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An Innovative Reconfigurable Hybrid AC/DC Technique Utilizing a Solar Converter Topology

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Abstract **-** This work proposes and implements a reconfigurable inverter topology for a solar-powered hybrid AC to DC home system. The key advantages observed include efficient DC to DC and DC to AC conversion, as well as grid-tie operation. This approach minimizes power loss, converter cost, and volume. The hybrid system accommodates both AC and DC equipment, reducing power losses by avoiding unnecessary two-stage conversions and improving harmonic profiles. The methodology involves segregating DC loads to the DC supply side and other loads to the AC supply side. Simulation using MATLAB/Simulink validates the results, aligning with the theoretical analysis. The suggested novel inverter topology presents promising opportunities for future energy-efficient smart grids and microgrids.

Index Terms: Reconfigurable inverter, hybrid AC/DC, solar converter topology, DC to DC conversion, DC to AC conversion, grid-tie operation.

I. INTRODUCTION

The increasing demand for renewable energy sources has led to the widespread adoption of solar power systems. Solar energy offers a clean and abundant source of electricity, making it an attractive option for various applications, including residential homes. However, efficiently converting solar energy into usable AC or DC power poses challenges due to the intermittent nature of solar irradiance and the varying energy requirements of different loads.In this context, this research proposes a novel reconfigurable hybrid AC/DC technique utilizing a solar converter topology. The aim is to optimize the power conversion process by seamlessly switching between AC and DC modes based on system requirements and the availability of solar energy. This approach offers several advantages, including improved efficiency, reduced power losses, minimized converter cost and volume, and enhanced harmonic profiles.The main focus of this study is the development and implementation of a single-phase single-stage reconfigurable inverter topology for a solar-powered hybrid AC to DC home system. By integrating DC to DC and DC to AC conversion capabilities, as well as grid-tie operation, this system enables efficient utilization of solar energy and reduces reliance on external power sources.To achieve these objectives, the methodology involves segregating DC loads to the DC supply side, while the remaining loads are powered by the AC supply side. This approach helps to mitigate power losses associated with unnecessary two-stage conversions and improves the overall performance and stability of the system.

The simulation of the proposed reconfigurable hybrid AC/DC system is conducted using MATLAB/Simulink. The obtained results are compared to the speculative analysis, validating the effectiveness of the topology in achieving the desired power conversion efficiency and harmonic profile improvement.The implications of this research are significant, as the suggested reconfigurable inverter topology opens up new opportunities for energy-efficient smart grids and microgrids. By optimizing solar power utilization, minimizing power losses, and improving system performance, this approach contributes to the development of sustainable and environmentally friendly energy systems.

In the following sections, literature , existingstudies, the detailed design, implementation, and performance evaluation of the reconfigurable hybrid AC/DC system will be presented, highlighting its advantages and potential applications in residential solar power systems.

II. LITERATURE

In the field of residential power distribution, harmonic compensation and control strategies for photovoltaic (PV) interfacing inverters have been extensively studied. Munir and Wei (2013) investigated the application of a PV interfacing inverter for harmonic compensation in residential distribution systems. Their study focused on mitigating harmonic distortion caused by nonlinear loads and improving power quality. Von Appen et al. (2014) proposed local voltage control strategies for PV storage systems in distribution grids, aiming to enhance grid stability and optimize PV power injection. Their research highlighted the importance of voltage control in maintaining grid reliability and efficiency. Vossos, Garbesi, and Shen

(2014) explored the energy-saving potential of direct current (DC) systems in residential buildings. Their study assessed the benefits of DC distribution in terms of efficiency and energy savings. Sasidharan, M., Singh, J. G., and Ongsakul, W. (2014) presented an efficient hybrid AC/DC solar-powered Homegrid system based on the load characteristics of residential homes. Their approach aimed to optimize power utilization by considering the load requirements and characteristics of different appliances within the home. The literature review reveals the significance of harmonic compensation, voltage control, energy efficiency, and load characteristics in the design and operation of residential power systems incorporating PV and hybrid AC/DC technologies.

