



Modelling And Analysis Of Mli Based Dvr In Grid Fed Ev Fast Charging Station For Power Quality Mitigation

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Abstract:

This paper deals with an power quality (PQ) solution for the compensation of voltage sag on grid fed electric vehicle fast charging stations (EVFCS) using a T-type 7-level inverter based dynamic voltage restorer (DVR). In this work, a lithium-ion battery pack with a rating of 48 V, 10 Ah, and 5 A is used as an electric vehicle (EV) battery. Firstly, the voltage sag shows a significant effect on the performance of EVFCS. The analysis of the effect of voltage sag on different characteristics of EVFCS, such as DC-bus voltage, battery current, state-of-charge (SOC), and battery voltage is carried out in MATLAB/Simulink and through experimentation. Further, the design of the charging system is carried out using a 1- ϕ rectifier and DC-DC converter with closed loop current control. The performance of a closed loop current controlled buck converter is investigated experimentally for different magnitudes of sag (0%, 25% and 50%). Furthermore, the $\alpha\beta$ to dq transformation based synchronous reference frame (SRF) theory operated closed loop voltage controller is employed for 1- ϕ DVR to mitigate a voltage sag of 50%. This DVR maintains rated DC-bus voltage (110 V) and rated battery current (5 A) under a severe voltage sag condition of 50%. Also, DVR protects the PCC (grid) from voltage harmonics generated by the EVFCS, reducing the PCC voltage THD to 2.42% from 9.8%.

Index Terms - MLI, DVR, EVFCS, Power Quality, Voltage Sag, THD

INTRODUCTION:

With the growing global concern over environmental pollution and the depletion of fossil fuels, there has been a considerable shift away from internal combustion (IC) engine-based vehicles. This transition has placed electric vehicles (EVs) at the forefront of clean mobility solutions due to their eco-friendly operation and potential for carbon footprint reduction.

However, despite their advantages, EVs still encounter significant hurdles in practical deployment—primarily due to long charging times and issues related to power quality (PQ) during charging, especially in grid-connected environments. Conventional electric vehicle chargers typically require 5 to 10 hours for a complete charge, which hinders their suitability for rapid urban and intercity transport systems. Consequently, the demand for fast-charging infrastructure capable of achieving full charge in under 2 hours—typically using a C/2-rate—has gained momentum. Such EV fast charging stations (EVFCS) can be powered either by grid sources or renewable energy sources like solar photovoltaic (PV) systems. The integration of grid-fed fast-charging stations (EVFCS) is essential for supporting the widespread adoption of electric vehicles (EVs). However, these systems introduce significant power quality (PQ) challenges,

particularly voltage disturbances and loading stresses on the grid infrastructure [1], [2]. Among various PQ issues, voltage sag stands out as a critical factor that can impair charger performance, causing inefficient battery charging or even malfunction of power electronic components. Therefore, there is an urgent need for effective mitigation strategies to ensure stable and reliable operation of EV charging systems under such disturbances. This work focuses on analyzing the impact of voltage sags on grid-connected EVFCS and proposes a T-type five-level Dynamic Voltage Restorer (DVR) as a mitigation technique.

Multilevel DVRs are well-regarded for their ability to deliver high-quality voltage compensation with minimal total harmonic distortion (THD), making them ideal for dynamic PQ management in modern smart grids. Previous studies have explored various methods to enhance EV charging while addressing PQ concerns. For example, a multi-pulse thyristor-based rectifier with a flexible topology is proposed in [3] to maintain constant current charging for EVs. However, this solution does not consider voltage disturbances. In [4], the impact of voltage sags on EV charging systems is evaluated, yet no specific mitigation strategies are offered. Likewise, [5] examines voltage sag tolerance limits for EV batteries but does not address protective methods during such events. To counter voltage sag effects, energy storage solutions have been proposed. In [6], a PV-based charging station with a supercapacitor for sag compensation is studied. While effective for short-term sags, the limited energy capacity of supercapacitors makes them unsuitable for prolonged events. Alternatively, battery energy storage systems (BESS) are explored in [7] to support fast DC charging and stabilize weak grid connections. To bridge these gaps, this paper proposes a DVR-based solution to enhance voltage stability during sag events. The proposed T-type five-level DVR is evaluated for its performance in compensating voltage sags and improving the PQ of grid-connected EV fast-charging stations.

