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Integrating Renewable Energy into Hybrid Grids: A Fuel Cell-Based Interlinking Converter Approach

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Abstract
This paper presents an innovative interlinking converter architecture designed for hybrid grids, facilitating the integration of renewable energy sources in a versatile manner. The proposed converter features one AC port and two DC ports, offering flexibility in connecting a wide range of DC and AC power sources. Its configurable options include DC-DC, DC-AC inverter, and DC-DC/AC multiport configurations, enabling diverse applications. The letter provides an overview of the design, analysis of common mode voltage, and description of operational modes. To validate the converter's performance with a tailored modulation strategy, comprehensive tests were conducted, demonstrating its capability for flexible conversion, high-power density, low leakage currents, and controllable power flow.

Keywords: Power converters, renewable energy integration, Hybrid DC/AC grid, flexibility, leakage current, Fuel Cell

I. INTRODUCTION

In spite of their potential, RENEWABLE ENERGY SOURCES (RES) like wind, photovoltaic (PV), and fuel cells are met with widespread skepticism. Our increasing reliance on renewable energy sources may put a pressure on the electrical infrastructure as a whole. For a more adaptable, secure, and reliable power supply, as well as one that can accommodate a greater number of RES systems, an AC/DC hybrid grid remains the primary concept [1]. As a result, increasing the efficiency of energy conversion and self-consumption [2, 3] can be accomplished by allowing a large number of DC generation RESs to be consumed flexibly by local loads. Further, intelligent power conversion and near-zero energy building initiatives [4, 5] can work with this hybrid grid design. The majority of the current literature is concerned with power management and control in hybrid AC/DC grids. The basics of hybrid micro grids, such as their design, modes of operation, power management, and control, are outlined in references such as [6]. Because of rising modern DC loads and renewable energy sources (RES) that can be combined with energy storage, the hybrid microgrid is becoming a more viable option. Positive characteristics of the connecting converter are essential for incorporating alternative energy sources into the grid (such as reliability, manageability, and stability). Power-sharing strategies were developed to ensure continued operation when connecting converters under varying conditions [6]. Despite the potential for interconnected converters to significantly boost the efficiency of hybrid energy systems, little research has been conducted in this area. That they would all function better with a converter that accepts a wide range of inputs and outputs is only logical (e.g., DC ports and AC ports).

You can do this by creating custom multiport configurations [7]–[13] or by assembling a multistage conversion system out of standard DC-DC and DC-AC converters [6]. Single-node hybrid topologies have many advantages over the previous approach (owing to their increased reliability, higher power density, and lower system cost due to the reduced number of

conversion stages). Split-source inverters, for instance, were created to improve small size, high efficiency, flexible power flow, and voltage enhancement, but they could not tackle the leakage current problem [9, 10]. To put it simply, this is a major problem for PV systems. To lessen leakage currents, you can utilise converters [12], [13] without an internal trans formator, however they can only handle one direction of power. In contrast to the advantages of stand-alone hybrid converters, the poor power density produced by a dual-buck inverter is a direct result of the need for large AC filter inductors [12].
In AC/DC hybrid grids, the state-of-the-art converters can only be employed for a single step of conversion. From what has been said, it appears that the author of this letter is advocating for a connecting conversion architecture as a practical method of incorporating RES into hybrid grids. Given its high dependability, simple implementation, and adaptability, it is a viable alternative. Section II discusses the pros and cons of an alternative architecture in which the boost converter's power device is replaced by an active switch and a voltage source inverter. Power density, leakage current suppression, and system efficiency are all enhanced by the use of a symmetrical impedance network. A specialized modulation scheme is demonstrated to efficiently improve power quality and permit for more adaptable control [14].

II. METHODOLOGY

Fuel cell

Two DERs, PEMFC and PV, are considered DGs in this research. PEMFC and PV have high benefits and growth potential in the power sector. Detailing modelling and simulation results.

