

Reconfigurable Three-Switch Leg Multi-Port Boost Inverters with Novel Modulation Schemes for Hybrid DC/AC Microgrid Systems

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ABSTRACT: This paper proposes reconfigurable single-stage three-switch leg multi-port boost inverters (TSLMPBIs) that feature novel hybrid modulation schemes for hybrid DC/AC microgrid system applications. The TSLMPBI topologies are designed to accommodate various configurations, including two DC ports with two AC ports, three DC ports with one AC port, and three DC ports with two AC ports, tailored for different applications. A hybrid modulation scheme was proposed, dynamically adapted to the configuration of DC and AC ports, facilitating seamless boost and dual inversion operations or combined boost, buck, and inversion functionalities within a single converter. The AC ports operate at various voltages, frequencies, and phases, while the DC ports support multiple voltage levels. The proposed control modulation scheme effectively addresses crossover issues in modulation signals, resulting in enhanced AC voltage gain, improved DC bus utilization, and optimized power transfer among DC and AC ports. Additionally, these topologies reduce active switch count compared to state-of-the-art designs, even with increased ports. To validate the performance of the proposed TSLMPBI and its control modulation scheme, a 500 W laboratory prototype was developed, and experimental results under various operating scenarios were presented and analyzed.

KEYWORDS: AC voltage gain, Boost inverter, DC-link voltage utilization, DC voltage gain, modulation scheme, multi-port DC/AC converter

I. INTRODUCTION

The electrical power generated by the burning the fossil fuels yields negative impact on environment like air pollution, water pollution, and climate change. In recent years, the concentration of fossil fuels is diminishing day by day due to overuse of electricity. In view of above, other alternative resources are required to be explored to meet the growing load demand. Few available resources are solar, wind energy and tidal energy etc. in the nature. The issues related to these resources are intermittent nature, which are highly unreliable. Therefore, one renewable energy source (RES) cannot meet the consumer's demand alone. Thus, the various types of RESs are integrated to meet the continuous supply demand of consumers via grid connected/ standalone system. Especially, in remotes areas, the utilization of solar power is enhancing to compensate the load demands and other applications of solar are established in the power range of microwatt to megawatt scale [1,2]. The intermittency of the solar power can be compensated by integration of other sources such as fuel cell, energy storage element battery and diesel generator set etc. The integration of solar with diesel generator-set is presented in [3]. The design, power management and performance analysis of integration of solar, diesel generator-set and energy storage element are discussed in [4]. Peak detection-based control algorithm approach is utilized for power management in the above integrated said system.

The integration of RESs in a DC microgrid offers more advantages over ac microgrid in terms of requirements of number of power converters, utilization of power transformers and regulation of voltage as well as frequency. A standalone PV system in DC microgrid consists of decentralized solar modules, power converters, and energy storage elements. The design of power converters for a grid connected systems are discussed in [[5], [6], [7], [8], [9]] and their stability, fast dynamic response and local control algorithms for MPPT are discussed in. Generally, the generating voltage of solar is low. Especially, in DC microgrid applications, the DC bus voltage for single-phase ac supply is 350

V and for three-phase ac supply it should be 700 V. So, to meet the DC bus voltage, the generated solar voltage rises to required DC bus voltage by boost converter, but the recovery of diode in boost converter is very difficult at higher duty cycles. So, the necessity of high gain converters is arrived. This high gain converter is employed to integrate the RESs to DC microgrid and exhibits continuous input current which is more desirable for PV applications. Several high gain converters are suggested for photovoltaic applications in. Non-isolated high gain converter is suggested for DC microgrid applications in. This converter comprises of three switches which are operated by different duty cycles. Generally, all MPPT techniques are generating single duty cycle. So, if the same converter is used for photovoltaic applications, the controlling of converter is very difficult using MPPT algorithms. The 9-level quadruple boost inverter for photovoltaic applications is proposed in. In this converter, the dc voltage directly converted into 9-level ac voltage. In case, if same converter is used for PV applications, there is no control for PV voltage regulation. The control is discussed about the generation of 9-level ac voltage only. So, the converter can be used for standalone applications along with DC-DC converter.