I. OBJECTIVES

To develop an MLI-based DVR system that compensates for voltage disturbances and improves power quality in EV fast-charging stations. To reduce total harmonic distortion (THD) and improve power factor by utilizing a multilevel inverter for high-quality AC power conversion. To enhance grid stability by integrating real-time monitoring and adaptive control strategies for dynamic voltage regulation. To optimize energy efficiency by minimizing power losses and ensuring smooth voltage transitions during EV fast charging.

II. PROPOSED SYSTEM

The proposed system introduces a Multilevel Inverter (MLI)-based Dynamic Voltage Restorer (DVR) integrated into a grid-fed Electric Vehicle Fast Charging Station (EVFCS) to enhance power quality and system reliability. The DVR employs a T-type 7-level inverter that enables smoother voltage compensation with reduced switching stress and lower Total Harmonic Distortion (THD). A lithium-ion battery rated at 48 V, 10 Ah serves as the energy source for voltage restoration during disturbances. For moderate voltage sags (up to 25%), a current-controlled buck converter is used to maintain a stable DC output, thereby ensuring uninterrupted charging. For severe voltage sags (up to 50%), the DVR uses a voltage-controlled closed-loop system based on Synchronous Reference Frame (SRF) theory to inject appropriate compensating voltages at the Point of Common Coupling (PCC). The DVR not only restores nominal voltage levels but also filters harmonics generated by high-frequency switching in EV chargers, thereby reducing THD at the PCC and protecting sensitive grid-connected equipment. The combination of the MLI and DVR provides robust and adaptive voltage regulation, ensuring efficient, stable, and safe operation of the EVFCS under various grid disturbances.

MULTI-LEVEL INVERTER :

In recent years the Multi-Level Inverters are very popular for Industrial and powers system applications due to their advantages on two-level inverters i.e. High power rating, Low Harmonics so they give the higher efficiency. The different topologies of Multi-Level Inverters are Neutral-point clamped (NPC) or Diode Clamped (DC) inverter, Flying capacitor inverter and Cascade inverter. As the level increases, NPC require more clamping diodes so the control of real power flow becomes very difficult. In flying capacitor inverter as the level increases, number of storage capacitors also increases hence they becomes bulky and costly; there are more switching losses in this topology. A 7-level MLI was generated with 9 switches reducing 3 switches from the main conventional CMLI. It offers good results yielding desired a 7-level output with low THD.

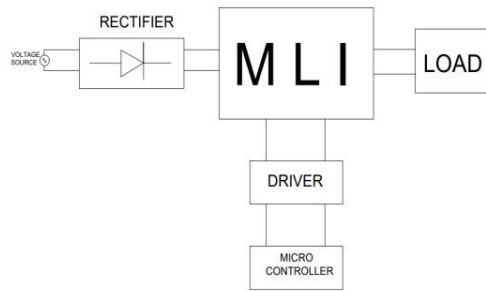


Figure 1: Block Diagram of Multi-level Inverter

DYNAMIC VOLTAGE REGULATOR :

The basic block diagram of a Dynamic Voltage Restorer (DVR) integrated into the power system. The DVR is connected in series with the load through an injection transformer and consists of a Voltage Source Converter (VSC), energy storage unit, passive filters, and a control system. The control system detects voltage disturbances and generates triggering signals to the VSC. The VSC converts the stored DC energy into an AC voltage of the desired magnitude and phase.

This injected voltage, through the series transformer, compensates for voltage sags or swells, ensuring the load receives a stable voltage. A filter is included to eliminate switching harmonics from the VSC, and an impedance element is placed to limit fault currents. This configuration ensures uninterrupted and high-quality power delivery to sensitive loads like Electric Vehicle (EV) fast charging stations.