PEM Fuel Cell Introduction (PEMFC)

Fuel cells have gained attention in the past decade and may be the future power source. Electrochemical fuel cells convert chemical energy into DC electricity. All fuel cells have two electrodes (Anode and Cathode) and an electrolyte (a membrane). Electrons are transferred from the anode to the cathode via an external conductor, where they are responsible for reducing the oxidant and producing electricity. FC can produce energy as long as fuel and oxidant are supplied to the electrodes.
Increasing the voltage of a single fuel cell requires connecting multiple fuel cells in series. When compared to conventional alternatives like gasoline-powered cars and rechargeable batteries, fuel cells come out on top.

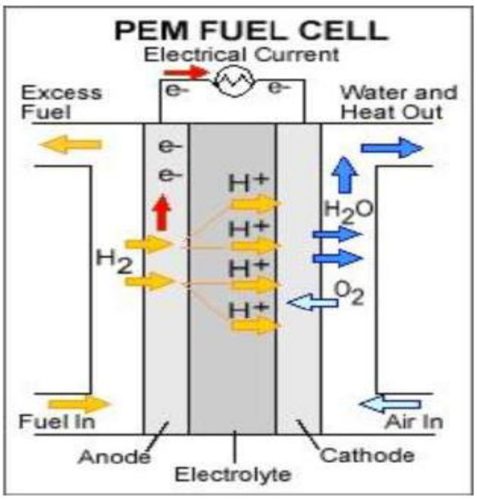

Figure 1: Basic Scheme of PEMFC

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Working of Fuel Cell
Electrical power can be produced by fuel cells by combining hydrogen and oxygen. During the Apollo program, this type of cell provided both water and fuel.
A solution of sodium hydroxide was used to conduct the hydrogen and oxygen from carbon electrodes. Cell reaction:

- Cathode Reaction: $O2 + 2H2O + 4e– \rightarrow 4OH–$
- Anode Reaction: $2H2 + 4OH– \rightarrow 4H2O + 4e–$
- Net Cell Reaction: $2H2 + O2 \rightarrow 2H2O$

Electrochemical reactions are slow. Platinum or palladium catalysts solve this problem. Finely dividing the catalyst before adding it to the electrodes increases the surface area.

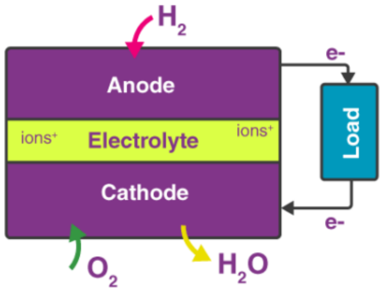

Figure 2: A block diagram of this fuel cell

As seen in Fig. 3, the suggested hybrid grid interlinking converter architecture is shown. The converter is depicted in Figure 3 to have two DC inputs and an AC output. The low-voltage direct current (DCL) side can consist of photovoltaic panels, batteries, or some other RES, while the high-voltage direct current (DCH) side can be a direct current (DC) grid or DC loads. In both power grids and loads, AC is the norm. It is recommended that any power conversions put forward be two-way for maximum adaptability. The following proves it:

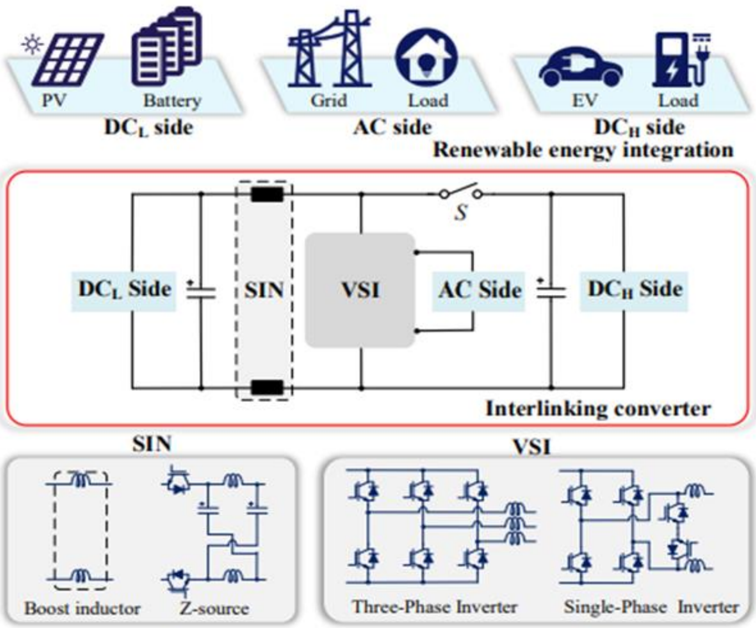

Figure 3: S represents an active switch allowing bidirectional power flow in the proposed interlinking converter architecture.

