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An Interlinking Converter for Renewable Energy Integration into Hybrid Grids

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Abstract: ***With the rise in global warming, distributed generators (DGs) based on renewable energy sources have become increasingly important in the power sector. Due to their small size and the capacity to 'island' while providing most of their loads during situations, microgrids provide an excellent framework to build smart grids, which increases system resilience. Given that renewable-based DGs dominate microgrids and are defined by their statistical properties and unpredictable power, sustaining load-generation balance is a significant challenge. Although microgrids are now widely used and researched, there is still considerable contention over whether they should use alternating current (AC) or direct current (DC), with the majority opinion leaning toward a combination of the two. nIn order to facilitate the flexible incorporation of renewable energy into hybrid grids, this article offers an interlinking converter design. The suggested converter may be configured as a DC-DC converter, a DC-AC inverter, or a DC-DC/AC multiport converter thanks to its one AC port and two DC ports, making it a versatile option for combining multiple DC and AC sources. Flexible conversion, high power density, low leakage currents, and tunable power flow are all features validated by the MATLAB/SIMULINK simulation results, proving the idea.***

Keywords: ***Hybrid DC/AC Grid, Interlinking Converter (IC), Renewable Energy Integration, Flexibility, Leakage Currents.***

1. INTRODUCTION

Renewable energy is anticipated to play a pivotal role in the future in order to fulfil the increasing energy demand, lower CO2 emissions, and deal with ecological problems. The integration of this renewable energy is possible at both the transmission and distribution levels. Wind power is a major factor at the transmission level, especially in Europe. Many offshore wind farms in northern Europe are linked to the mainland power grid by AC or DC

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cables. Wind farms that link to the grid via PE converters increase grid vulnerability and instability because of their intermittent nature.

More advantages (including improved dependability, more power density, & less cost to the compact number of transfer stages) and greater flexibility are provided by freestanding hybrid topologies than by the prior approach. For occurrence, split-source inverters were developed to improve on factors like small size, high efficiency, adaptable power flow, and voltage enhancement; nevertheless, the problem of leakage current was not taken into account. When used to PV systems, this presents a difficult problem. Stand-alone converters that don't include a transformer can be used to lessen leakage currents, however they can only convert energy in one direction. However, the advantages of freestanding hybrid converters are at odds with the comparatively low power density necessitated by the use of a dual-buck inverter, which necessitates the use of massive AC filter inductors. This research suggests a viable candidate for RES incorporation into hybrid grids: interlinking conversion architecture. Because to its excellent durability, simple implementation, and adaptable operation, it outperforms the competition. To achieve the suggested architecture, the boost converter's power device would be swapped out for an active switch & a VSI. As an added bonus, it uses a symmetrical impedance network, which improves system effectiveness, leakage current suppression, & power density. As an illustration of how power quality and control flexibility may be increased without sacrificing efficiency, a dedicated modulation technique is presented.

Microgrid Concept

"The MicroGrid structure envisions a combination of loads and microsources working as a unified system producing electricity and heat," writes the Consortium for Electric Reliability Technology Solution (CERTS). In order to guarantee regulated functioning as a single aggregated system, the vast majority of microsources will need to be power electronic based. The MicroGrid can satisfy the demands of its local consumers by being easily adaptable to new microsources and controls, while also appearing to the bulk power system as a single regulated entity. Among these requirements is a higher standard of trustworthiness and safety within the immediate vicinity. White Paper on Distributed Energy Resource Integration by the Consortium for Electric Reliability Technology Solutions. The MicroGrid allows for regulation of power flow and MicroGrid voltage in addition to individual source control.

