International Journal of Applied and Advanced Scientific Research (IJAASR)
International Peer Reviewed - Refereed Research Journal, Website: www.dvpublication.com
Impact Factor: 5.655, ISSN (Online): 2456 - 3080, Volume 11, Issue 1, January - June, 2026

PHOTOVOLTAIC MLI BASED DVR WITH BATTERY ENERGY STORAGE SYSTEM FOR POWER QUALITY IMPROVEMENT

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Cite This Article: C. Kavikumar, A. Ajith, V. Charudutta Hari, R. Dhanush Kumar & P. Hariharan, "Photovoltaic MLI Based DVR with Battery Energy Storage System for Power Quality Improvement", International Journal of Applied and Advanced Scientific Research, Volume 11, Issue 1, January - June, Page Number 83-86, 2026.

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Type of Review: Peer Reviewed as per |C|O|P|E| Guidance.

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DOI: https://doi.org/10.5281/zenodo.19811906

Abstract:

Power quality disturbances especially voltage sags, swells, and short-duration interruptions remain one of the biggest headaches for modern industrial and commercial consumers. Among the available solutions, the Dynamic Voltage Restorer (DVR) has emerged as one of the most effective and frequently deployed devices for protecting sensitive loads. Traditionally, DVRs are used on the load side to inject compensating voltages through an injection transformer, ensuring that downstream equipment receives a stable and regulated supply even when upstream faults occur. However, conventional DVRs mainly focus on voltage compensation and often struggle to handle severe fault currents without drawing excessive real power from the DC link. The proposed system upgrades DVR functionality by enabling it to operate as virtual impedance, dynamically adjusting its behavior using artificial intelligence-based control algorithms. This smarter DVR steps beyond simple compensation by actively limiting fault currents in the feeder during disturbances. When a fault occurs upstream, the DVR's virtual inductive behavior restricts the current flow to safer levels while ensuring that sensitive loads in parallel feeders continue to operate without disruption until protective devices isolate the faulted section. A key advantage of the proposed design is that the DVR behaves like a purely effective inductance during fault conditions, ensuring that it does not draw real power from external sources. This protects critical components such as the DC link capacitor and battery from stress and prevents unnecessary energy drain.

Introduction:

In modern power distribution networks, maintaining high-quality and uninterrupted electric power has become more than just a technical requirement it is now an absolute necessity. With industries growing more automation-driven, digital loads becoming hypersensitive, and consumers expecting glitch-free operation 24/7, even small dips or distortions in voltage can trigger malfunction, data loss, downtime, or catastrophic equipment failure. Power quality issues such as sags, swells, flicker, harmonics, and short interruptions have always been around, but in an era where everything from hospital equipment to semiconductor fabrication lines depends on stable voltage levels, the tolerance for these disturbances has dropped drastically. This is exactly where the Dynamic Voltage Restorer (DVR) proves its worth.

A DVR is a series-connected power electronic device designed specifically to shield sensitive loads from voltage anomalies. It operates by injecting a carefully conditioned voltage in series with the supply using an injection transformer, ensuring that the load side voltage remains undisturbed even when the upstream system misbehaves. Because it reacts almost instantaneously and handles different compensation modes, the DVR has become a go-to solution for industries seeking efficient mitigation of voltage sags and swells. The proposed system steps into this gap with a smarter, more adaptive, AI-enhanced DVR model that evolves the traditional design into something far more dynamic and protective. Rather than acting only as a voltage support device, the DVR in this concept also performs the role of fault current limiter by behaving like virtual impedance when disturbances occur.

