POWER QUALITY IMPROVEMENT USING DYNAMIC VOLTAGE RESTORER WITH IOT MONITORING

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ABSTRACT

Power quality disturbances such as voltage sags and swells pose significant challenges to the stability and reliability of modern electrical systems, especially in environments with sensitive electronic loads. This project proposes an efficient and compact Dynamic Voltage Restorer (DVR) system designed to mitigate such voltage fluctuations without relying on bulky transformers or conventional energy storage elements. The DVR architecture includes a DSPIC30F2010 microcontroller for real-time monitoring and control, a MOSFET-based inverter circuit for injecting compensating voltage, and a PI controller to maintain steady voltage levels. Furthermore, the system is enhanced with Internet of Things (IoT) capabilities using the ESP8266 Wi-Fi module, enabling remote voltage tracking through the Thing Speak cloud platform. Both simulation and hardware results confirm the DVR's effectiveness in compensating for voltage anomalies and improving load voltage stability. The integration of IoT not only supports real-time visualization of voltage trends but also allows for proactive maintenance and better system management. This approach offers a cost-effective and scalable solution for ensuring reliable power delivery in residential, commercial, and industrial settings.

Keywords: Dynamic Voltage Restorer, Power Quality, Voltage Sag and Swell, DSPIC Microcontroller, IoT Monitoring, Thing Speak.

1. INTRODUCTION

In modern electrical networks, power quality plays a crucial role in maintaining the reliability, efficiency, and operational integrity of sensitive loads. With the growing use of nonlinear and electronically controlled equipment in industries, hospitals, and data centers, power systems are increasingly vulnerable to voltage disturbances such as sags, swells, and transients. These disturbances can lead to equipment malfunction, production delays, data loss, and substantial financial losses [1]. Among these issues, voltage sag defined as a short-duration reduction in RMS voltage typically caused by motor starting or sudden load changes and voltage swell an overvoltage condition often due to load disconnection are particularly detrimental [2]. To counteract these voltage anomalies, power conditioning devices such as Uninterruptible Power Supplies (UPS), static compensators, and Dynamic Voltage Restorers (DVRs) are employed. Of these, DVRs have proven to be effective in series compensation, offering rapid dynamic response and lower harmonic distortion [3]. A DVR operates by injecting a compensating voltage in series with the supply voltage to maintain a constant voltage at the load end. Traditional DVR implementations, however, rely on transformers and energy storage components such as batteries or capacitors, which increase the system's complexity, size, and cost [4].

To address these limitations, a transformer-less and energy storage-free DVR architecture is proposed in this study. The system employs a dsPIC30F2010 microcontroller for real-time monitoring and control, a MOSFET-based inverter, and a PI control algorithm to dynamically compensate voltage disturbances. By eliminating the need for bulky transformers and storage devices, the proposed design achieves a compact and cost-effective configuration suitable for Indian low-voltage distribution networks, where power quality challenges are frequent due to load fluctuations and infrastructural limitations [5].Further enhancing system functionality, IoT-based monitoring is incorporated using the ESP8266 Wi-Fi module and the Thing Speak cloud platform, enabling real-time voltage tracking and remote visualization. This integration allows users to access system performance data, monitor power quality trends, and respond proactively to voltage anomalies, thus promoting predictive maintenance and improved grid stability [6][10]. Simulation studies conducted in MATLAB/Simulink validate the system's effectiveness in mitigating voltage sags and swells, while hardware implementation demonstrates consistent performance under practical conditions. The proposed DVR system offers a scalable, efficient, and digitally intelligent solution for power quality enhancement, making it well-suited for deployment in both urban and semi-urban Indian power systems.

