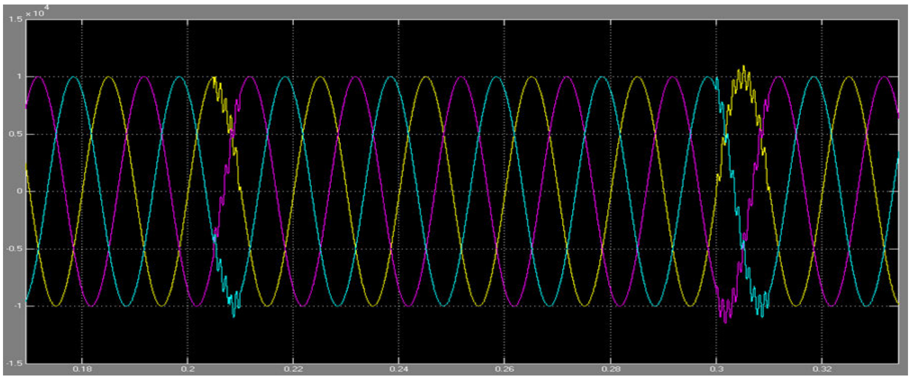

Figure 17: Fault Current Limiting By DVR

The figure illustrates the effectiveness of the DVR in limiting fault current during a disturbance in the distribution system. At the moment the fault occurs, a sharp rise in current can be seen, characterized by waveform distortion and increased amplitude in all three phases. Once the DVR enters its virtual impedance mode, the fault current is significantly reduced, and the waveform stabilizes to a controlled level.

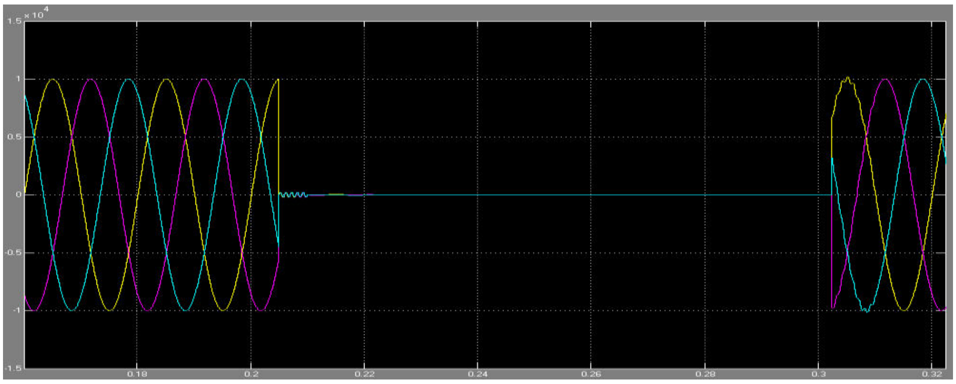

Figure 18: Three-phase load voltages

The figure illustrates the three-phase load voltages during a fault condition and the corresponding compensation provided by the DVR. Before the disturbance, the load voltages remain balanced with uniform sinusoidal waveforms. Once the fault occurs, a dramatic voltage collapse is observed, reducing the load voltage to nearly zero.

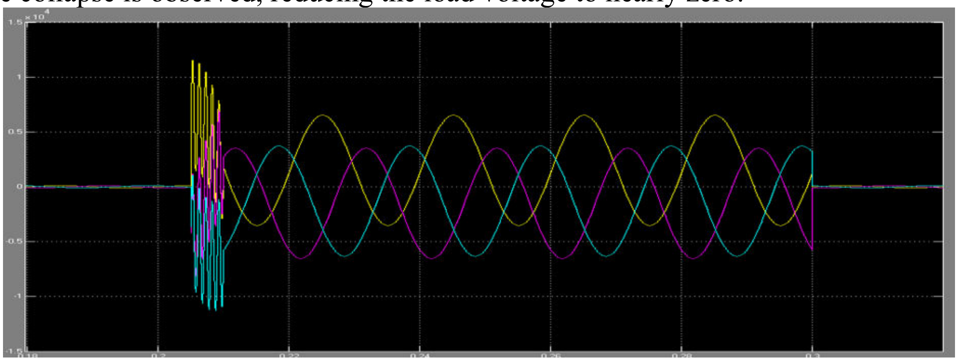

Figure 19: Three-phase currents.

The figure displays the three-phase current waveforms during a fault event and the subsequent system response. Prior to the disturbance, the currents remain minimal and balanced, indicating normal operating conditions. As the fault occurs, a sudden and steep rise in current magnitude appears across all phases, accompanied by significant waveform distortion typical of short-circuit behavior.

