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Research

THREE-LEG, STANDBY CONVERTER-BASED SINGLE-PHASE TRANSFORMERLESS UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT

This paper proposes a transformer less single-phase to single-phase unified power quality conditioner (UPQC) based on three-leg and standby converters. The system consists of a two-leg module series connected to a three-leg module; the control system offers shunt and series compensation and can be designed to operate with a high modulation index under rated conditions and voltage sag events; additionally, a low standby power consumption and a new decoupling method to compensate voltage swells using the two-leg module. In comparison to the conventional solution, the proposed converter shows lower semiconductor losses and reduced waveform harmonic distortion, while retaining the same or better operational features, such as the elimination of circulating currents and line-frequency transformers.

Keywords: Unified power quality conditioner, power quality, standby converter, three-leg converter

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I INTRODUCTION

Various dc–ac, ac–dc, and ac–dc–ac converter topologies have been reported in the literature to mitigate power quality (PQ) issues such as voltage sags, swells, harmonic distortion, and reactive power demand. Among these solutions, the unified power quality conditioner (UPQC) has gained significant attention due to its capability to provide simultaneous series and shunt compensation through a common dc-link, resulting in improved performance and reduced system size. In single-phase applications, the transformerless three-leg UPQC is widely adopted owing to its reduced switch count and absence of circulating currents. However, it exhibits limitations under voltage swell conditions, requiring a higher dc-link voltage and operating with a reduced modulation index, which increases losses and distortion. To address these challenges, the proposed configuration introduces an enhanced decoupling strategy that eliminates load dependency, improves steady-state performance, and validates its effectiveness through comprehensive analytical, simulation, and experimental investigations.

II LITERATURE SURVEY

Power quality improvement has become a major research focus due to the increasing use of nonlinear loads and renewable energy integration in modern distribution systems. The Unified Power Quality Conditioner (UPQC) has been widely studied as an effective solution to mitigate voltage sag, swell, harmonics, and reactive power issues simultaneously. Early developments of UPQC structures primarily relied on transformer-based configurations, which provided electrical isolation and voltage matching but increased system size, cost, and power losses.

To overcome these drawbacks, transformerless UPQC topologies were introduced. Khadkikar (2012) presented a comprehensive overview of UPQC structures and highlighted their capability to enhance power quality by combining series and shunt active filters. However, conventional transformerless three-leg UPQC (3L-UPQC) structures suffer from limitations such as high dc-link voltage requirements during voltage swell conditions and reduced modulation index operation under rated conditions. These constraints increase semiconductor stress and reduce overall efficiency.

Subsequent research focused on improving dc-link voltage utilization and reducing semiconductor losses. Various decoupling control strategies and modified converter topologies were proposed to enhance voltage compensation capability. However, many of these approaches still required continuous high dc-link voltage during voltage disturbances, leading to increased switching losses and thermal stress. Moreover, in several reported systems, the required dc-link voltage was dependent on load power factor and harmonic content, limiting flexibility in practical applications.

Recent studies explored the integration of auxiliary or standby converters to improve system performance during voltage swell events. Although these approaches enhanced compensation capability, they often increased control complexity and hardware requirements.

Furthermore, maintaining high efficiency during normal operating conditions remained a challenge.

Therefore, there exists a need for a transformerless UPQC configuration that can (i) operate with high modulation index under rated and sag conditions, (ii) compensate large voltage swells without continuous high dc-link voltage, (iii) reduce semiconductor losses, and

(iv) eliminate load dependency in dc-link design. The proposed SB-3LG-UPQC topology addresses these research gaps by integrating a three-leg converter with a two-leg standby module and employing an effective decoupling control strategy to enhance overall system performance.