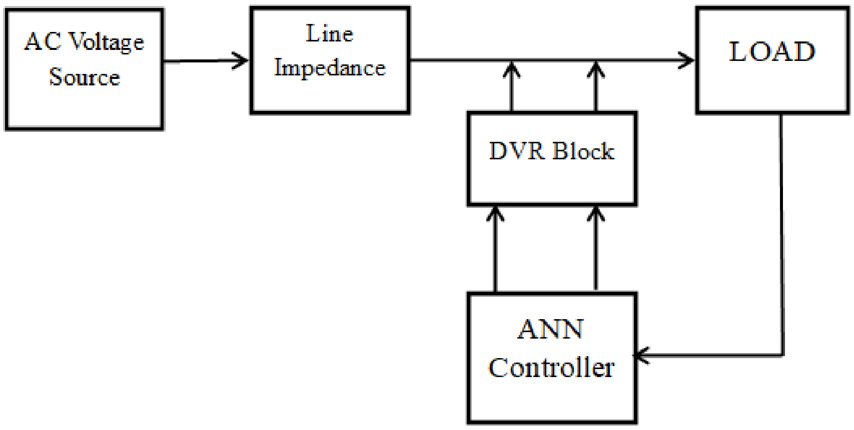
General Introduction:

Power quality has become one of the biggest deal-breakers in today's power distribution networks. Industrial automation, digital control systems, data centers, medical equipment, and large commercial loads all demand a stable and disturbance-free voltage supply. Even tiny sag lasting a few milliseconds can stop production lines, damage equipment, or corrupt sensitive data. With the electric grid growing more complex and more sensitive devices being integrated, disturbances like voltage sags, swells, flickers, and fault currents have become more frequent and more harmful. Because of this, utilities and industries are adopting fast-acting power conditioning devices to keep their operations running smoothly. Among all available solutions, the Dynamic Voltage Restorer (DVR) stands out as one of the most efficient and widely adopted technologies for maintaining voltage quality.

- Need for Advanced Power Quality Solutions: Modern industries operate with machines that are highly sensitive to even the smallest voltage fluctuation. Traditional voltage regulators and passive filters are too slow and inflexible to manage rapidly changing disturbances. A smarter and faster device is required to maintain stability. The DVR fills this gap by offering instant response and precise voltage correction. As power networks integrate renewable energy sources, electric vehicles, and nonlinear loads, disturbances have become more unpredictable. Hence, advanced solutions like the proposed DVR concept are now essential.

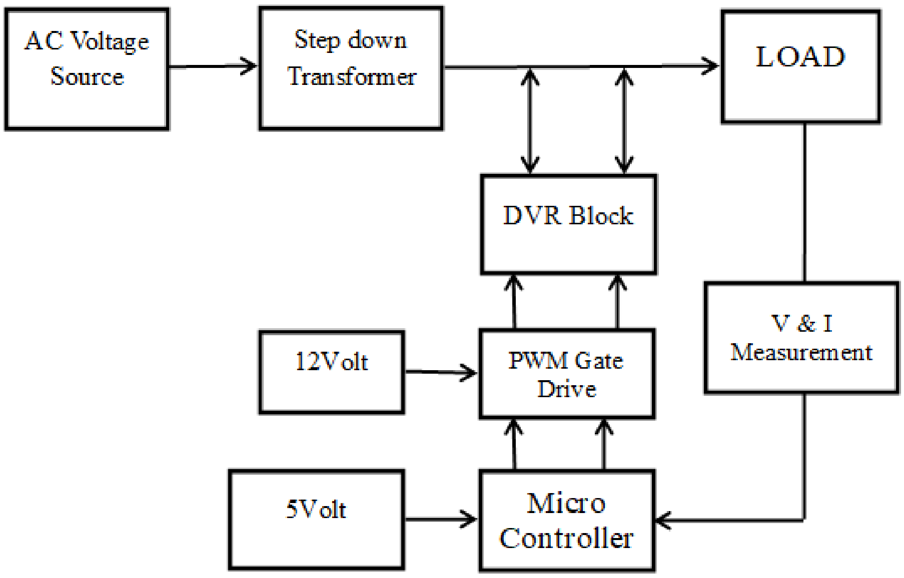
- DVR as a Series-Connected Protection Device: The Dynamic Voltage Restorer works by injecting a controlled compensating voltage in series with the feeder. When the supply voltage dips or swells, the DVR instantly synthesizes the missing or excess voltage to stabilize the load side. This injection is achieved using a solid-state inverter and an injection transformer. Because the DVR is located on the sensitive load side, it ensures maximum protection and keeps the voltage profile clean, even during upstream faults. Its fast acting capability gives it a major advantage over other power quality devices.
- Virtual Impedance Operation of the Proposed DVR: The unique feature of the proposed system is that the DVR behaves like a pure inductive impedance during fault conditions. This virtual inductance restricts the fault current, preventing heavy currents from passing through the feeder. Since the DVR does not draw real power while acting as an inductance, the DC link capacitor and battery remain protected. This removes the risk of energy depletion, heating, or component stress during fault events. The system continues to operate smoothly until the circuit breaker isolates the faulty feeder.
- AI-Based Control for Adaptive Protection: Artificial intelligence enhances the performance of the DVR by making its control system more adaptive and predictive. AI algorithms such as neural network controllers or fuzzy logic controllers quickly analyze voltage disturbances and tune the DVR's injection parameters in real time. This enables faster response, smoother compensation, and better decision-making during unpredictable faults. AI helps the DVR "learn" typical disturbance patterns and optimizes its actions, resulting in improved accuracy and stability.