2. LITERATURE REVIEW

Modern power systems require power quality as an essential element which affects both industrial processes and electrical services. DVRs recently proved their capability to control voltage sags while also addressing voltage swells and harmonics according to recent research findings [1]. The rise in renewable energy systems and nonlinear load devices leads to unstable voltage conditions which causes breakdowns of equipment while wasting energy. The DVR operates as an important power electronic device that injects adjustable voltage directly to stabilize the load voltage supply [2]. A conventional DVR system consists of a VSI (voltage source inverter) coupled with an energy storage unit through a series injection transformer under intelligent control strategies for voltage correction operations. Mathematical simulations within Simulink and MATLAB support the validation of DVR systems which restore voltage profiles while minimizing Total Harmonic Distortion (THD) and making the grid more stable [3]. The field of research has recognized DVR systems for their effectiveness in distribution networks that experience regular voltage variations affecting critical loads. Real-time data processing becomes enhanced and response times shorten while the compensation of voltage functions better through advanced control algorithms that include PID, FOPID and AI-based methods [4]. Power electronic advancements have allowed researchers to create the bipolar buck-boost AC-AC converter with five-switches that enhances DVRs through efficiency improvements and reduced power losses. This converter achieves cost-efficient operation through its ability to permit flexible frequency control and it functions as a budget-friendly substitute for traditional AC-AC converters [5]. Programming PI controllers into VSIs in DVRs results in stable voltage regulation by decreasing both overshoot and THD for industrial application purposes [6]. IoT-based power quality monitoring gives systems reliable operation through combined real-time data collection ability and remote-control features and automated disturbance management capabilities. WSNs allow wireless monitoring of cloud data which minimizes equipment downtime and decreases maintenance expenses. Future upgrades in equipment concentrate on processing power at the network edge and strengthening network stability for superior quality management of smart grids and industrial applications [7].

3. METHODOLOGY

The proposed Dynamic Voltage Restorer (DVR) system is designed to detect and compensate voltage sags and swells in real-time, using a transformer-less, energy storage-free topology. The methodology involves a structured approach that includes system design, simulation modeling, hardware implementation, and cloud-based monitoring. The overall block diagram of the system comprises key components such as a voltage sensing unit, a control unit based on the dsPIC30F2010 microcontroller, a MOSFET-based inverter, and an IoT module for remote data monitoring.

- Voltage Sensing and Detection: The first stage of the system involves sensing the input supply voltage using a resistive voltage divider and conditioning circuit. This analog signal is fed into the microcontroller's ADC module, which continuously samples the RMS voltage. The real-time value is compared with a predefined reference threshold (typically 230V ±10%) to detect the presence of voltage sags or swells. If the measured voltage deviates beyond these limits, the microcontroller activates the compensation mechanism.

- Control Strategy: A Proportional-Integral (PI) control algorithm is implemented within the dsPIC30F2010 controller to regulate the injected voltage. The error between the reference voltage and the actual supply voltage is calculated and processed through the PI controller, which then determines the appropriate compensating voltage magnitude. This value is used to generate PWM signals that control the operation of the inverter circuit. The use of the PI controller ensures a fast and stable response to voltage fluctuations without introducing significant overshoot or delay.

- Voltage Injection via Inverter: A single-phase full-bridge inverter is employed to inject the required compensating voltage in series with the supply. The inverter is constructed using high-speed IRF540N MOSFETs, and the gate pulses are driven by opto-isolated gate drivers (6N137) to ensure electrical isolation between the control and power circuits. The inverter output is filtered using LC components to produce a clean sinusoidal waveform, which is then added to the supply voltage via a series injection path. Unlike conventional DVR systems, the proposed design avoids bulky transformers by directly connecting the inverter output in series using solid-state switches, making the system compact and cost-effective.