III. EXISTING STUDIES

Existing systems in the field of residential power distribution have some drawbacks compared to the proposed approach. Munir and Wei (2013) focused on harmonic compensation using PV interfacing inverters, but their study did not consider the integration of energy storage or the reconfigurability of the system. Von Appen et al. (2014) proposed local voltage control strategies for PV storage systems, but their approach did not address the efficient utilization of DC power or the seamless switching between AC and DC modes. Vossos, Garbesi, and Shen (2014) explored the energy-saving potential of direct-DC systems, but their study did not incorporate the benefits of grid-tie operation or hybrid AC/DC configurations. Sasidharan, Singh, and Ongsakul (2014) presented an efficient hybrid AC/DC solar-powered Homegrid system, considering load characteristics, but their study did not explicitly focus on harmonic compensation or the reduction of power losses. the paper by Sagavkar and Diwan (2019) focuses on a switched coupled inductor DC-AC inverter. While this design can potentially improve efficiency, it may introduce additional complexity and cost compared to conventional inverter topologies. The practical implementation and control of such an inverter design may pose challenges, particularly in terms of reliability and system stability. These factors need to be carefully considered and addressed in the proposed reconfigurable hybrid AC/DC system to ensure practical feasibility and reliable operation.Similarly, the paper by Sawant and Diwan (2019) introduces a transformerless cascaded multilevel inverter configuration for PV systems. While this approach can enhance efficiency and reliability by eliminating the need for a traditional transformer, it may also introduce higher switching losses and complexity due to the cascaded multilevel structure. Proper control and management of the multilevel inverter topology are crucial to mitigate these drawbacks and ensure stable and efficient operation. Integration of such a complex topology into the proposed reconfigurable hybrid AC/DC system may require sophisticated control algorithms and advanced power electronics techniques.

The proposed approach overcomes these drawbacks by integrating harmonic compensation, efficient power conversion, grid-tie operation, and load segmentation, resulting in a reconfigurable hybrid AC/DC system that optimizes power utilization, minimizes power losses, and improves overall system performance.

IV. PROPOSED TOPOLOGY

1. TOPOLOGY OF RSC

The reconfigurable solar inverter circuit diagram is depicted in Figure 1. While this design aims to minimize the number of power conversion stages, it should be noted that it introduces certain drawbacks. The utilization of mechanical switches and increased cable requirements are necessary for this topology. These additional components can add complexity and potential points of failure to the system. However, the proposed single-phase single-stage converter offers multiple modes of operation, providing flexibility and adaptability to meet varying system requirements.

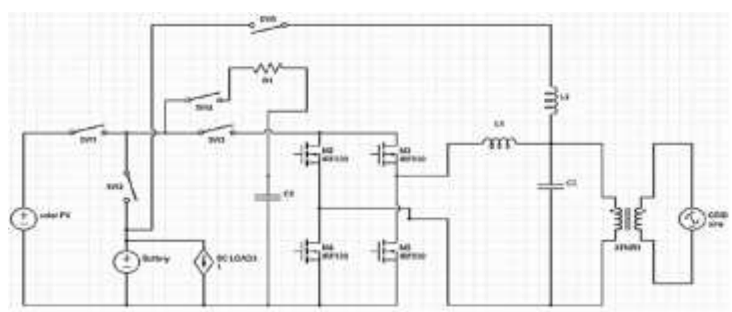

Fig.1 Schematic of the proposed RSC circuit.

A. MODE-1

The schematic in Figure 2 demonstrates a direct connection setup between the PV panel and the inverter, enabling a straightforward connection without intermediate components. To optimize the PV panel's power output, a maximum power point tracking (MPPT) controller is utilized. The MPPT controller dynamically adjusts the panel's input voltage and current, ensuring that it operates at its maximum power point. This control mechanism plays a crucial role in maximizing the system's efficiency and overall performance.