Hybrid systems

One example of a hybrid system is one that uses both conventional photovoltaics and concentrated solar power, or (C)PV and CSP, in addition to other power sources like diesel, wind, or biogas. With this hybrid approach, it's possible that the system's power output can be adjusted in response to changes in demand, mitigating the intermittent nature of solar energy and cutting down on the use of fossil fuels. Most island communities use hybrid structure.

MICRO GRID

Microgrids are small-scale electrical networks that can disconnect from the larger, centralised electrical grid (macro grid) and operate independently when necessary (due to physical or economic factors). In this way, distributed generation (DG), especially renewable energy sources, can be effectively integrated (RES). It can switch between islanded mode and grid-connected mode for emergency power. Control and protection are big challenges.

Figure 4: Common microgrid design using grid-connected renewables

Photovoltaics

Cells that use the photovoltaic effect to convert sunlight into electricity are known as solar cells or photovoltaic cells (PV). Charles Fritts developed the first practical solar cell in the 1880s. Ernst Werner von Siemens, a commercial tycoon in Germany, was among many who immediately recognised the significance of this finding. After the prototype selenium cells developed by German engineer Bruno Lange in the early 1900s converted less than one percent of incident light into electricity, silver selenide was developed as a replacement for copper oxide in 1931. Developing on Russell Ohl's work from the 1940s, silicon solar cells were invented in 1954 by Gerald Pearson, Calvin Fuller, and Daryl Chapin. These first-generation solar cells had an efficiency of 4-6% and a cost of $286 USD per watt to generate electricity in the United States.

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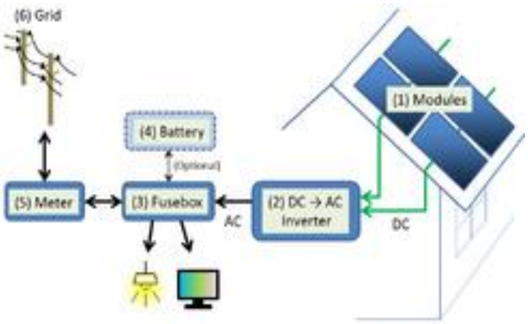

Figure 5: PV system layout showing grid connection.

III. RESULTS & DISCUSSION

To realise the proposed architecture, the boost converter's power devices are swapped out for a voltage source inverter (VSI) and an active switch. With the suggested interconnected conversion architecture, we can achieve low leakage currents, good power quality, high efficiency, and flexible power flow control.