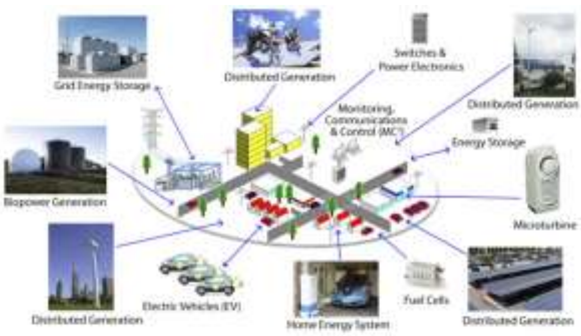

Fig.1 MicroGrid structure

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Figure 1 depicts the components of a MicroGrid, which include many consumers and several power generators in a small region. Energy independence for local power producers and customers is made possible by connecting a separate power source to the MicroGrid. Both low and high voltage systems are viable for the MicroGrid. Figure 2 depicts the hybrid system's configuration. The AC & DC bus are associated to the various AC & DC sources & loads. Power inverters and transformers connect the AC to DC bus.

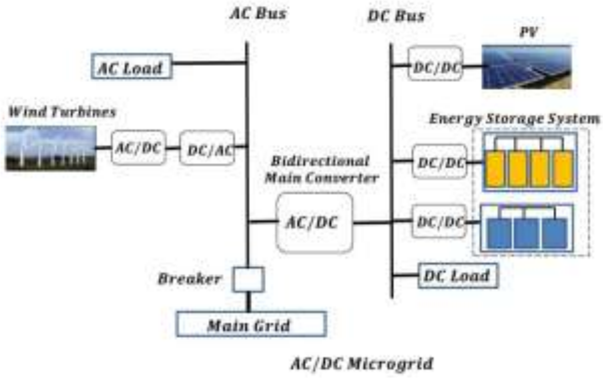

Fig. 2 Hybrid AC/DC MicroGrid System

Proposed Interlinking Converter

General Concept

The suggested interconnecting converter design for hybrid grids is seen schematically in Fig. 3. Figure 3 shows that the converter has three inputs: two DC ports & one AC port. The AC side may either be an AC load or grid. Importantly, the suggested design would benefit greatly by having bidirectional power conversions at every step. The following factors are important to keep in mind when doing so: To get an alternating current (AC) output, a voltage source inverter (VSI) is used in place of the boost converter's control switch, & the VSI's common-mode voltage (CMV) is clamped. This allows the hybrid converter to perform either boost or buck conversion between the DCL & DCH sides.

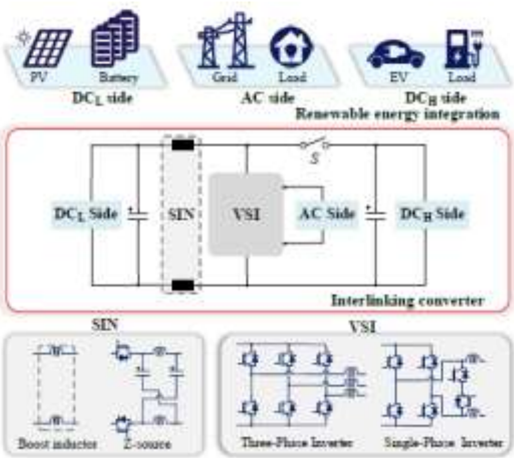

Fig. 3 Proposed architecture.

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Since the impedance and VSI are set up symmetrically, the CMV is limited to be equal to half the DCL voltage in this design. In Fig. 4, the CMV clamping is illustrated by illustrating the suggested interlinking converter design with a 1-Φ inverter.

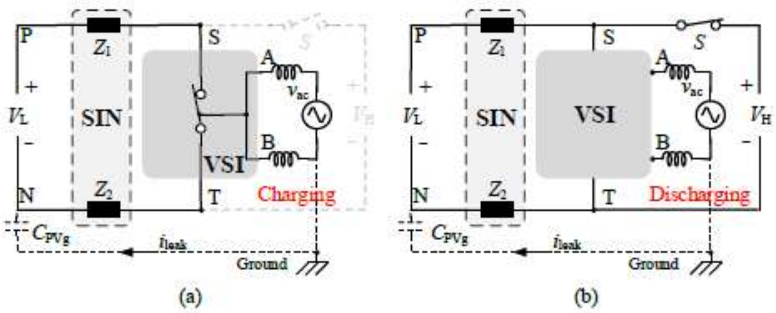

Fig.4 System stages operation.

