

A Novel Multilevel THSeAF-Based System for Power Quality Improvement in Smart Homes

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ABSTRACT:

In this project a multilevel transformer less hybrid series active filter is proposed to enhance the power quality of a single-phase residential household. The proposed topology reflects new trends of consumers toward electronic polluting loads and integration of renewable sources which in fact may lead to the scope of a reliable and sustainable supply. This project contributes to improvement of power quality for a modern single phase system and emphasis integration of a compensator with energy storage capacity to ensure a sustainable supply. A proportional resonant (P+R) regulator is implemented in the controller to prevent current harmonic distortions of various non-linear loads to flow into the utility. The main significant features of the proposed topology include the great capability to correct the power factor as well as cleaning the grid

simultaneously, while protecting consumers from voltage disturbances, sags, and swells during a grid perturbation. It investigates aspects of harmonic compensation and assesses the influence of the controller's choice and time delay during a real-time implementation. Simulation of with THSeAF and multilevel THSeAF system is developed in this project. Results of various systems are to be verified in MATLAB/SIMULINK environment.

Index Terms—Hybrid active filters, power quality, renewable energy sources, multilevel converters, smart grids, real-time control, resonant controller, nonlinear loads.

I.INTRODUCTION

The growing trends toward implementing smart grids and the increasing use of nonlinear loads from industrial, commercial, and residential sources have significantly increased harmonic distortions in power systems, raising concerns about power quality. The proliferation of electronics and devices with fast charging and external power supplies, as shown in Fig. 1, requires

investigating solutions for harmonics and reactive power compensation. The widespread use of harmonic generating devices reduces system efficiency and causes detrimental voltage distortion. Distorted current waveforms also create additional heating losses and can lead to failures in sensitive electrical equipment. While previous research has examined specific cases of voltage distortions or current harmonics, new challenges remain for power electronics to mitigate electrical pollution and enhance grid reliability. This paper proposes an affordable solution using a multilevel converter configuration that reduces dc voltage for low-voltage distribution systems. This device facilitates integrating energy storage and renewables in modern households without requiring a bulky series transformer, thereby providing a cost-effective way to improve power quality on future grids. The multifunctional compensator filters the current drawn from the utility to supply households with clean, reliable power despite increasing harmonic pollution from nonlinear loads.

The proliferation of electric vehicles and renewable energy sources in residential neighborhoods necessitates monitoring their power quality impact on the grid. This work proposes an efficient transformer less hybrid series active filter (THSeAF) to mitigate current issues in micro grid applications. The THSeAF

sustains reliable voltage at the point of common coupling (PCC) where residential loads connect, despite harmonic distortions from EVs and renewables.

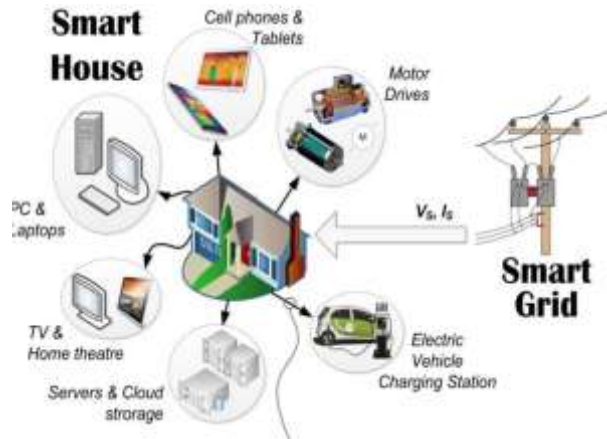


Fig 1.1 Typical modern residential consumer with non-linear electronic loads

It injects or absorbs active power to regulate voltage during fluctuations, ensuring quality supply. The main contribution is a control algorithm for the THSeAF to identify and filter voltage and current harmonics. First, the operating principle of the proposed THSeAF configuration is introduced. Next, its control scheme is modeled and analyzed. Finally, the harmonic detection method is described in detail. This addresses power quality challenges of integrating EVs and renewables in micro grids.