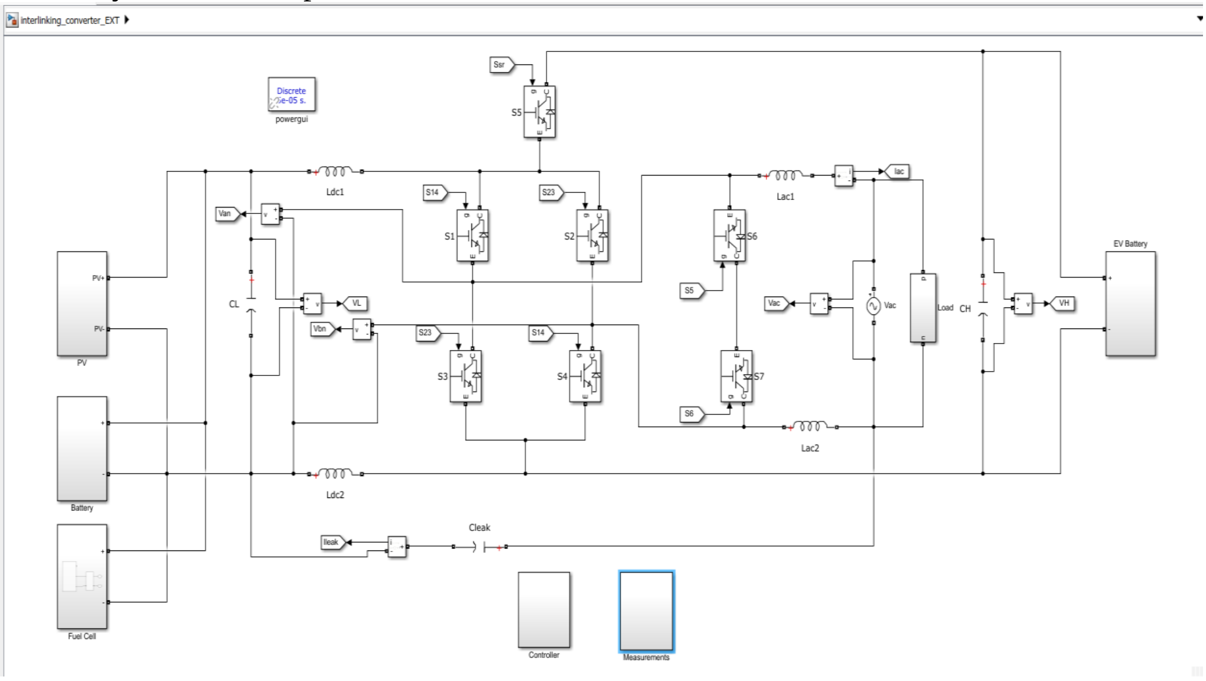

Figure 6: Proposed Simulink with Normal operation

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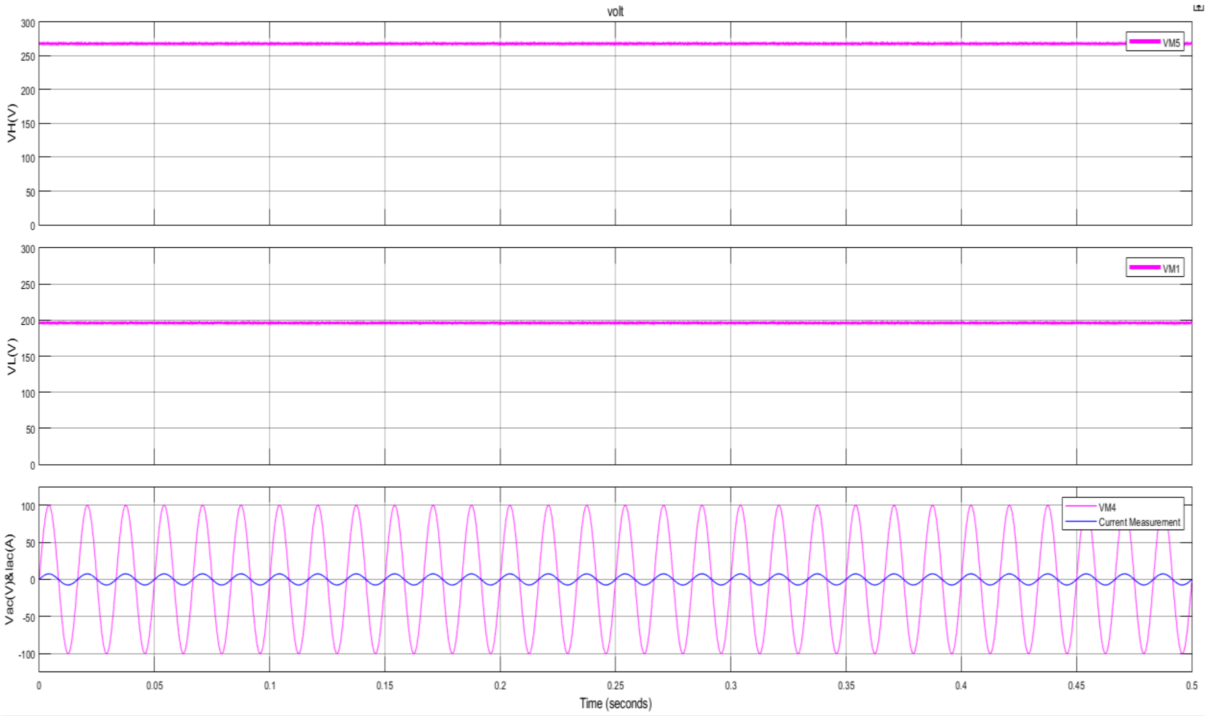