According to Fig. 4, the SIN can be in one of two states: a charged condition, as shown, or a discharged state, as shown below. First, as shown in Fig. 4, the active switch S is turned off and the VSI runs in shoot through mode while loading (a). Accordingly, vAN = vBN = VL=2, & the CMV vcm is found by using these values.

$$v_{\mathrm{cm}} = \frac{v_{\mathrm{AN}} + v_{\mathrm{BN}}}{2} = \frac{V_{\mathrm{L}}}{2}$$

S is ON, the VSI is converting DC to AC, and the SIN is releasing, as shown in Fig. 4(b). Considering that the selected VSI fully clamps the CMV, the resulting CMV of the suggested conversion may be calculated as

$$\begin{aligned} v_{\mathrm{cm}} &= \frac{v_{\mathrm{AN}} + v_{\mathrm{BN}}}{2} = \frac{(v_{\mathrm{AT}} - V_{Z_1}) + (v_{\mathrm{BT}} - V_{Z_2})}{2} \\ &= \frac{V_{\mathrm{H}} - (V_{Z_1} + V_{Z_2})}{2} = \frac{V_{\mathrm{L}}}{2} \end{aligned}$$

where VZ1 and VZ2 are the SIN voltages, i.e., VZ1 = VZ2. From the equations, it is clear that the SIN & the VSI with its CMV clamped are utilised in the planned interlinking conversion architecture, allowing it to keep its CMV constant. For this reason, the suggested interconnecting converter is a good fit for PV systems. Keep in mind that the DCL side is the sole place where leakage current reduction is possible. According to the needs of the application, additional isolation hardware at the DCH side may be considered.

Operational Flexibility

Power may flow in both directions between the DC ports thanks to the synchronous rectifier switch, as shown in Fig. 3. The power factor of the VSI may be varied between [-1, 1] with the use of a specialised modulation technique, allowing it to accomplish reactive power injection. For integrating RES into hybrid grids, the proposed hybrid converter offers a great deal of controllability and adaptability. The many operation modes, such as the power feed-in mode (Mode I), the power feedback mode (Mode II), and the power factor mode (Mode III) depicted in Fig. 5, demonstrate this adaptability.

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(1) When in Mode I, the DCL side acts as a generator (via PV panels, for example) for the DCH side, the AC side, or both. Here, the converter boosts the DC-DC conversion from the DCL side to the DCH and DC-AC conversion from the DCL side to the AC side. Furthermore, in this mode, power can be transferred from the DCL side to the AC/DCH side.
(2) There are three distinct use-cases for Mode II. First, the converter operates in active rectification for the DCH side and buck DC-DC conversion for the DCL side from the AC side, with the power being fed back to the DCL and DCH sides (i.e., the two DC ports are loads). Second, when just the DCL side is acting as a load, the power feed-back mode is in effect (e.g., charging batteries). What this means is that power is being supplied from both the DC and AC sources. The third issue is that both the DCL and AC sides are acting as loads, when the DCH side should be responsible for the buck DC-DC and DC-AC conversions.
(3) In Mode III, the power factor at the AC side must be regulated flexibly to allow grid-connected applications, regardless of the power flow modes between the DCL and DCH sides. As shown in Fig. 5, this is possible with the proposed converter design when the DC-AC conversion modulation approach includes reactive power injection capabilities.

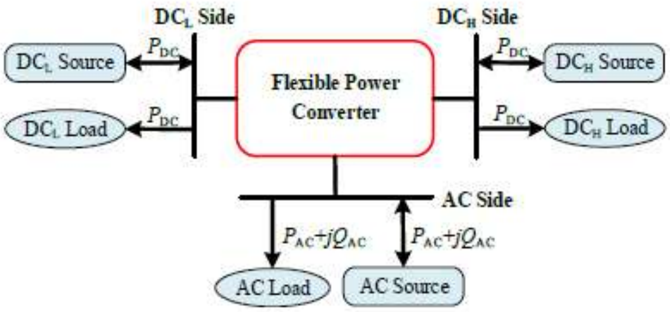

Fig.5 Proposed modes of operation.