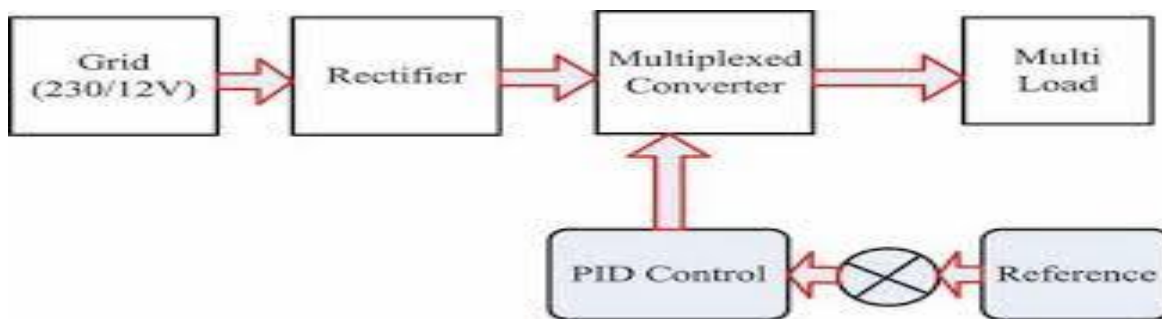


Fig 1: A novel design of switched boost action based multiport converter

The integration of solar and energy storage element battery using high gain converter is presented in. This converter includes the coupled inductors and it maintains the power balance among PV, battery and three-phase load using PI controller and sinusoidal pulse width modulation technique. It has disadvantages of large number of components counts and large voltage spikes due to coupled inductors. To reduce this spike, additional circuitry is required that yields increased in cost. Multi-input converter is presented that integrate the PV and wind energy to DC bus bar and single-phase grid is connected to DC bus bar through single-phase inverter. Both PV and wind energy are controlled by P&O algorithm. The disadvantage of this converter is input current from both PV and wind are discontinuous currents. This is not desirable for renewable energy applications. The boost converter with multiple inputs is discussed that integrate the PV, fuel cell and battery to DC bus bar. The controlling of three electrical sources using this converter is very difficult. Multi-port DC-DC converter with parallel coordination of sources for standalone photovoltaic systems is proposed. This converter integrates the one photovoltaic system and two energy storage elements to DC bus bar through interleaved boost converter and resonant converter. In this system, interleaved boost converters are used for reducing the input current ripples and resonant converters are used between electrical sources and DC bus bar. The drawback of this converter is large number of switching components. The grid connected PV system with enhanced performance using Luo converter is suggested. In this converter, active power decoupling circuit is used. This active decoupling circuit consists of inductor, capacitor, diode and switch. This converter can integrate photovoltaic source and battery to DC bus bar. This converter required large rating of the battery which is equal to DC bus voltage or DC link voltage. The 17 level-inverter is proposed for grid connected photovoltaic system in [26]. In this converter, a separate CC circuit is used for regulation of solar voltage. The high gain interleaved boost converter for PV applications is proposed in. This converter also consists of coupled inductors. The disadvantages of coupled inductors are aforementioned.

II. RELATED WORK

Now days, the load demand increasing greatly day by day. In this case, single dc microgrid unable to compensate the load demands. So, group of dc microgrid connections are required. The group of microgrid connections is controlled by coordinated control schemes or methods. Flexible interlinking and coordinated power management is suggested for clusters of dc microgrids in [28]. In flexible interlinking scheme, the group of microgrids is interlinked through isolated

bidirectional dc-dc converters (IBDC). These IBDC's are controlled by standard droop and unified control methods. Fast free sliding mode and Intelligent control is developed for shipboard dc microgrids in [29]. The intelligent and sliding mode control provides fast response for regulation of dc voltage and optimal current sharing among parallelly connected dc microgrids. In intelligent control scheme, fuzzy logic controller based single input type-2 combines with sliding mode controller for better regulation of voltage and improves the accuracy of current sharing. Model predictive control is proposed for bidirectional dc-dc converters in dc microgrid applications in [30]. The utilization of PID controller is restricted in model predictive control. Model predictive control uses MPCP and MPVP algorithms. The interlinking converter between ac and dc is controlled by MPVP algorithm.

The main objective of this paper is the more utilization of renewable energy resources in the nature and provides an electricity to remote areas where the utility grid is not established. The main contribution of this paper is the low output voltage of PV is step-up to dc bus voltage (in case of 1- \emptyset ac supply, the required dc bus voltage is 350 V and in case of 3- \emptyset ac supply, it should be 700 V) using single switch high gain converter and maintained the power balance between electrical sources as well as load using unified control method.