Figure 7: Interlinking converter performance with Mode-1 VSI.

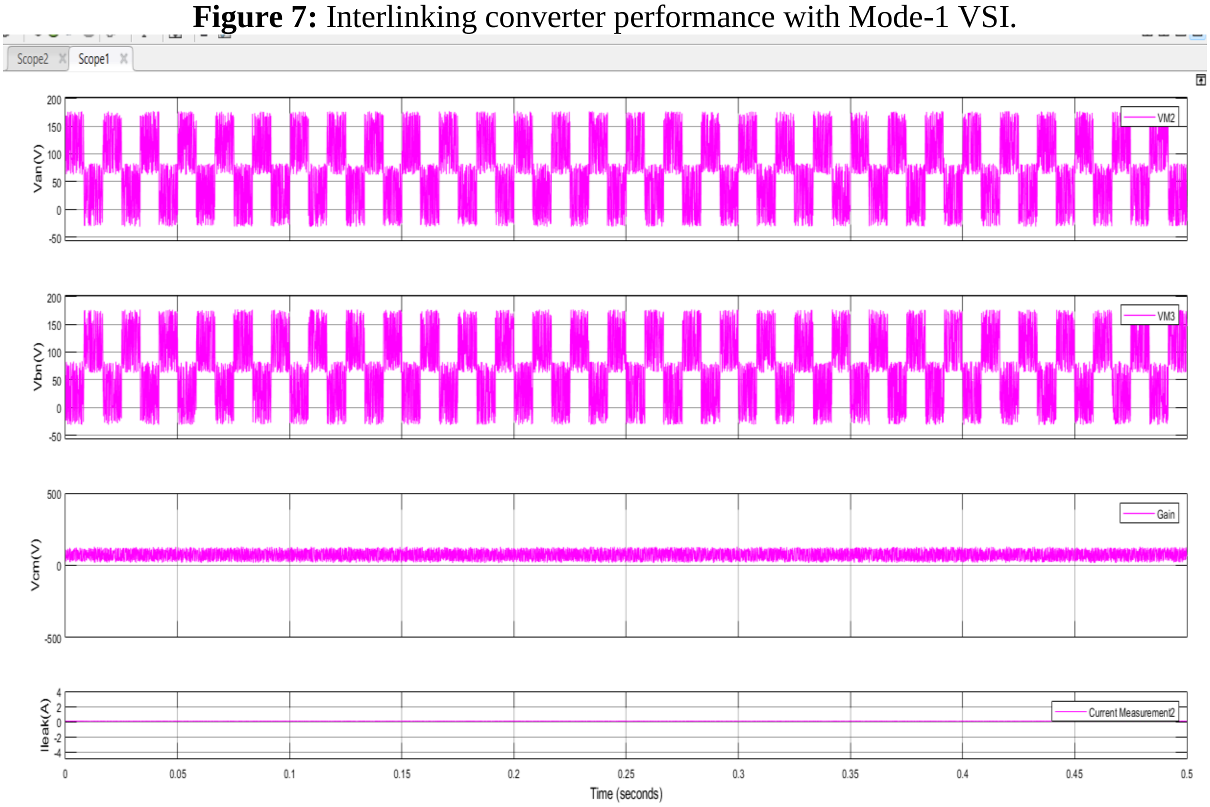

Figure 8: vAN and vBN are the terminal A and B to N voltages, and vcm and ileak are the CMV and leakage current.