III EXISTING SYSTEM

The existing single-phase transformer-based Unified Power Quality Conditioner (UPQC) using a three-leg voltage source converter is designed to mitigate power quality problems such as voltage sag, swell, harmonics, and reactive power issues in distribution systems. In this configuration, the system consists of a series converter and a shunt converter connected through a common DC-link capacitor. The series converter is interfaced with the supply line through an injection transformer and is responsible for compensating voltage-related disturbances by injecting the required voltage into the line. The shunt converter is connected in parallel with the load and compensates current harmonics, supplies reactive power, and regulates the DC-link voltage. The three-leg converter topology improves DC-link balancing and control flexibility compared to traditional two-leg configurations. However, in conventional existing systems, standby converter support is either absent or not properly coordinated, which limits fault tolerance and system reliability. Additionally, the use of an injection transformer increases system size, cost, and power losses. Although the existing system effectively improves power quality under normal operating conditions, its performance and robustness decrease during severe disturbances and fault condition.is shown in below circuit diagram.

CIRCUIT DIAGRAM:

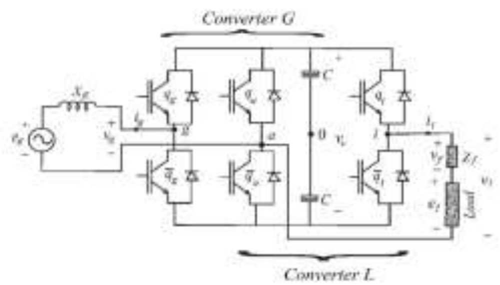


Fig (1): Transformer Unified Power Quality Conditioner Based on Three-Leg and Standby Converters

IV PROPOSED SYSTEM

In addition to offering shunt and series compensation, the suggested control system may be built to function with a high modulation index under rated settings and voltage sag occurrences. Furthermore, a low standby power consumption and a novel decoupling technique that uses the two-leg module to adjust for voltage swells are suggested. The suggested converter has lower semiconductor losses and less waveform harmonic distortion than the conventional solution, but it still has comparable or better operational characteristics, such as the ability to compensate for voltage swell and the removal of circulating currents and line-frequency transformers. The control system approach, the applied standby idea, the scalar PWM technique, and the system model are all covered.

SIMULINK DIAGRAM

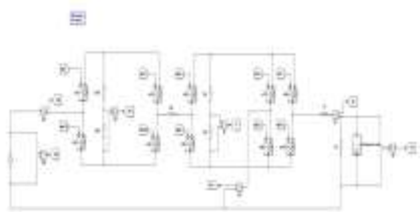
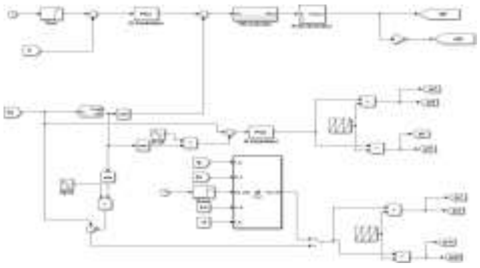


Fig (2): MATLAB/SIMULINK circuit of the

Proposed single-phase ac-dc-ac SB-3LG-UPQC converter



Fig(3): Control System

V RESULTS

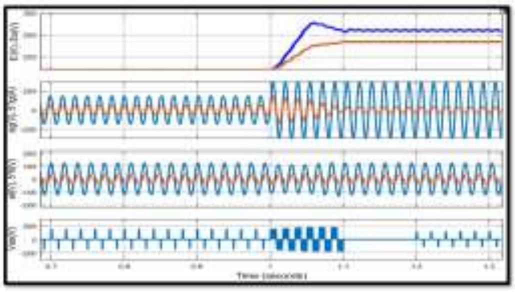


Fig (4): Simulation results with voltage swell transient. Transient caused by a grid voltage swell of 50%