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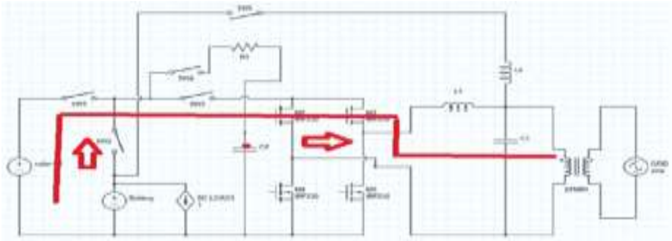

Fig.2. PV to grid

B. MODE- 2

In Figure 3, a configuration is presented where power is supplied to the grid from both the solar PV and battery sources. This operational mode is engaged when there is an insufficiency of power from the solar PV system, typically caused by external factors like adverse weather conditions or shading. In this arrangement, the solar PV output is linked to the inverter, while the battery output is connected to the DC bus of the inverter. The primary function of the inverter is to convert the DC power generated by the PV panel and battery into AC power that aligns with the voltage and frequency of the grid. This configuration enables the combined utilization of solar and battery power, ensuring a reliable and continuous power supply to the grid.

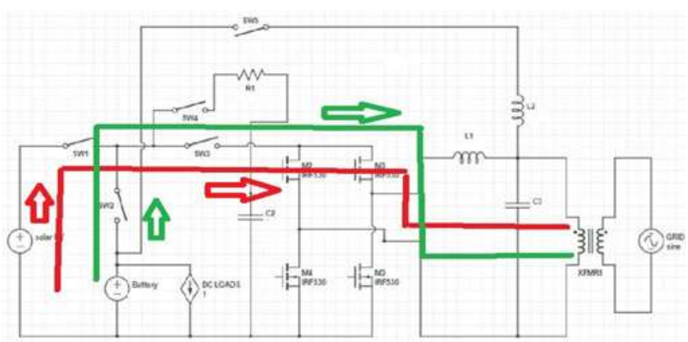

Fig.3. PV - Battery to grid.

C. MODE-3

Figure 4 depicts the DC/DC operation of the hybrid system, where the battery is charged through the chopper action of the converter. The converter plays a crucial role in adjusting the input voltage from the solar PV panel to match the higher battery voltage level. This step-up or step-down process ensures efficient charging of the battery. The chopper action of the converter enables precise regulation of the charging current, which is vital for optimizing battery life and performance. By controlling the charging current, the converter helps in extending the lifespan of the battery and maintaining its overall health.

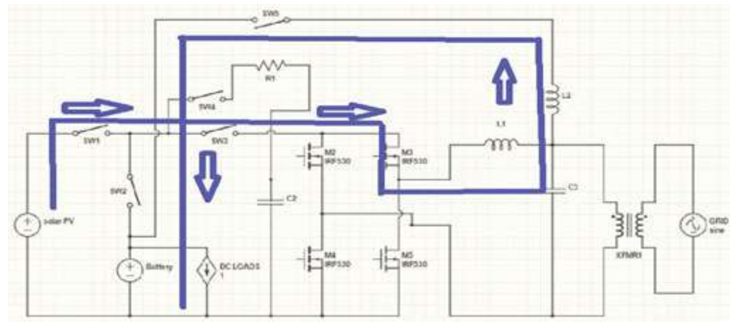

Fig.4. PV - Battery charging.

D. MODE-4

In Figure 5, the configuration is presented where the stored energy in the battery is utilized to power devices or provide grid support during periods of low or no solar radiation, such as nighttime or cloudy/rainy conditions. In this setup, the battery is connected to the DC bus of the inverter. The primary function of the inverter is to convert the DC power stored in the battery into AC power that can be used by various appliances or fed into the grid. This configuration ensures a continuous power supply, even when solar energy is unavailable, allowing for uninterrupted operation of devices and facilitating grid support when needed..

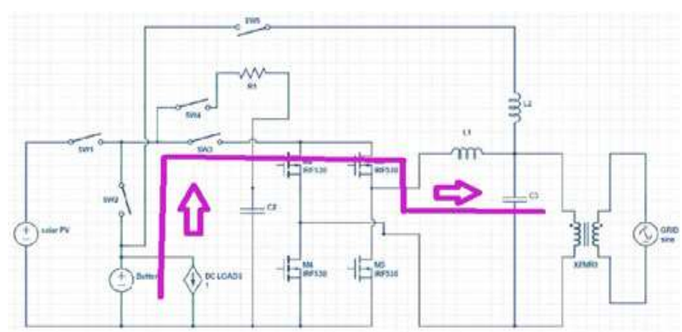

Fig.5. Battery to the grid.