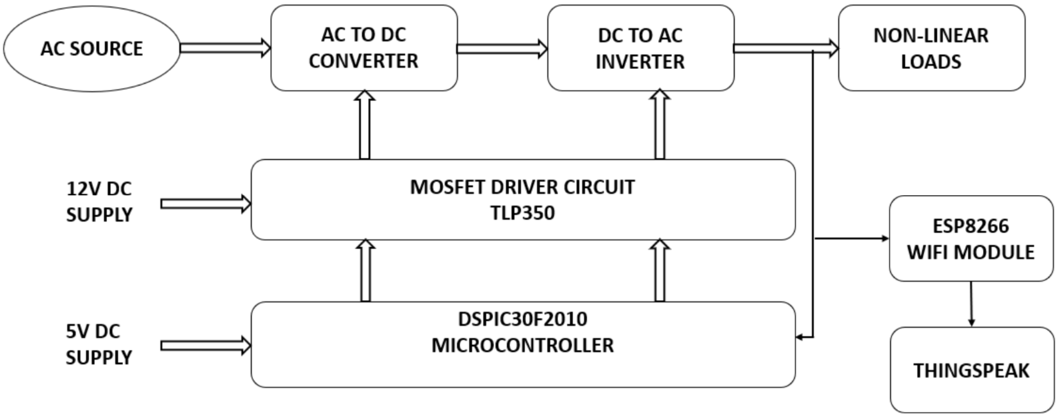

Figure.1. Block Diagram

- IoT-Based Voltage Monitoring: To facilitate remote monitoring and system transparency, the DVR is integrated with an ESP8266 Wi-Fi module that communicates voltage data to the ThingSpeak cloud platform. The dsPIC controller transmits real-time voltage readings to the ESP8266 via UART communication, and these values are periodically uploaded to the cloud through a local Wi-Fi network. This enables users to visualize live voltage graphs, log historical data, and receive alerts in case of voltage anomalies. The integration of IoT not only enhances user accessibility but also supports predictive maintenance and data-driven system optimization.

- Simulation and Hardware Implementation: The proposed system is first modeled and tested using MATLAB/Simulink, where the control algorithm, inverter dynamics, and compensation behavior are validated under various sag and swell conditions. Simulation results are used to fine-tune the PI controller parameters and PWM generation logic. Subsequently, the hardware is implemented on a custom PCB designed for the control and inverter circuits. The system is tested under practical conditions using a variac and programmable load to emulate real-time voltage disturbances. The results are analyzed in terms of voltage compensation accuracy, response time, harmonic distortion, and stability.