II.SYSTEM CONFIGURATION

The THSeAF shown in Fig. 2.1 is composed of an H-bridge converter connected in series between the source and the load. A shunt passive capacitor ensures a low impedance path for current harmonics. A dc auxiliary source could be connected to inject power during voltage sags. The dc-link energy storage system is described. The system is implemented for a rated power of 2200 VA. To ensure a fast transient response with sufficient stability margins over a wide range of operation, the controller is implemented on a dSPACE/dsp1103. The system parameters are identified in Table I. A variable source of 120 Vrms is connected to a 1.1-kVA nonlinear load and a 998-VA linear load with a 0.46 PF.

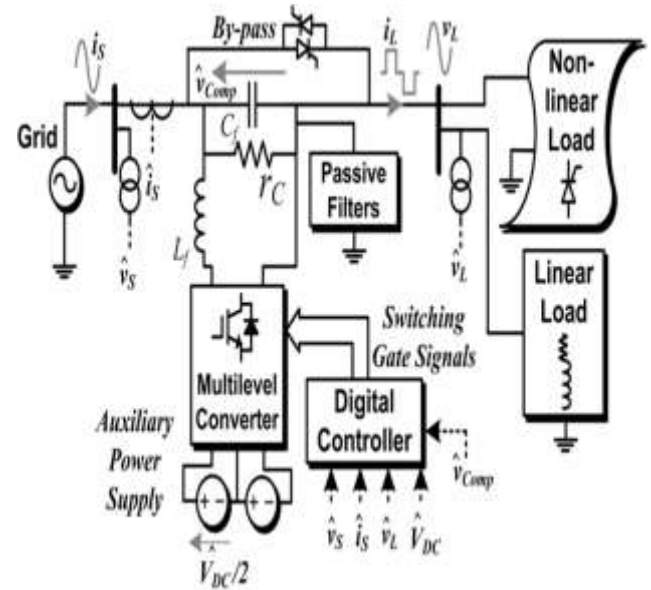


Fig 2.1. (a) Schematic of a single-phase smart load with

the compensator installation.(b) Electrical diagram of the THSeAF in a single-phase utility.

The THSeAF is connected in series in order to inject the compensating voltage. On the dc side of the compensator, an auxiliary dc-link energy storage system is installed. Similar parameters are also applied for practical implementation.

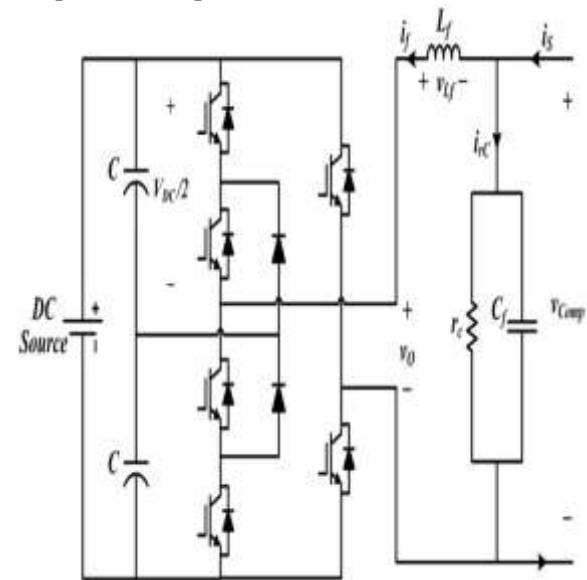


Fig.2.2 Hybrid converter topology for the proposed series compensator.

III. Operation Principle

The SeAF represents a controlled voltage source (VSI). In order to prevent current harmonics i_{Lh} to drift into the source.

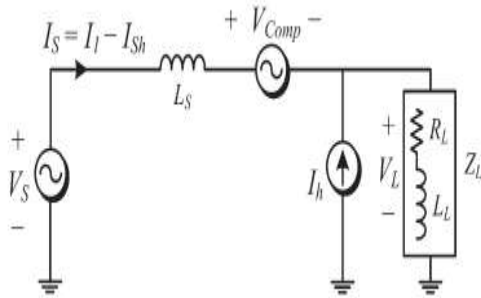


Fig. 3.1. THSeAF equivalent circuit for current harmonics.