2. CONTROL OF THE PROPOSED CONVERTER

A PQ controller is employed to regulate the active and reactive power output of the inverter, providing precise control over both parameters based on a reference signal. This controller offers notable advantages as it enables effective management of both active power (P) and reactive power (Q) output.

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However, controlling the variables of an AC system can be complex due to their dynamic and time-varying nature.

In Figure 6, the RSC (Reconfigurable Solar Converter) operates as an inverter to extract maximum power from the solar panel. By measuring the current and voltage of the solar panel, the required voltage for optimal power extraction is calculated and compared to the set DC-link voltage. To regulate the DC-link voltage, a PI controller is employed. This controller generates a reference current, which is then compared to the reference current produced by the PQ controller. The comparison generates an error signal that is inputted to another PI controller, which produces a reference voltage for active power control. Reactive power is controlled separately using a dedicated PI controller. The reference voltages are converted to rotating reference frame voltages and fed into space vector pulse width modulation (PWM) to drive the inverter.

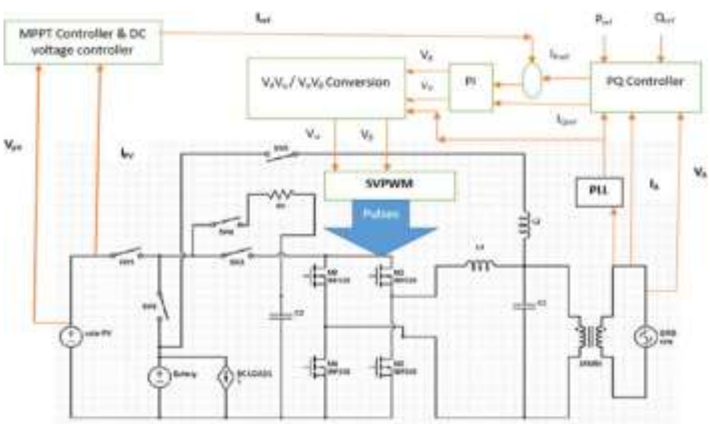

Fig.6. DC/DC inverter operation

In Figure 7, the RSC is utilized for battery charging from the solar panel in the DC/DC conversion mode. A MOSFET switch is employed to achieve the required voltage level for the battery. The MPPT controller calculates the necessary current and provides it to a PI controller, which generates the reference voltage. This reference voltage is then compared to the battery voltage, resulting in the generation of a duty cycle. PWM pulses are generated based on this duty cycle and applied to the MOSFET switch.

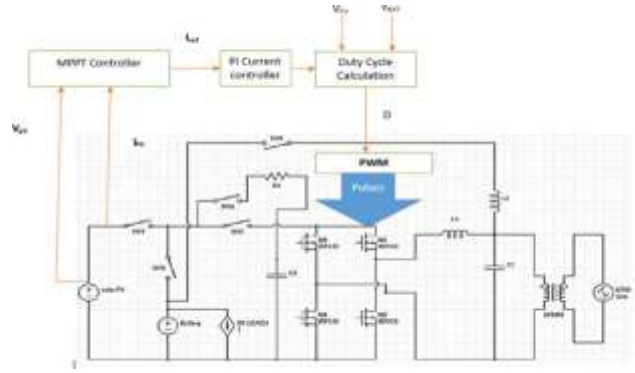

Fig. 7. DC/DC chopper operation.

3. CONTROL TECHNIQUE

In the proposed system, the control technique employed utilizes Space Vector Pulse Width Modulation (SVPWM) to generate switching signals for the inverter. SVPWM is a widely used PWM technique for three-phase converters, but its application to single-phase inverters is relatively less explored. The control principle of SVPWM is simpler in a single-phase scenario. In MATLAB Simulink, SVPWM strategy is implemented for switching signal generation. The up and down bridge arms of the inverter cannot be conducting simultaneously, and their switch states are complementary. By considering the switch states of the full-bridge inverter, four switching vectors (V1, V2, V3, V4) in two voltage sectors can be obtained. The output of the single-phase inverter, Vab, can take one of three values (+Vref, 0, -Vref) based on the SVPWM method, achieved by two complementary switching signals and two zero states. The sectors are identified as Sector 1 when Vab > 0 and Sector 2 when Vab < 0. The inverter's operating state is represented by two binary numbers that describe the switching devices' states. This control technique enables precise control and regulation of the inverter's output based on the desired voltage levels and sectors.