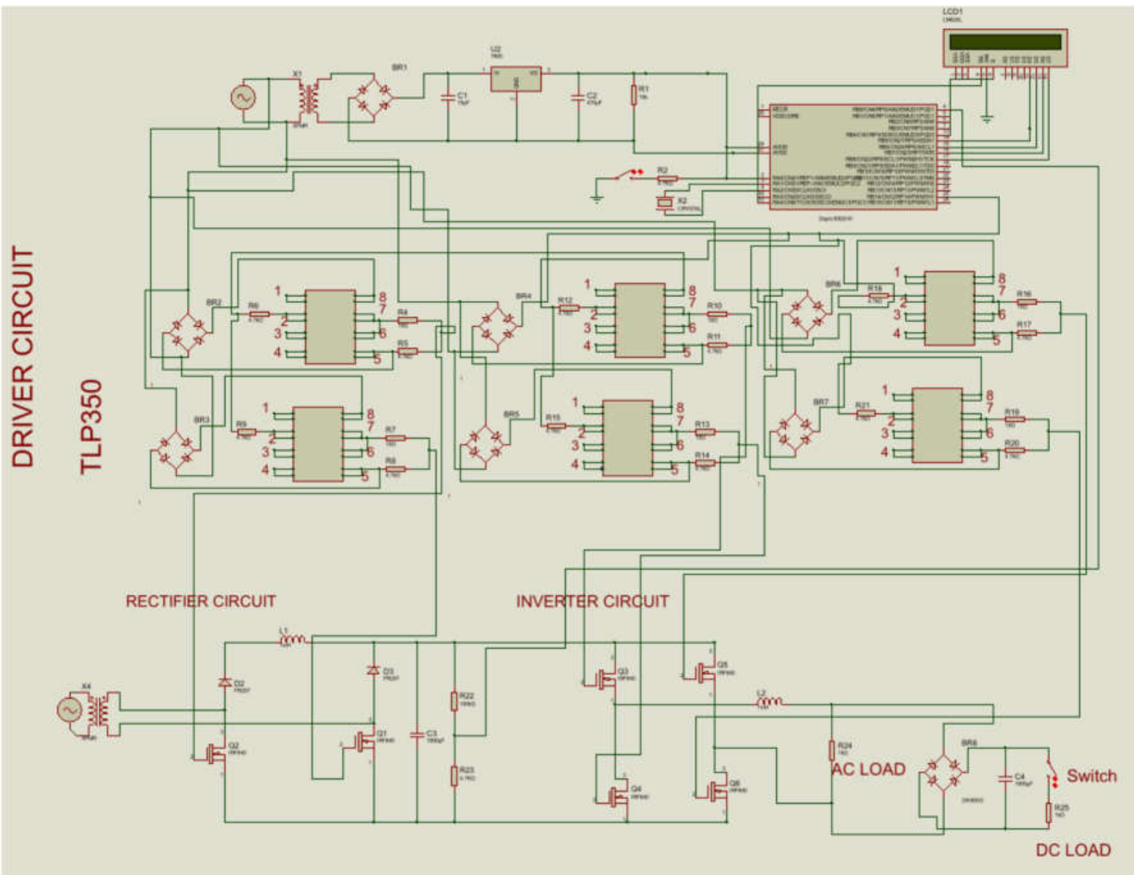

Figure.2. Circuit Diagram

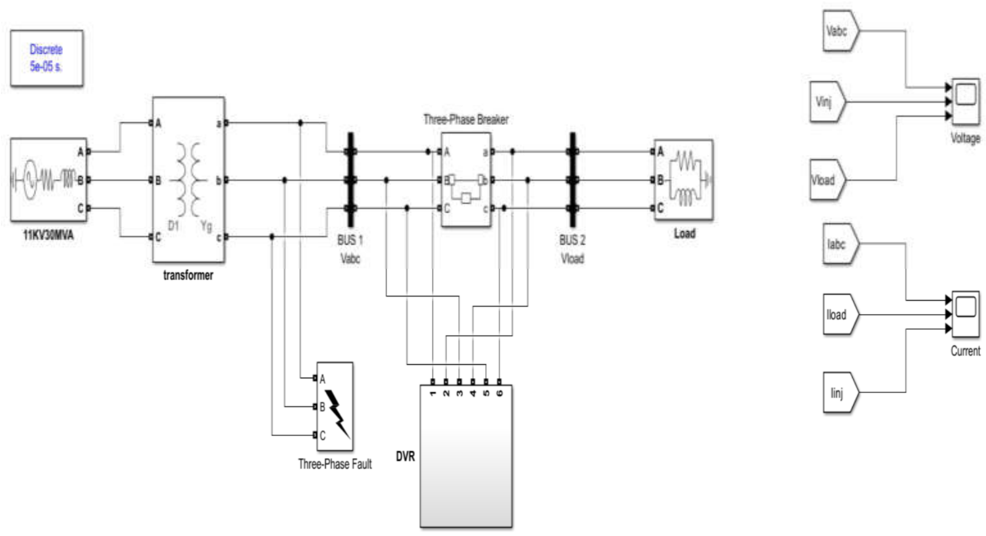

Figure.3. Simulation Diagram

4. RESULTS AND DISCUSSION

SIMULATION RESULTS

The given simulation demonstrates the operation of a Dynamic Voltage Restorer (DVR) in mitigating voltage sags caused by a three-phase-to-ground fault. The first graph (Vabc) represents the system's three-phase voltage waveform before and during the fault. At 0.03 seconds, a fault occurs, creating a significant voltage sag in all three phases. This is due to the low fault resistance (0.03 Ω), causing a drop in system voltage. The fault remains active until 0.07 seconds, after which the system starts recovering.