This series source should present low impedance for the fundamental component and high impedance for all harmonics as shown in Fig. 3. The principle of such modeling is well documented in [20]. The use of a well-tuned passive filter is then mandatory to perform the compensation of current issues and maintaining a constant voltage free of distortions at the load terminals. The behavior of the SeAF for a current control approach is evaluated from the phasor's equivalent circuit shown in Fig. 3.1 The nonlinear load could be modeled by a resistance representing the active power consumed and a current source generating current harmonics. Accordingly, the impedance Z_L represents the nonlinear load and the inductive load. The SeAF operates as an ideal controlled voltage source (V_{comp}) having a gain (G) proportional to the current harmonics (I_{sh}) flowing to the grid ($V_s = G \cdot I_{sh} - V_{Lh}$). (1) This allows having individual equivalent circuit for the fundamental and harmonics

$$V_{source} = V_{s1} + V_{sh}, V_L = V_{L1} + V_{Lh}. \quad (2)$$

The source harmonic current could be evaluated

$$V_{sh} = -Z_s \cdot I_{sh} + V_{comp} + V_{Lh} \\ V_{Lh} = Z_L (I_h - I_{sh}). \dots (4)$$

Combining (3) and (4) leads to (5)

$$I_{sh} = \frac{V_{sh}}{(G - Z_s)} \quad (5)$$

If gain G is sufficiently large ($G \rightarrow \infty$), the source current will become clean of any harmonics ($I_{sh} \rightarrow 0$). This will help improve the voltage distortion at the grid side. In this approach, the THSeAF behaves as high-impedance open circuit for current harmonics, while the shunt high-pass filter tuned at the system frequency creates a low-impedance path for all harmonics and open circuit for the fundamental; it also helps for PF correction.

IV. Simulation Block Diagrams:

The compensator shown in Fig. 4.1 consists of a multilevel single-phase converter connected in series

between the utility and the building's entrance terminals. This transformerless hybrid series active filter uses a five-level NPC converter connected between the utility and building entrance. An auxiliary supply connects to the DC side. A passive filter at the converter output filters high frequency switching harmonics. Tuned passive filters provide a low impedance path for current harmonics.

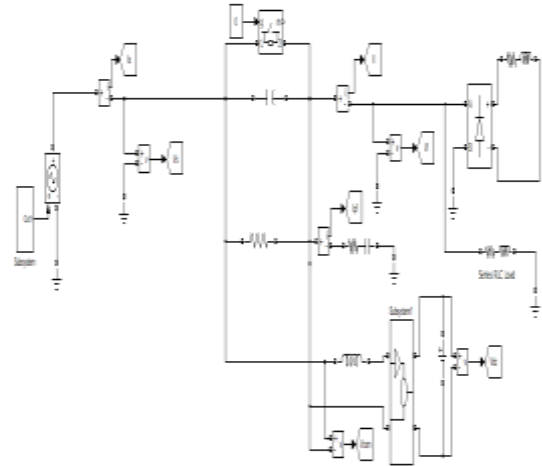


Fig 4.1 Simulation diagram with controller

V. RESULTS

Compensator regulates the load voltage magnitude by injecting active power while compensating current and harmonics and correcting the PF. Experimented results illustrate high fidelity towards simulations. During a grid's voltage sags, the compensator regulates the load voltage magnitude, compensates current harmonics and corrects the power factor as shown in Fig 5.1