V. SIMULINK MODELLING AND RESULTS

A comprehensive model of the proposed novel reconfigurable solar inverter configuration for a solar power-driven hybrid home is constructed using the MATLAB software with the Simulink toolbox. This model encompasses the various components and control strategies of the reconfigurable solar inverter system. Through Simulink, the model captures the dynamic behavior and interactions of the solar panels, battery, inverter, power electronics, and associated control algorithms. It allows for the simulation and

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analysis of the system's performance, including power generation, power conversion, energy storage, and grid interaction. The MATLAB Simulink model serves as a powerful tool for studying and evaluating the effectiveness and feasibility of the proposed reconfigurable solar inverter configuration for residential hybrid energy systems.The phase-locked loop (PLL) is a crucial control system utilized in grid-connected solar inverters to ensure synchronization between the inverter's output and the grid voltage. By using the grid voltage as a reference signal, the PLL continuously monitors and tracks the frequency and phase of the grid voltage in real-time. The output of the PLL provides valuable information regarding the phase difference between the grid voltage and the inverter's output voltage. This information is then utilized by the inverter controller to make necessary adjustments in order to synchronize the phase and align the inverter's output with the grid. Once synchronization is achieved, the inverter can effectively transfer active power to the grid. The inverter controller dynamically adjusts the output voltage and frequency to match the grid voltage and frequency, enabling the inverter to supply power to the grid in a coordinated and synchronized manner. In conclusion, the PLL plays a vital role in grid-connected solar inverters by facilitating synchronization with the grid voltage and enabling efficient power transfer to the grid.

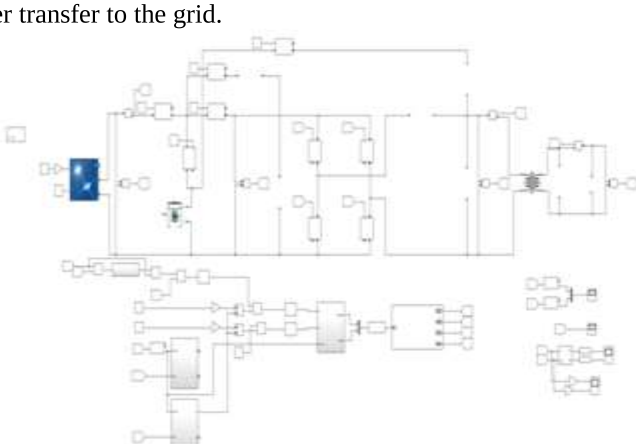

Fig. 8 Simulink Block Diagram

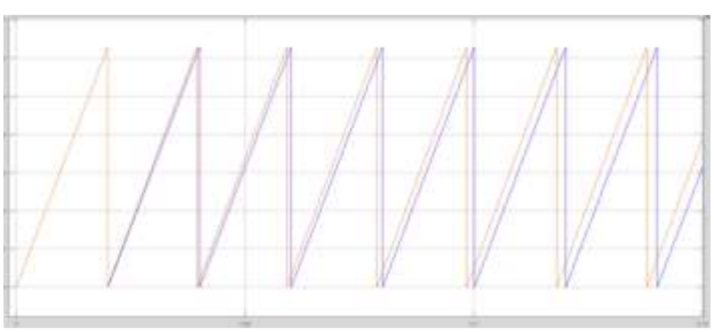

Fig. 9 Phases in radians

Fig. 10 Active and reactive power generation

A phasor diagram is presented to illustrate the interaction between the inverter and the grid supply during power transfer in the proposed system. The charging method for the battery is discussed, with a specific focus on utilizing a Li-ion battery for energy storage. The constant voltage charging method is implemented, and a figure showcases the output voltage profile during the charging process. To validate the performance of the proposed converter, comprehensive simulations are conducted using MATLAB/Simulink. The obtained results are thoroughly analyzed, and it is observed that the control algorithm operates flawlessly in the simulation environment, demonstrating the effectiveness of the proposed topology in achieving the desired outcomes.