The structure of suggested system and operating modes are discussed in Section 2. Control strategies of standalone PV system using high gain converter is elaborated in Section 3. Design of high gain converter is developed in Section 4. Simulation results are elaborated in Section 5. Prototype model of suggested system is discussed in Section 6. Finally, the paper concluded with experimental results in battery charging and discharging modes.

III. PROPOSED SYSTEM

To address these challenges, a novel modulation scheme was introduced in [8], [9], and [10] to improve DC bus utilization and mitigate the double-frequency ripples in the DC-link current and voltage at the DC port. The sizes of the inductors and capacitors are larger to mitigate the double-frequency ripple and increase the lifetime was proposed with a novel modulation scheme. However, this topology has a limited voltage transfer ratio at the ripple port, reduces DC-link voltage utilization, and involves a complex dependent control scheme. A multi-output, which can operate in both buck and boost modes relative to the AC port, was also introduced, although it requires a larger number of components. The single-leg boost inverter uses a hybrid PFM and SPWM scheme to overcome the over-modulation issues caused by load variations. However, its input DC current is discontinuous.

The carrier and discontinuous space vector modulation have been applied to three-switch leg-based nine-switch converters, quasi-Z-source nine-switch converters, and six-switch converters, addressing issues such as reference signal crossover, minimizing switching losses, and enabling independent control of voltage and switch stress. A novel buck voltage-based dual output inverter is introduced, utilizing a carrier-based PWM scheme. In contrast, introduces a single-stage AC-DC-AC converter with a phase-shifted carrier-based PWM scheme to eliminate double-frequency current ripples and boost the AC output voltage. Feature additional low-voltage DC ports or provide boost and buck voltage gain for the DC port, limiting their ability to perform both boost (DC-DC) and inverter (DC-AC) operations in a single converter. In addition, they do not incorporate the concept of DC or AC voltage gain.

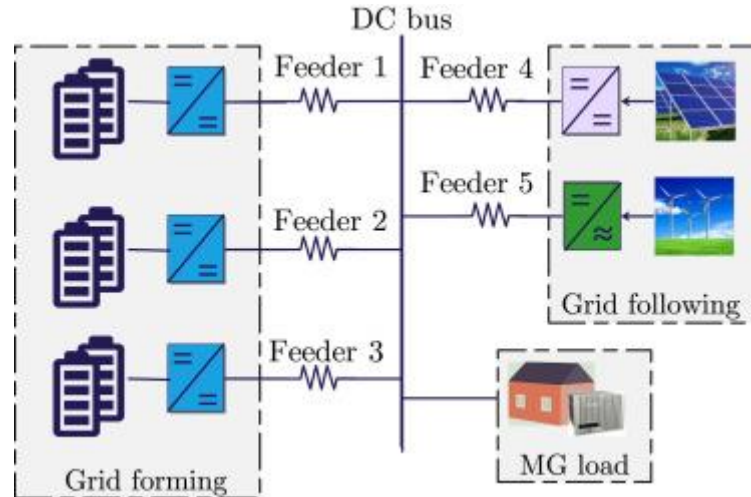


Fig 2: Accurate power sharing for islanded DC microgrids considering mismatched

In recent studies, multi-port DC-AC boost converters, featuring two or three DC and two AC ports, or three DC and one AC ports have been developed, as block diagram shown in The single-phase dual output converter in has a greater number of active switches and drawbacks of limited AC voltage gain, low DC-link voltage utilization, and constraints on maximum power transfer to AC ports, which is not effective for two-phase applications due to its modulation scheme. Optimal modulation schemes for three-switch leg multi-port DC-AC converters are designed to enable boost, inversion, and buck operations. Considering the limitations of the discussed topologies and their modulation schemes in the literature, as well as the growing demand for multi-port DC-AC converters in hybrid DC/AC microgrid systems, hybrid solar PV-battery integration for home DC and AC loads, EV charging systems, and two-phase applications, this paper proposes reconfigurable single-stage three-switch leg multi-port boost inverters (TSLMPBIs) with novel hybrid control modulation schemes. The proposed TSLMPBIs topologies are designed to address the aforementioned problems and extend the work presented. The hybrid modulation control scheme is adapted based on port configurations to achieve boost, dual inversion, or combined boost, buck, and inversion operations in a single converter. Table 1 presents the advantages, disadvantages, and applications of the three-switch leg multi-port boost inverter (THSLMPBI) configurations combined with the hybrid modulation scheme.