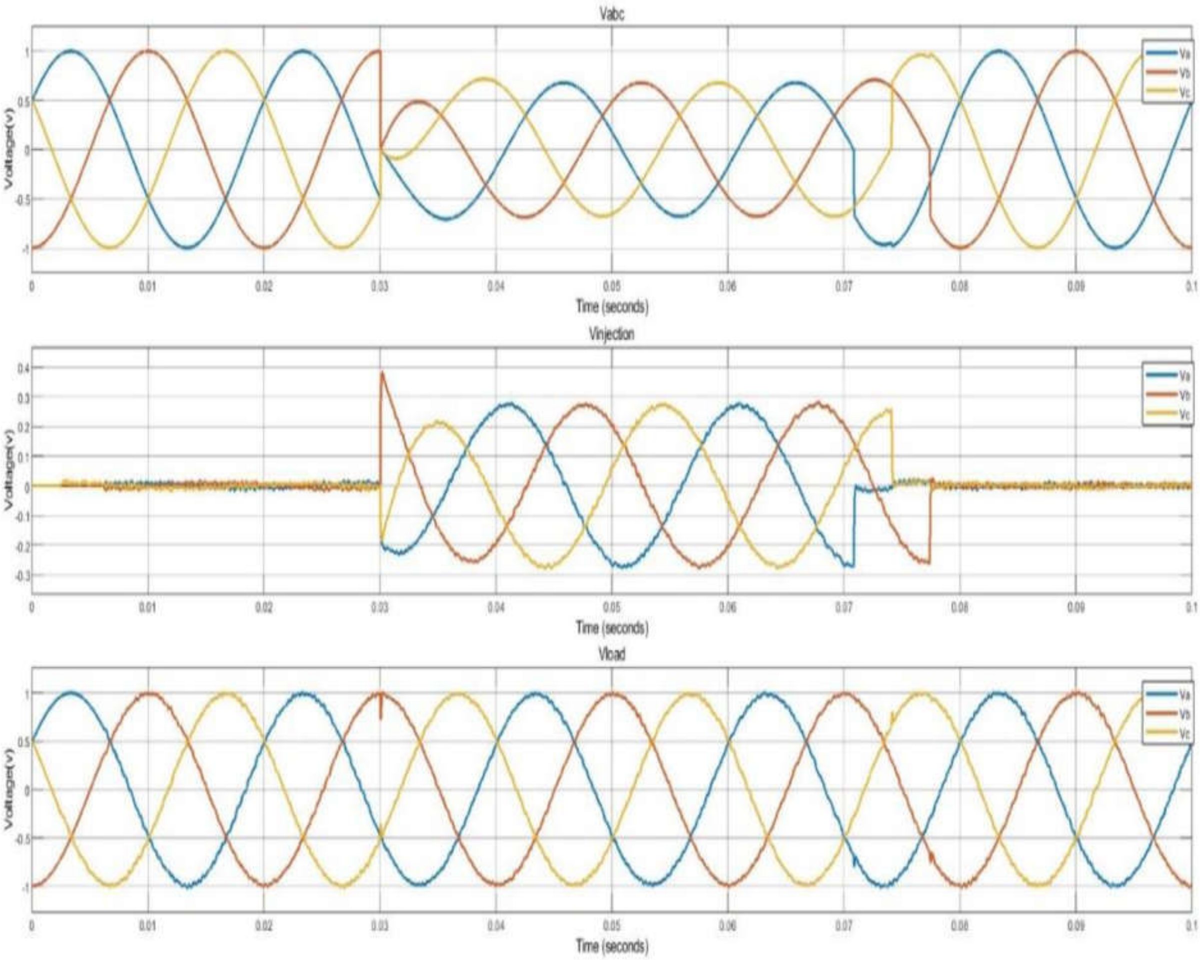

Figure.4. Simulation Results

Fig .4. a) Voltage waveform with voltage sag, b) Injecting voltage waveform, c) Compensated voltage waveform. The second graph (Vinjection) shows the compensating voltage generated by the DVR. Once the control system detects the voltage sag at 0.03s, it activates the Voltage Source Inverter (VSI) to generate the missing voltage. This voltage is injected into the system through an injection transformer to counteract the drop caused by the fault. The waveform illustrates how the DVR actively injects voltage during the fault duration (0.03s to 0.07s), restoring the voltage profile.

The third graph (Vload) represents the final mitigated output voltage at the load. It confirms that despite the disturbance in the supply voltage, the DVR successfully restores the voltage to its normal level. The output waveform remains stable before and after the fault, proving the effectiveness of the DVR in maintaining power quality

HARDWARE RESULTS

The DVR was subjected to voltage variations to assess its behaviour under both nominal and abnormal conditions. The input to ThingSpeak is the load voltage, which is continuously monitored and transmitted to the IoT platform for real-time data visualization and analysis. This voltage is obtained using a voltage divider circuit, which scales down the actual load voltage to a safe level before feeding it to the A0 (analog input) pin of a microcontroller, such as an Arduino or ESP8266. The given ThingSpeak voltage data graph presents voltage fluctuations over time, highlighting critical events such as voltage swell and voltage sag.