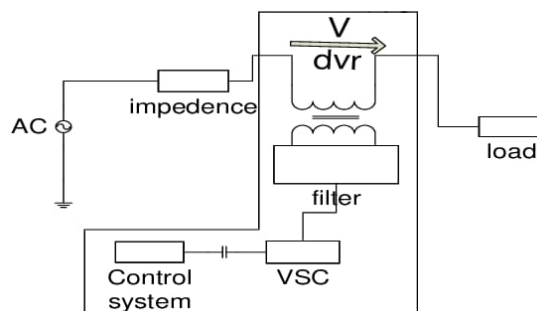


Figure 2: Block Diagram of Dynamic Voltage Restorer

IV. HARDWARE DETAILS :

VOLTAGE REAGULATOR :

This voltage regulator includes three pins namely input pin, ground pin, and output pin. Each pin and its function can be discussed below.

- Pin1 (Input): This is an input pin, where a positive unregulated voltage can be given like an input toward this pin.
- Pin2 (Ground): This is the GND pin where this pin is common to both input & output.
- Pin3 (Output): This is the output pin where the 5V of regulated voltage can be taken at this pin.



Figure 3: Voltage Regulator

PIC MICROCONTROLLER (PIC16F874A/877A) :

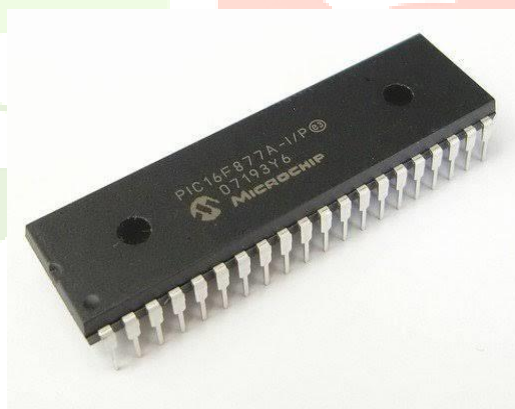


Figure 4: PIC Microcontroller

The core control logic is implemented using a PIC16F877A microcontroller. It is an 8-bit high-performance RISC-based controller with built-in peripherals like timers, ADC, USART, and PWM modules. In this project, it is programmed to detect voltage sags using real-time feedback from voltage sensors and to generate precise PWM control signals for the T-type 7-level inverter. Its low power consumption, cost-effectiveness, and ease of programming make it an ideal choice for embedded DVR applications.