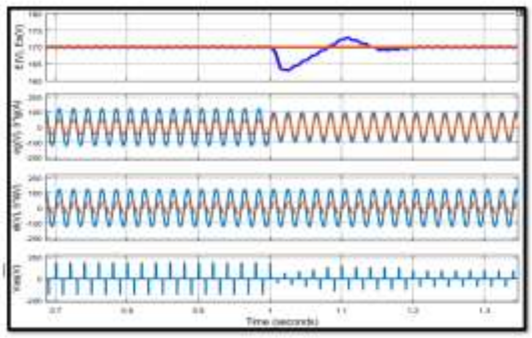
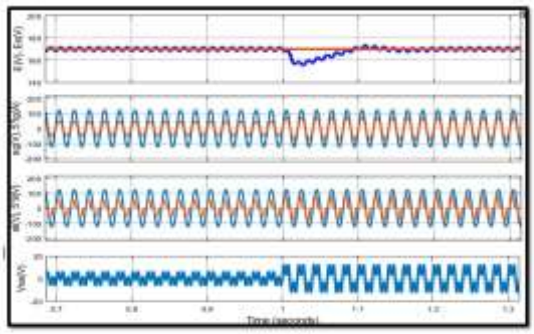


Fig (5): Simulation results with voltage sag transient. Transient caused by a grid voltage sag of 30%.



Fig(6): Simulation results with step in the load power. Transient caused by a increase in the load power from Sl = 0.8kVA to Sl = 1.6kVA.

The behavior of the SB-3LG-UPQC configuration running under rated voltage and with 50% voltage swell is shown in Figure (4). On the grid side, the converter runs at unity power factor under rated conditions (t = 0.7 s to 1 s). Additionally, there is compensation for the load voltage el. 50% of the voltage swell is supplied to the system at t = 1.0s. In order to balance the input voltage of the three-leg module (e′), the two-leg module now begins to function as a series active filter (see A transient brought on by a load power increase from Sl = 0.8kVA to Sl =1.6kVA is seen in Figure (5). The dc-link voltage may be regulated since an increase in load current causes an increase in grid current. (Vses). In order to manage the voltage swell, the three-leg module's dc-link reference voltage (E∗) is adjusted simultaneously. The two-leg module returns to standby mode when the voltage E reaches its new reference value. The behavior of the suggested converter at 30% voltage sag is shown in Figure(5). Observe how the series converter voltage (Vse) guarantees the voltage amplitude required to correct the load voltage el at the beginning of the disturbance (t = 1 s). seeing that because the grid current is kept under control during the transient, the dc-link voltage is maintained. A transient brought on by a load power increase from Sl = 0.8kVA to Sl = 1.6kVA is seen in Figure (6). The dc- link voltage may be regulated since an increase in load current causes an increase in grid current.

VI CONCLUSION

The proposed transformerless single-phase Unified Power Quality Conditioner (UPQC) based on three-leg and standby converters presents a significant advancement over conventional three-leg transformerless UPQC structures. By integrating a two-leg standby module with a three-leg converter, the system successfully overcomes key limitations related to dc-link voltage dependency, low modulation index operation, and inefficient voltage swell compensation. Unlike conventional configurations, the proposed SB-3LG-UPQC operates with a high modulation index under rated and voltage sag conditions, while the two-leg module remains in low-power standby mode, thereby reducing switching losses and improving overall efficiency. During voltage swell events, the standby converter temporarily functions as a series active filter, enabling compensation of up to 100% grid voltage swell without requiring continuous high dc-link voltage operation. The decoupling method introduced eliminates dependence on load power factor and harmonic content for dc-link voltage design, ensuring stable performance under varying load conditions. Steady-state and experimental results confirm reduced semiconductor power losses, lower total harmonic distortion (THD), smaller AC filter requirements, and improved efficiency compared to the conventional 3L-UPQC. Furthermore, the simplified control strategy using PI and PR controllers along with hysteresis- based standby regulation enhances system robustness and dynamic response during sag, swell, and load transients. Overall, the proposed topology offers a compact, efficient, and technically superior solution for single-phase power quality improvement applications, making it highly suitable for modern distribution systems and sensitive load environments.

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