Proposed System:

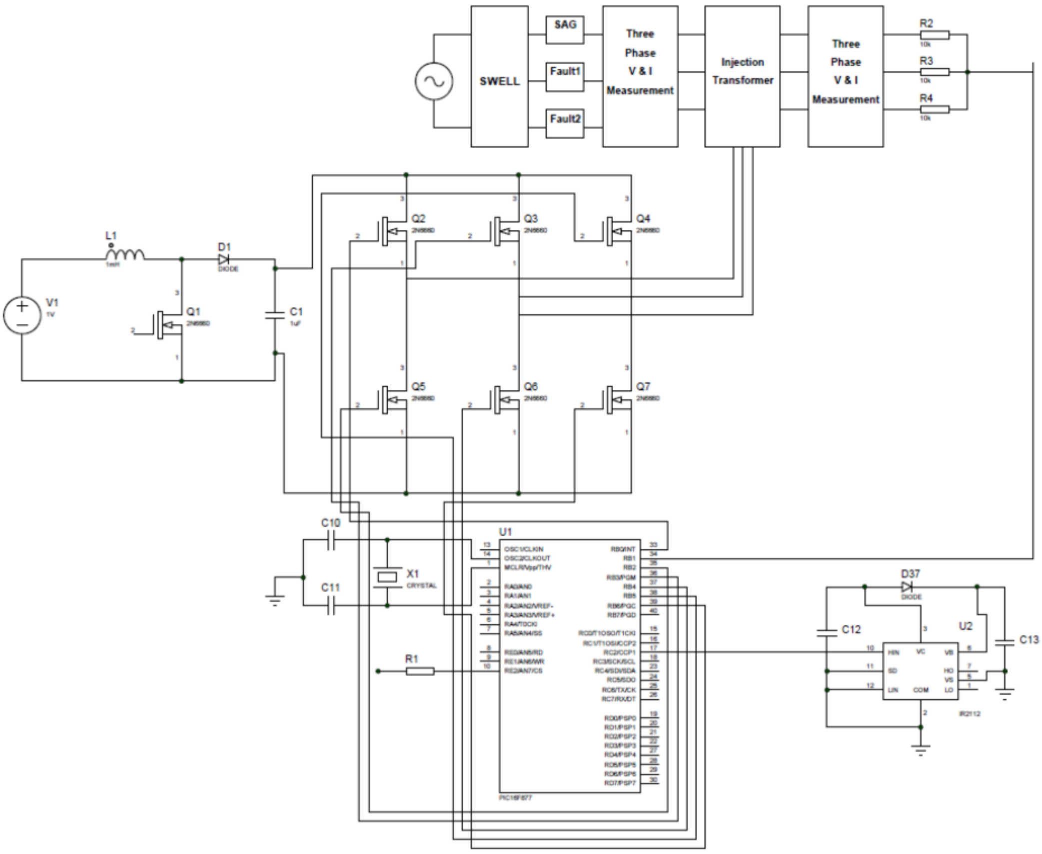


The proposed DVR-based system introduces an advanced approach for improving power quality and enhancing protection within distribution networks. Unlike conventional DVRs that mainly focus on voltage compensation, this system integrates dual functionality voltage regulation and fault current limitation by leveraging virtual impedance behavior and artificial intelligence (AI) driven control. This upgraded DVR is installed on the sensitive load side, where it can react quickly to disturbances and shield critical equipment from disruptions caused by upstream faults. In this proposed design, the DVR injects voltage in series with the supply using an injection transformer, ensuring that the sensitive load continues to receive stable and regulated voltage under sag, swell, or fault conditions. However, the standout innovation is the DVR's ability to operate as virtual impedance, particularly during fault events. When a large fault current flows through the feeder, the DVR mimics a pure inductive element, effectively restricting the magnitude of the current without consuming real power from the external source. The integration of artificial intelligence enhances the DVR's responsiveness and adaptability. AI-based control algorithms enable the DVR to analyze disturbances in real time, adjust virtual impedance characteristics, and optimize the injected voltage waveform.

Block Diagram:



Circuit Diagram:



Methodology:

- System Modeling and Disturbance Analysis (100 Words): The methodology begins by modeling the distribution feeder, sensitive loads, and typical voltage disturbance conditions such as sags, swells, and fault currents. Simulation tools like MATLAB or PSCAD are used to create a realistic test environment. Different fault types L-G, L-L, DLG, and three-phase faults are applied to analyze their effect on load voltage and current flow. This step helps identify the exact disturbance characteristics that the DVR must compensate or limit. The collected data establishes baseline behavior for comparison and guides the tuning of control algorithms for optimal DVR performance under dynamic grid conditions.