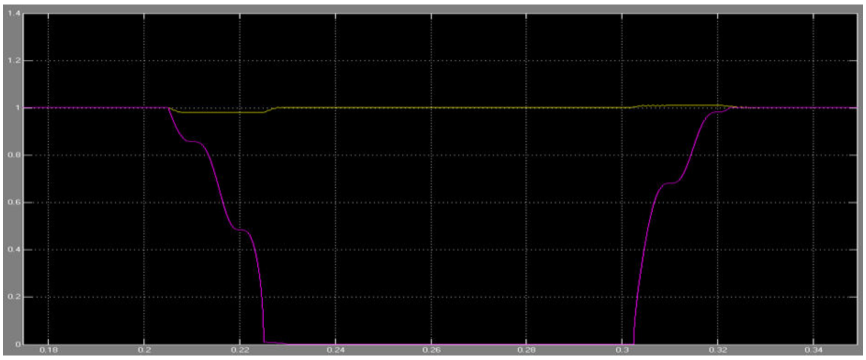

Figure 20: RMS voltages of the PCC and load

The figure illustrates the RMS voltage profiles of both the PCC and the load during a voltage sag and its subsequent compensation. As the disturbance occurs, the PCC voltage drops sharply, reaching a deep sag and remaining at a reduced level throughout the fault interval. In contrast, the load voltage remains nearly constant, held close to its nominal value due to the corrective action of the DVR. Once the disturbance is cleared, both voltages gradually return to steady-state levels. This behavior demonstrates the DVR's effectiveness in isolating sensitive loads from upstream voltage depressions and ensuring continuous, stable voltage supply during fault conditions.

Discussion

The simulation results demonstrate that the proposed multifunctional DVR significantly enhances voltage stability under sag and swell conditions while also providing effective emergency control in the distribution system. The integration of Posicast and P+Resonant controllers results in noticeably improved transient behavior, minimizing overshoot and reducing settling time during sudden disturbances such as induction motor starting and short-circuit faults. The DVR's ability to operate as a virtual impedance further strengthens its performance by successfully limiting downstream fault currents and maintaining PCC voltage without excessive real-power injection. This dual functionality makes the DVR not only a voltage-restoring device but also a protective element during grid emergencies. Overall, the results confirm that the proposed control strategy provides enhanced robustness, faster compensation, and improved system reliability compared to conventional DVR methods.

Conclusions

To enhance the damping of the DVR's response, this project proposes a multifunctional DVR and uses a closed-loop control method to control it. In addition, the Posicast and P+Resonant controllers are employed to eradicate the steady-state error and optimize the transient response even further. The second purpose of this DVR is to apply the flux-charge model to the regulation of the equipment in such a way that it acts as a variable impedance, limiting the downstream fault currents and protecting the PCC voltage during these faults. To avoid active power absorption, connect an impedance in parallel with the dc-link capacitor and the battery in series with a diode; this will prevent power from entering the circuit at the beginning of this type of malfunction. The simulation results show that the suggested DVR can prevent voltage drops due to short circuits and starting a big induction motor, restrict fault currents downstream, and safeguard the PCC voltage.

Future scope

Future work can focus on enhancing the multifunctional DVR by integrating intelligent control methods such as adaptive, fuzzy, or AI-based algorithms to further improve its dynamic performance under complex grid disturbances. The system can also be extended for use in renewable-rich microgrids, where DVRs can support voltage stability during fluctuating solar or wind generation. Hardware implementation using DSP or FPGA platforms will help validate the proposed control strategy in real-time conditions. Additionally, refining the virtual impedance feature for more accurate fault-current limitation and incorporating advanced energy-storage interfaces can make the DVR even more reliable for next-generation distribution networks.

References

1. Hingorani, N. G. (2000). Introducing custom power devices. *IEEE Spectrum*, 32(6), 41–48.
2. Gyugyi, L. (2001). Power electronics in electric utilities: Static VAR compensators and custom power. *Proceedings of the IEEE*, 89(6), 76–84.
3. Benachaiba, C., & Ferdi, B. (2009). Voltage quality improvement using DVR: Analysis and simulation. *International Journal of Electrical Power & Energy Systems*, 31(1), 1–7.
4. Ferdi, B., Benachaiba, C., Dib, D., & Bousserhane, I. (2010). Enhancement of voltage quality using DVR under nonlinear loads. *Journal of Electrical Engineering*, 10(4), 137–144.
5. Ghosh, A., & Ledwich, G. (2012). *Power Quality Enhancement Using Custom Power Devices*. London: Springer-Verlag.
6. Nguyen, T. T. (2016). Improving transient performance of a dynamic voltage restorer using Posicast control. *IEEE Transactions on Industrial Electronics*, 63(4), 2464–2474.
7. Song, Y., & Lee, J. (2017). Proportional-resonant control strategy for DVR to eliminate steady-state error under distorted grid conditions. *Electric Power Systems Research*, 149, 148–157.
8. Karimi, H., Martinez, R., & Iravani, R. (2017). Fault ride-through capability of DVR during symmetrical and asymmetrical faults. *IEEE Transactions on Power Delivery*, 32(3), 1355–1364.
9. Kaviani, M., Farhadi, M., & Alavi, S. (2018). Virtual impedance–based DVR for downstream fault current limitation and PCC voltage support. *IEEE Transactions on Smart Grid*, 9(6), 5910–5920.
10. Li, X., Zhang, C., & Zhu, Y. (2020). Intelligent control of DVR using fuzzy logic and neural networks for improved sag/swell compensation. *IET Power Electronics*, 13(10), 2071–2081.