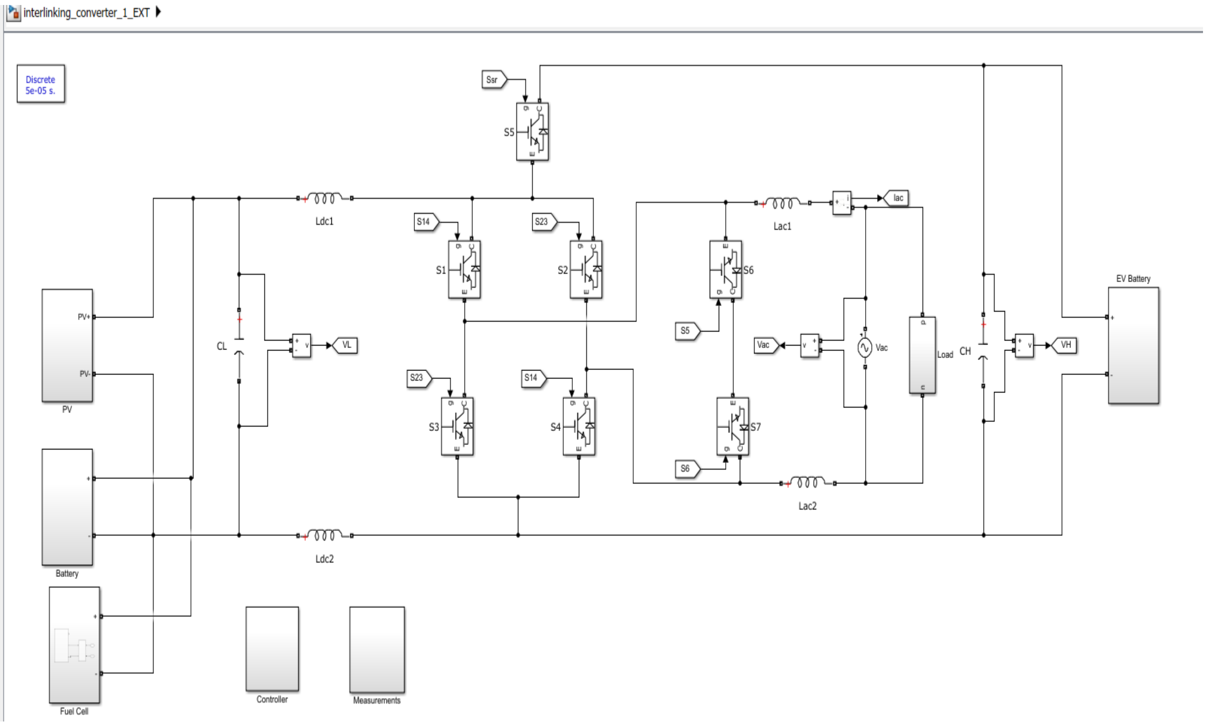

Figure 9: Proposed Simulink Under load condition

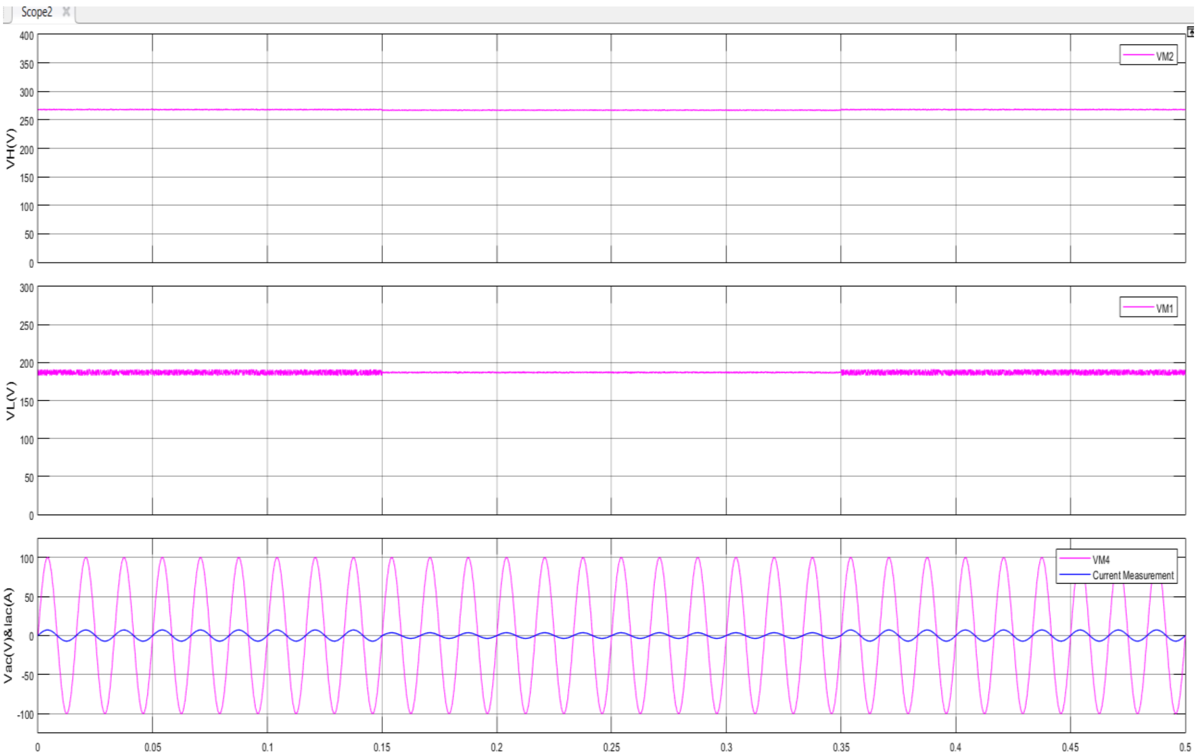

Figure 10: The proposed interlinking converter's Mode1 load step response.