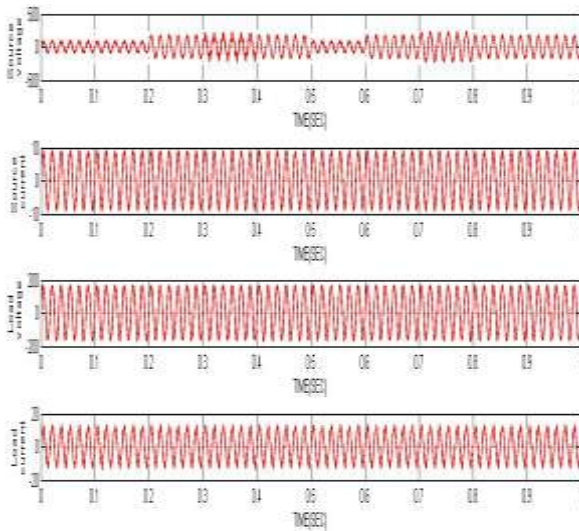


Fig 5.1 System response during grid sags and swells. (a) Source voltage v_S , (b) source current i_S , (c) load voltage v_L

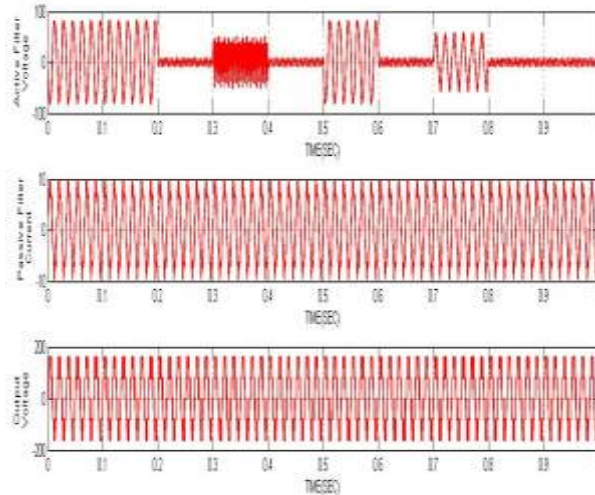


Fig 5.2(e) active-filter voltage V_{Comp} , (f) Harmonics current of the passive filter i_{PF} , (g) Converter's output voltage V_{Out} .

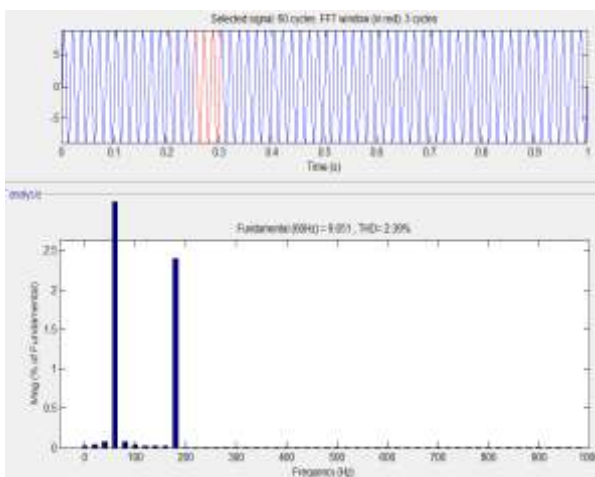


Fig6.3:THD graph

CONCLUSION

This paper developed and tested a transformer less harmonic selective active filter (THSeAF) to improve power quality. The research highlighted that with the increasing use of nonlinear loads and rising consumer demand for reliable electricity, concrete actions should be considered for future smart grids to smoothly integrate electric vehicle chargers. A key novelty of the proposed THSeAF is its ability to compensate a wide range of harmonic currents, thereby generally improving power quality despite specifically regulating the point of common coupling voltage. When connected to a renewable auxiliary source, the topology can actively counteract power flow, an essential capability for supplying critical loads consistently. By behaving as a high-harmonic impedance, it cleans the power system and ensures unity power factor. The theoretical modeling of the proposed configuration was investigated, with the multilevel THSeAF reducing total harmonic distortion compared to THSeAF based system in simulations. Without the usual bulky and costly series transformer, this active compensator responded properly to source voltage variations by providing a constant, distortion-free supply at load terminals while eliminating source harmonic currents.

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