- Design of DVR with Injection Transformer Interface (100 Words): The next step involves designing the DVR power circuit, which includes a PWM-based voltage source inverter, DC link capacitor, and series injection transformer. The injection transformer enables the DVR to place a synthesized voltage directly in series with the feeder. The inverter is configured to produce three independent single-phase voltages with controlled magnitude and phase angle. System parameters such as transformer turns ratio, filter size, switching frequency, and DC link voltage are optimized to ensure fast and accurate voltage injection. This setup forms the hardware foundation for compensating disturbances and controlling fault current through impedance synthesis.
- Virtual Impedance Implementation for Fault Current Limiting (100 Words): This step introduces the virtual impedance feature that allows the DVR to behave like a pure inductance during fault conditions. Using advanced control logic, the DVR synthesizes an effective inductive voltage drop that restricts fault current magnitude without drawing real power from the grid. This protects the DC link capacitor and battery from excessive stress. The impedance value is dynamically adjusted based on the severity of the disturbance. This method ensures that sensitive loads in parallel feeders continue receiving stable voltage while the DVR limits the fault current until the protection breaker isolates the affected feeder.

Conclusion:

The proposed Dynamic Voltage Restorer system introduces a more advanced, reliable, and intelligent solution for addressing power quality disturbances in modern distribution networks. By combining virtual impedance operation with artificial intelligence based control, the system goes far beyond the abilities of conventional PI-controlled DVRs. Through its series injection mechanism, the DVR effectively stabilizes voltage during sags, swells, and disturbances, ensuring uninterrupted supply to sensitive loads. The standout advantage is its ability to behave like a pure inductive element during fault conditions, enabling it to limit fault current without drawing real power from the external source. This protects the DC link capacitor, minimizes energy stress, and extends the lifetime of internal components. The AI controller enhances system adaptability by making real-time decisions based on disturbance characteristics. This results in faster response, smoother voltage tracking, and more accurate compensation even under unpredictable fault scenarios. The DVR successfully maintains the voltage in parallel feeders and allows protective devices adequate time to isolate the faulted section.

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