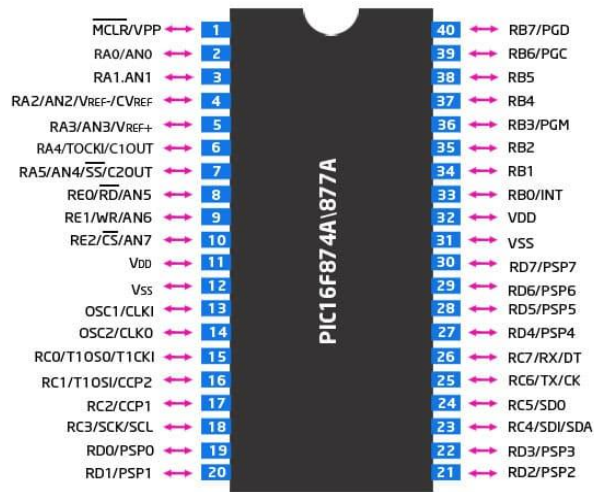


Figure 5: Pin Diagram of PIC16F874A/877A

V. EXPERIMENTAL SETUP :

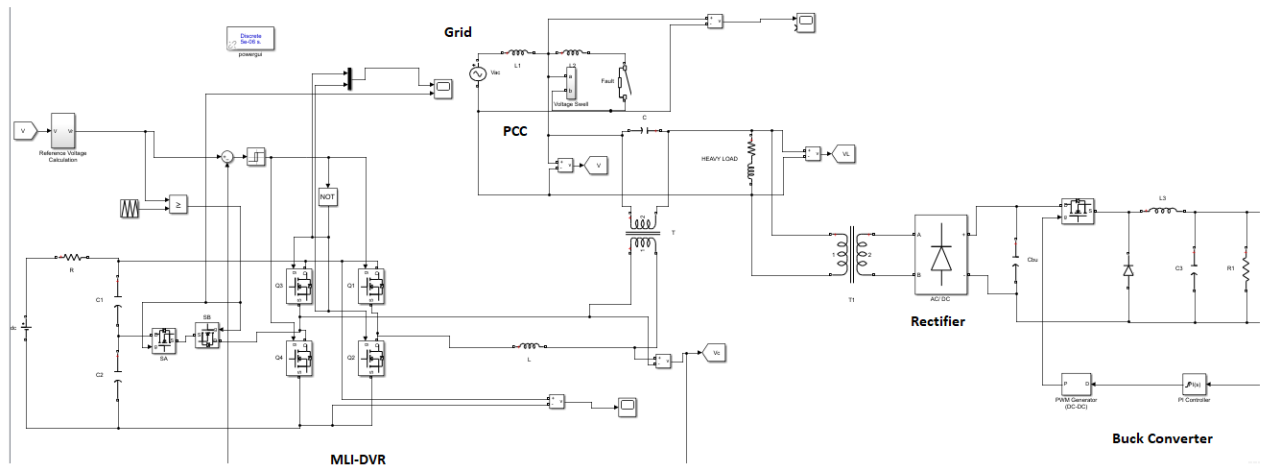
To implement the proposed system practically, an experimental hardware prototype was developed using a PIC microcontroller (PIC16F877A), driver circuit, and power supply unit. The microcontroller was programmed to generate the necessary control signals based on the system requirements. These signals were fed to the driver circuit, which consisted of opto-isolators and driver ICs to provide isolated gate pulses to the power electronic switches.



Figure 6: Hardware Arrangement

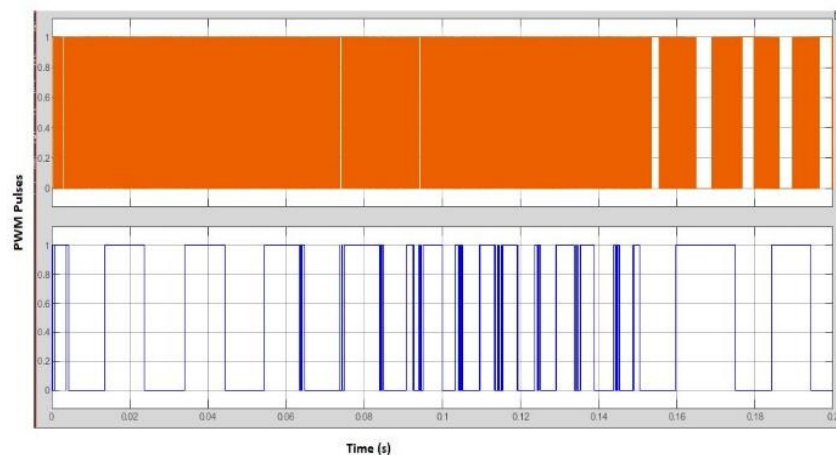
The power supply unit was designed using step-down transformers, bridge rectifiers, and filter capacitors to provide regulated DC voltage to all sections of the hardware. The layout of the hardware was modular, allowing easy identification and testing of each individual block such as control, driver, and output stages.

The experimental setup, as shown in Figure 6, was used to validate the performance of the proposed system under practical operating conditions. The results obtained from this hardware implementation were found to be in good agreement with the simulated results, confirming the effectiveness and reliability of the proposed model.

SIMULATION :**Figure 7: Simulation Diagram**

The above simulation diagram illustrates the working model of the proposed system developed using MATLAB. It consists of key components such as the Multilevel Inverter (MLI), Dynamic Voltage Restorer (DVR), grid connection, and Electric Vehicle (EV) fast charging station. Each block represents a specific functional unit that performs a defined task in the power quality improvement process.

The DVR is placed between the grid and the load to compensate for voltage disturbances such as sags and swells, while the MLI is used to enhance the quality of voltage supplied to the EV charging station. Control blocks are implemented to monitor the system parameters and generate appropriate gate pulses for the power electronic switches. This simulation helps in validating the performance and effectiveness of the proposed system under various fault conditions and load demands.

**Figure 8: Waveform for PWM Pulses**

The waveform shown represents the Pulse Width Modulation (PWM) pulses generated for the switching devices in the Multilevel Inverter (MLI). These gate pulses are produced based on the comparison of a reference sine wave and carrier signals, enabling precise control over the output voltage. The PWM technique ensures better harmonic reduction and improved voltage quality, which is essential for driving sensitive loads and enhancing the performance of the DVR.