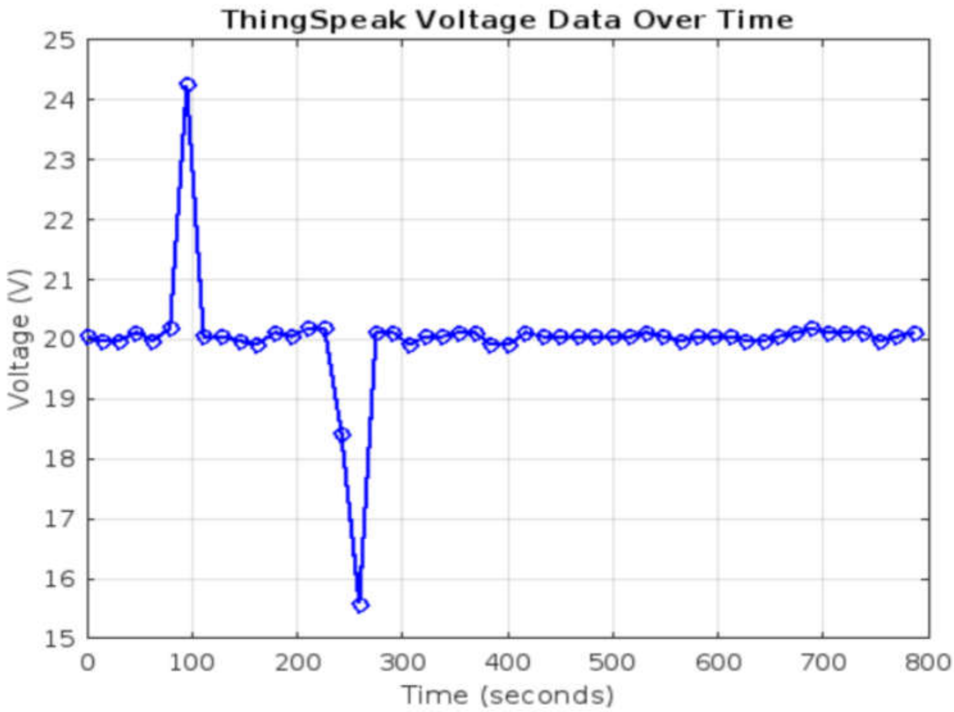

Figure.5. Think Speak Output

When a DC load with a lower impedance is added at the 100-second mark, a voltage surge takes place, peaking at about 24V. This occurs because lowering the load results in a brief increase in voltage since less current is drawn from the power source. About 120 seconds in, the voltage drops back to the nominal 20V, as the DVR compensated the voltage, bringing the voltage back to the nominal 20V. The DVR achieves this by injecting the necessary corrective voltage in series to counteract the rise and maintain a steady supply

Figure.6. Mitigated output

5. CONCLUSION

This work presents a compact and cost-effective solution for improving power quality in low-voltage distribution networks through the implementation of a transformer-less, storage-free Dynamic Voltage Restorer (DVR). By employing a high-speed dsPIC30F2010 microcontroller and a MOSFET-based inverter, the system successfully detects and compensates for voltage sags and swells in real time. The incorporation of a Proportional-Integral (PI) controller ensures fast and stable voltage regulation without significant overshoot, while the opto-isolated gate drivers enhance system safety and noise immunity. The addition of IoT-based monitoring via the ESP8266 Wi-Fi module and ThingSpeak cloud platform enables remote voltage tracking and data logging, providing enhanced transparency and facilitating predictive maintenance. Simulation and hardware results validate the system's performance under various disturbance conditions, confirming its effectiveness in stabilizing load voltage and maintaining power quality. The proposed design, with its reduced hardware footprint and remote monitoring capability, is particularly well-suited for deployment in Indian residential and commercial settings where power fluctuations are frequent and reliable voltage regulation is essential. Overall, the DVR system developed in this work provides a scalable and intelligent solution for modern power distribution networks, contributing to the broader goals of grid reliability, efficiency, and smart energy management.

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