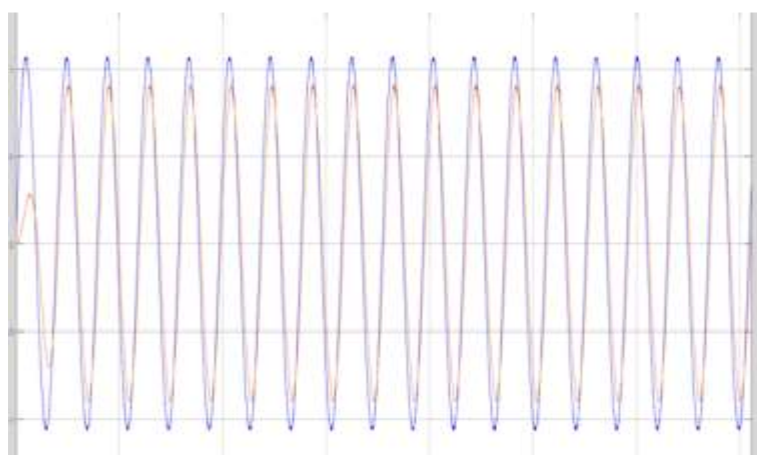

Fig. 11 A phasor diagram that shows the inverter and grid supply during power transfer

VII. Conclusion

This work focuses on the development of a highly reliable and energy-efficient inverter designed for a solar-powered hybrid AC/DC home. The key aspect of the proposed configuration is the utilization of a single power transformation process for both AC to DC and DC to AC conversions. This approach leads to improved efficiency, reduced converter volume, and enhanced reliability. Additionally, the proposed converter enables DC/DC, DC/AC, and grid-tie operations, offering versatile functionality. The converter's design also addresses the issues of power loss, cost, and size, resulting in added advantages. Extensive simulations and testing have been conducted to validate the performance of the converter, utilizing MATLAB for analysis. The simulation results demonstrate the flawless operation of the control algorithm within the MATLAB environment. Although this study primarily focuses on solar energy as the power source, the proposed inverter configuration can be further extended to incorporate other sources such as wind, fuel cells, and more.

References

[1] S. Munir and L. Y. Wei, "Residential distribution system harmonic compensation using PV interfacing inverter," IEEE Trans. Smart Grid, vol. 4, no. 2, pp. 816–827, Jun. 2013.
[2] J.Von Appen, T. Stetz, M. Braun, andA. Schmiegel, "Local voltage control strategies for PV storage systems in distribution grids," IEEE Trans. SmartGrid, vol. 5, no. 2, pp. 1002–1009, Mar. 2014.

[3] V. Vossos, K. Garbesi, and H. Shen, "Energy savings from direct-DC in U.S. residential buildings," Energy Buildings, vol. 68, no. Part A, pp. 223–231, Jan. 2014.
[4] N. Sasidharan, N. M. M., J. G. Singh, and W. Ongsakul, "An approach for an efficient hybrid AC/DC solar powered Homegrid system based on the load characteristics of home appliances," Energy Buildings, vol. 108, pp. 23–35, Dec. 1, 2015.
[5] B. Mariappan, B. G. Fernandes, and M. Ramamoorty, "A novel single stage solar inverter using using hybrid active filter with power quality improvement," in Proc. 40th Annu. Conf. IEEE Ind. Electron. Soc., Oct. 29, 2014-Nov. 1, 2014, pp. 5443– 5449.
[6] Sagar R. Sagavkar, Seema P. Diwan, "A Novel Switched Coupled Inductor DC-AC inverter," published in 2019, 2 nd International on Intelligent Computing, Instrumentation and Control Technologies, 5 th and 6 th July 2019.
[7] Rahul H. Sawant, S. P. Diwan, "Transformerless Cascaded Multilevel Inverter with Reliable and High Efficient Configuration for PV System," published in ieeeforum international conference, 16 th Jun, 2019.