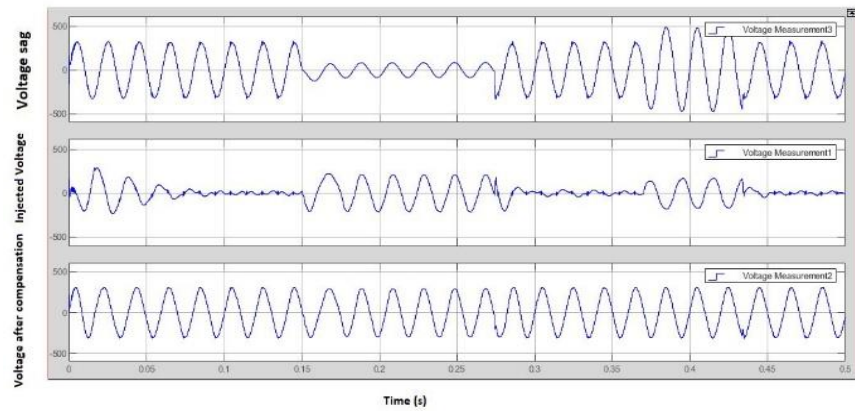


Figure 9: Waveform for Voltage Sag Compensation

This waveform illustrates the voltage sag compensation capability of the Dynamic Voltage Restorer (DVR). Initially, a voltage sag is observed at the load side, simulating a power quality disturbance from the grid. As the DVR is activated, it injects the required compensating voltage in series, thereby restoring the voltage to its normal value. This confirms the effectiveness of the DVR in maintaining a stable voltage supply during disturbances.

OUTPUT :

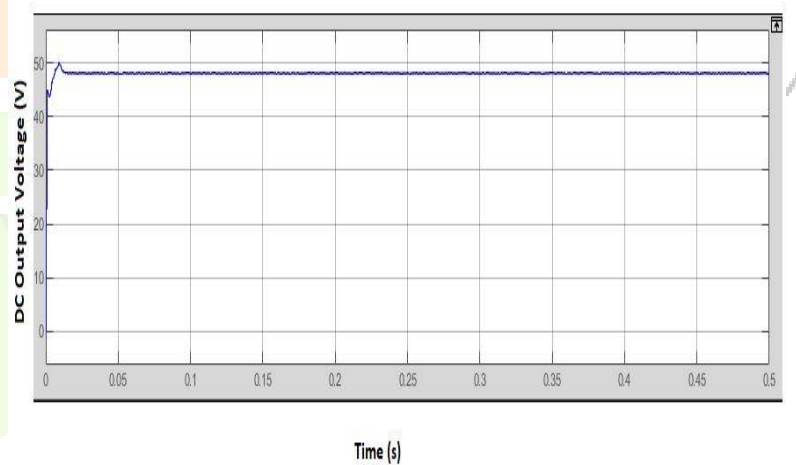


Figure 10: Waveform for DC Output Voltage

The DC output voltage waveform represents the voltage generated from the DC source, which is used to power the inverter and DVR system. A stable and regulated DC voltage is crucial for maintaining the overall efficiency and performance of the system. This waveform indicates a steady DC voltage level, confirming the reliable performance of the DC link in the proposed model.

VI. CONCLUSION :

The proposed MLI-Based DVR in Grid-Fed EV Fast Charging Stations (EVFCS) effectively enhances power quality, ensuring uninterrupted and stable charging operations. By addressing voltage sag and harmonic distortions, the system significantly improves the reliability and efficiency of EV charging infrastructure.

Key findings from the study include:

- Mitigation of Voltage Sag:
 - A current-controlled buck converter effectively compensates for 25% sag, stabilizing the charging voltage.
 - A voltage-controlled T-type 7-level DVR successfully mitigates 50% sag, ensuring optimal grid stability.
- Harmonic Reduction at the PCC:
 - The DVR actively filters out voltage harmonics generated by EVFCS, protecting the Point of Common Coupling (PCC) and maintaining grid integrity
- Enhanced Power Quality and Efficiency:
 - The use of a multilevel inverter (MLI) in DVR design reduces Total Harmonic Distortion (THD) and improves the overall power factor.

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