IV. RESULT ANALYSIS

In the three-switch multiport boost inverter configuration C1, shown in 3(a), the low-voltage DC port and AC port 2 are connected between the middle and bottom switches, while AC port 1 is connected between the top and middle switches. To achieve the required operations, a constant PWM signal is used for boost operation, and unipolar sinusoidal reference modulation signals are required for inversion at AC ports. Both the constant PWM and unipolar sinusoidal modulation signals are combined to enable simultaneous boost and inversion at the DC port and AC port 2. Additionally, an independent unipolar sinusoidal reference modulation signal is used for AC port 1. However, directly applying these modulation signals results in over-modulation and crossover issues, affecting the efficiency of boost and dual inversion operations. To overcome these challenges and ensure maximum AC voltage gain and DC-link utilization, the modulation signals are transformed into two hybrid categories: rectified inverse sinusoidal modulation signals (V_{m1}, V_{m2}) and phase-shifted rectified level-shifted sinusoidal modulation signals (V_{m1}, V_{m2}). These hybrid modulation signals, illustrated in 5(a), facilitate seamless integration of boost and dual-inversion operations.

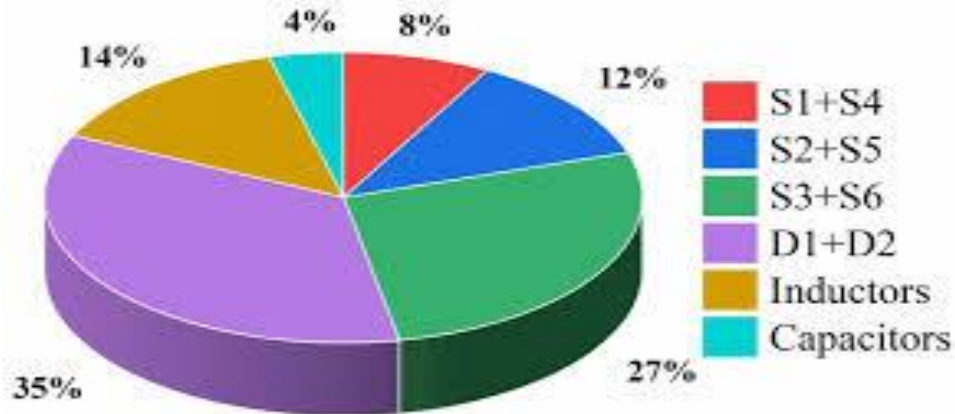


Fig 3: Reconfigurable Three-Switch Leg Multi-Port Boost Inverters with Novel Modulation Schemes

Additionally, employs a greater number of active and passive components despite lacking boost or buck or boost and buck capabilities. The modulation techniques used in these works are not suitable for achieving simultaneous boost and dual inversion operations or integrated boost, buck, and inversion functionalities within a single converter, as enabled by the proposed topology. The single-phase dual-output boost DC-AC converter incorporates a greater number of active switches and does not support buck operation. Its AC voltage gain is restricted, DC-link voltage utilization is inefficient, and the maximum power transfer to AC ports is constrained. Furthermore, its modulation strategy is not well-suited for achieving higher AC gain or facilitating boost, buck, and inversion functions as efficiently as the proposed approaches.

The AC voltage control loop 2 governs the voltage (V_{ac2}) at AC port 2. The peak reference voltage ($V_{ac2-ref}$) is input into a feed-forward control structure, where the voltage error signal is processed by a discrete PI controller ($PI4(z)$). This controller generates the modulation indices (ML) for the reference modulation signals used to regulate V_{ac2} . The loop employs a phase-shifted rectified sinusoidal or rectified sinusoidal pulse-width modulation (PRSPWM or RSPWM) technique to ensure stable AC voltage regulation at AC port 2. The combined outputs of the DC boost voltage control loop and the AC voltage control loop 2 generate the reference modulation signals (V_{m3} , V_{m4}), enabling effective control of both V_{dc2} and V_{ac2} .

V. CONCLUSION

This paper presents reconfigurable single-phase, single-stage three-switch-leg multi-port boost inverters (TSLMPBIs) with novel hybrid control modulation schemes. A detailed study was conducted, encompassing topology descriptions, operating modes, modulation strategies, steady-state analysis, design parameters, control schemes, power loss evaluation, and comprehensive comparative analysis. The proposed TSLMPBI topologies are designed to accommodate various DC and AC port connection configurations for diverse applications. Configurations 1 and 2, featuring two DC ports and two AC ports, support boost and dual inversion operations. Configuration 3, comprising three DC ports and one AC port, offers flexible boost and buck operations at the DC ports along with inversion at the AC port using a single converter.

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