In a combination AC/DC grid, the overall network function is greatly enhanced if the AC & DC ports are coupled to grids. When the AC grid requires help, the power flow from the input DCL side may be modified, & the DCH grid can also provide benefit by supplying power to the AC port. In a similarly, if the DC side experiences steady state difficulties under faults, the AC grid can be run in the correction mode to aid the DC grid in sustaining the fault. Altogether, the proposed energy conversion structure can be a flexible and viable method for integrating RES into hybrid AC/DC grids.

Topology and Modulation Example
Moreover, in Fig. 6, a converter is presented that implements the suggested structure by employing a very effective and dependable inverter concept (HERIC) circuit as the VSI & a symmetry inductor network as the SIN, with the modulation method being illustrated on this setup.

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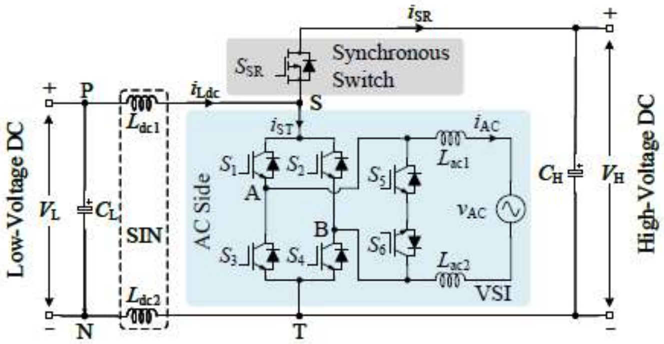
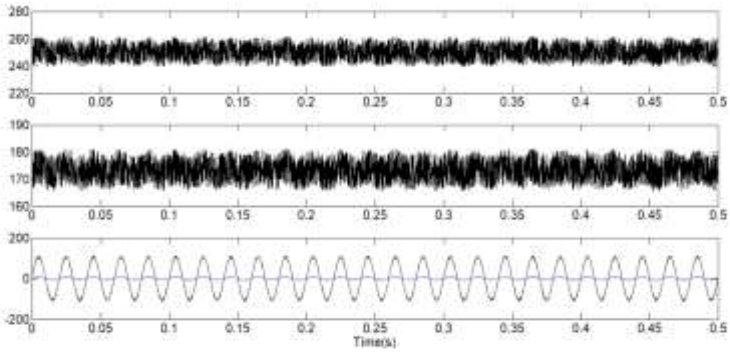


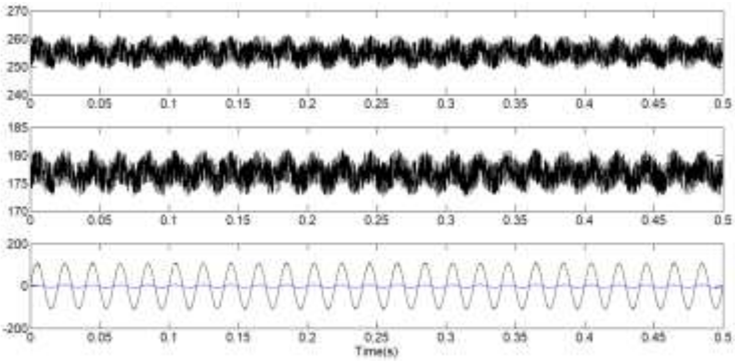
Fig.6 Proposed architecture.

2. SIMULATION RESULTS

Case-1:-



Existing waveforms



Proposed waveforms

Fig .7 Proposed Mode I waveforms.

For the suggested converter's Mode I operation, seen in Fig. 7, the DCL side supplies energy to the DCH side as well as the AC output. In Fig. 7 we can see that the suggested design can deliver both AC & DC outputs at the same time. According to Fig. 7, ripples can be seen in both DC voltages owing to power connection and the features of the consumer DC source. This can be mitigated by employing power decoupling measures for regular VSIs.