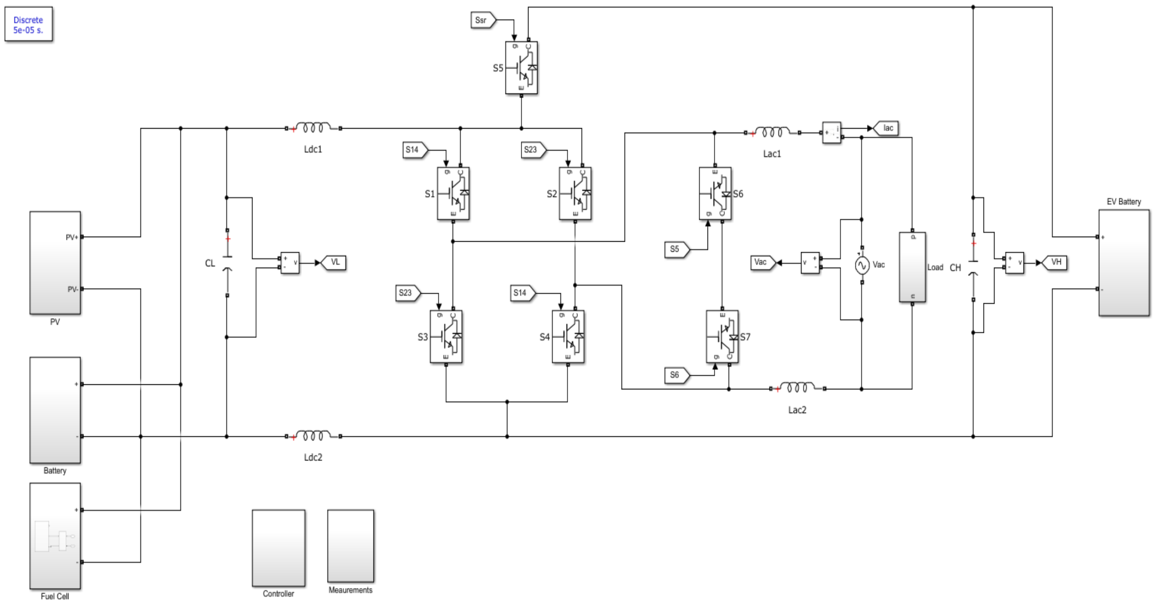

Figure 11: Proposed Simulink Under lagging condition

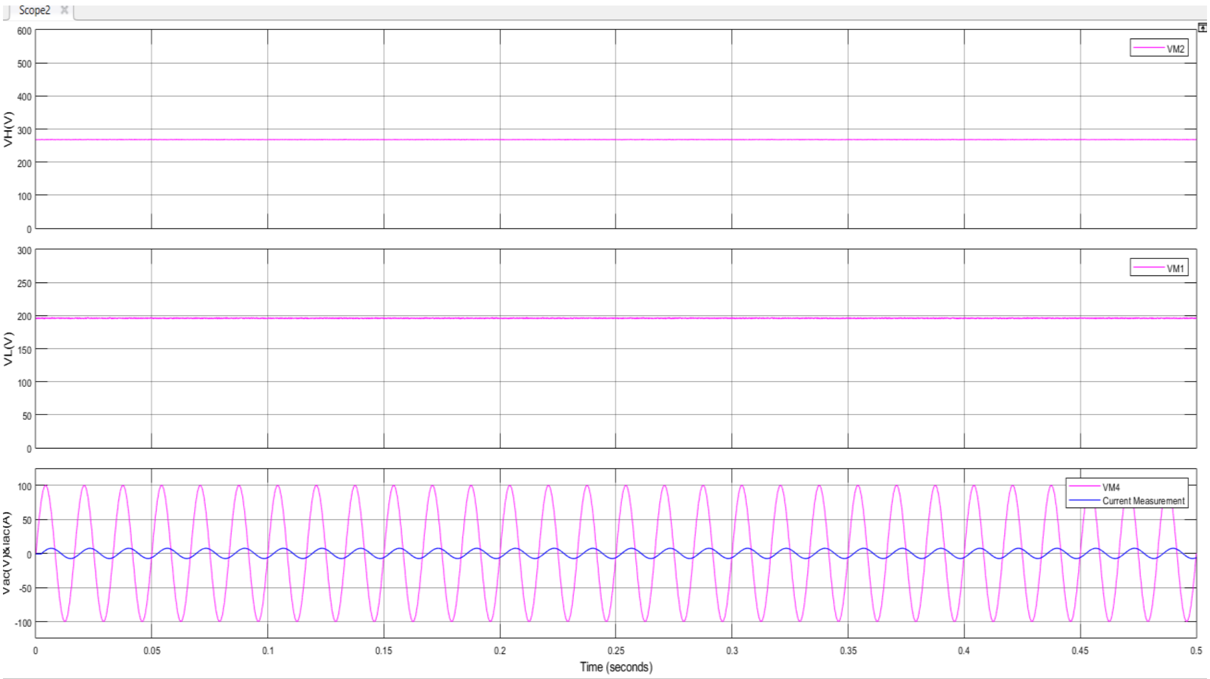

Figure 12: In Mode3, the proposed interlinking converter lags vAC.

Table 1: Comparison for with & without fuel cell

S. No	Name of the parameter	Case1 VL (vol)	Case1 VH (vol)	Case2 VL (vol)	Case2 VH (vol)	Case3 VL (vol)	Case3 VH (vol)
1	Without fuel cell	171.6	247.8	171.6	247.8	171.6	247.8
2	With fuel cell	195.7	267.7	185.6	267.7	195.7	267.7

The interlinking conversion architecture that has been proposed is capable of achieving low leakage currents, high efficiency, good power quality, and flexible control over the flow of power.

IV. CONCLUSION

This article introduces a novel approach to integrating multiple renewable energy sources into hybrid grids, proposing a networked conversion architecture. The architecture replaces the power components of a boost converter with a voltage source inverter (VSI) and an active switch. This modification enables the achievement of various objectives such as low leakage currents, high efficiency, good power quality, and flexible control over power flow. Experimental data was used to verify the performance of the proposed architecture. As interest in hybrid energy systems continues to increase, the potential use of this flexible power conversion architecture as an intermediate linking step becomes increasingly attractive.

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