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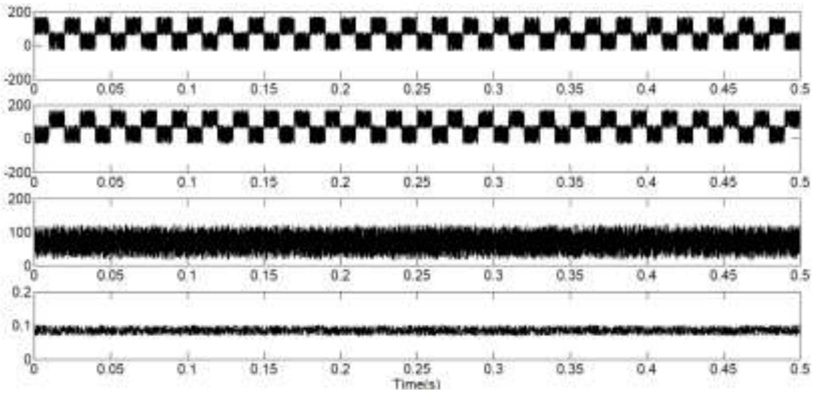

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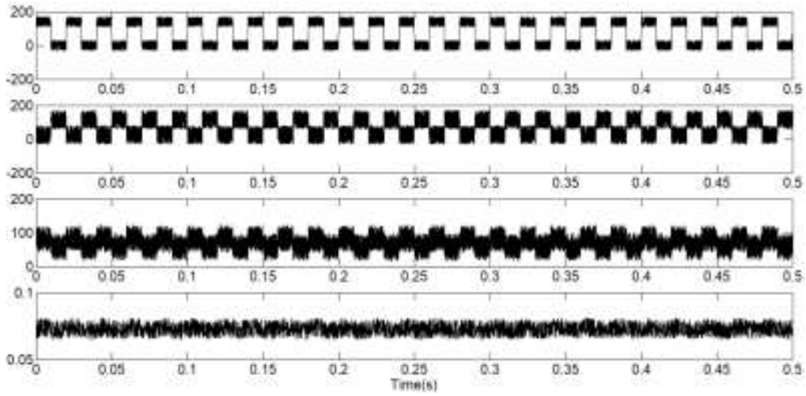
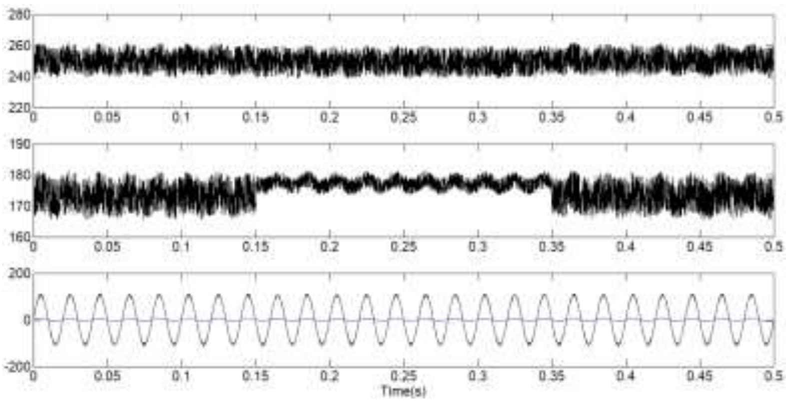


Proposed waveforms

Fig.8 Proposed system waveforms.

The CMV & leakage currents of the suggested topology for PV applications are shown in Fig. 8. According to Fig. 8, the leakage current ileak is acceptable. The inverter voltages vAN and vBN in Fig. 8 further demonstrate that the proposed modulation approach can match the HERIC's effectiveness when using unipolar PWM. As a result, the suggested converter can keep leakage currents to a minimum while providing clean electricity.

Case-2:-



Existing waveforms

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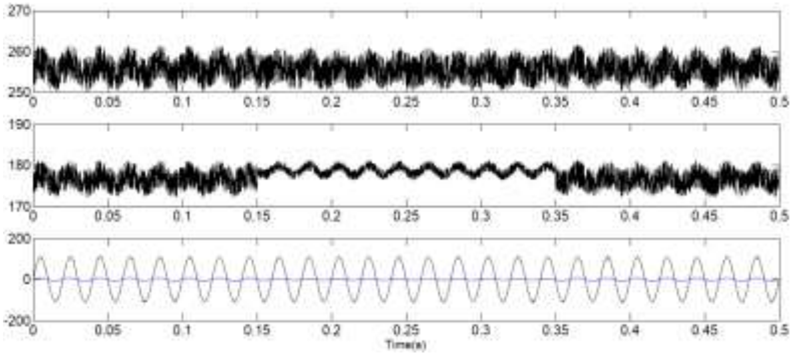
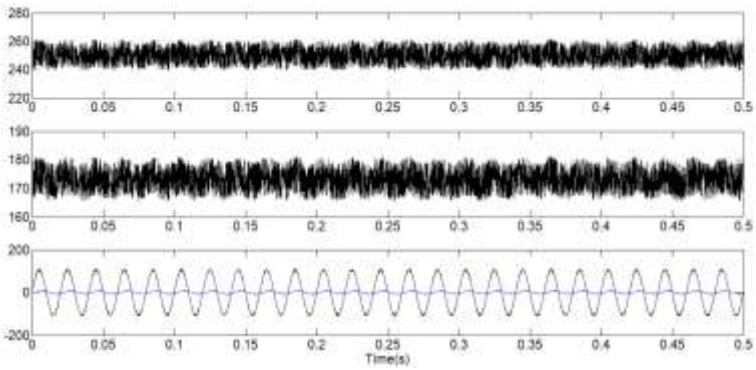


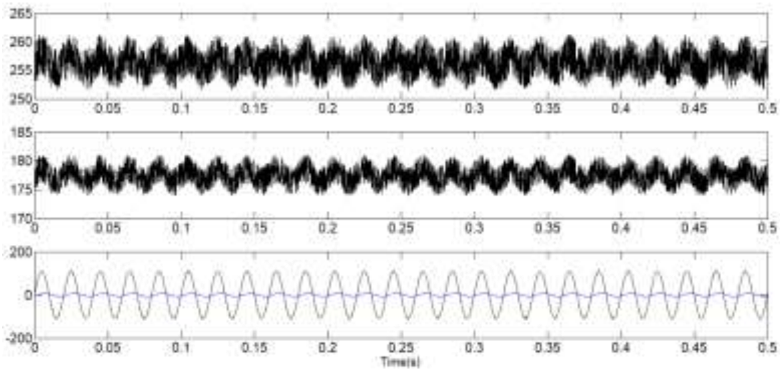
Proposed waveforms
Fig.9 Mode I waveforms

Moreover, an AC load change test has been conducted to evaluate the converter's system characteristics in Mode I. Figure 9 depicts the results of reducing the grid current amplitude (RMS) to 2.5 A and subsequently increasing it to 5 A. It has been shown experimentally that the suggested converter can maintain stability even when subjected to varying loads. Additionally, the current quality is immune to variations in load because to the independent regulation of the DC-DC and DC-AC conversions.

Case-3:-



Existing waveforms



Proposed waveforms
Fig.10. Mode III waveforms

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The suggested converter's efficacy is confirmed even more by numerical simulations in Mode III, where the DC-AC conversion runs with a non-unity power factor, and the results are displayed in Fig. 10. Based on what we see in Fig. 10, the suggested converter may be useful for the whole system because of its ability to provide adjustable reactive power injection.

3. CONCLUSION

In this work, a potential approach to the problem of integrating diverse forms of energy into hybrid grids was suggested: an interlinking convert structure. To realise the suggested design, the boost converter's power components are swapped out for a voltage source inverter (VSI) and an operational switch. The suggested interconnected conversion design has the potential for low system losses, highly efficient, excellent power quality, and adaptable regulation of power flow. The effectiveness of the suggested design has been demonstrated using MATLAB/SIMULINK simulations. Flexible power conversion architecture may prove to be a useful connecting component as the need for hybrid energy systems grows.

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