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RESEARCH ARTICLE

Application of Bidirectional DC Converter for Battery Energy System

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ABSTRACT

The quasi-Z-source (qZS) converter is used to create a new bidirectional dc-dc converter. It functions as a traditional qZS full-bridge structure with a synchronous voltage doubler rectifier during battery draining. It functions as a half-bridge structure with a synchronous full-bridge rectifier and LC-filter during battery charging. For switching between the two modes, a relay is utilized. The operating concept is described, as well as design recommendations. For analysis of constant regulation parameters and efficiency tests in the input voltage area compatible with an eight-cell LiFePO4 battery, a prototype with a nominal power of 300 W was utilized. In two control scenarios: dc-bus signalling and direct reference specified by a master controller via a data channel, a closed loop control structure for the converter application in dc microgrids is described and verified.

Keywords: quasi-Z-source converter, bidirectional converter, dc-dc converter, battery energy storage system.

INTRODUCTION

The interest in energy and system output in the designing area has grown in recent years across the world. According to estimates, residential and commercial buildings account for almost 40% of total output use in the European Union and the United States [1]. This industry is growing at a rapid pace, resulting in increased energy utilization and carbon emissions [2]. As a result, in the construction industry, energy conservation and the use of non conventional energy sources are critical steps that must be taken to decrease energy requirement and greenhouse gas emissions [3], [4]. Power electronics plays a significant role in this context, allowing for efficient electric power conversion and simple integration and management of renewable energy sources and energy storages, resulting in the best possible power system performance [5], [6]. Engineering scientists have begun to introduce power electronics in brand new applications, such as the Electronic Power Distribution System (EPDS), also known as Active Distribution Network or Smart Grid [7]-[10], thanks to rapid advances in semiconductor and packaging technologies, as well as the development of new power converter topologies. Such ideas may be used for a single building [11]-[14] or a district [15]-[18] depending on the power scale, allowing for greater proportions of distributed energy production and storage, demand-side efficiency, and energy trading activities. One of the most common conceptual approaches to the EPDS for residential structures is shown in Figure 1 [19]. Due to the absence of grid-tied inverters, which are integral parts of the interface converters for traditional AC power distribution systems, the interconnection and interaction of distributed generators (DGs), energy storages (DESs), and loads is realised through the high-voltage dc-bus, which results in simplified power processing and increased power conversion efficiency [20], [21].

Renewable energy sources cover a substantial portion of the energy demand of zero-energy and resource-efficient buildings [22]. The major contributions to the energy performance of the domestic power system are energy storage technologies [22]-[24]. The proposed EPDS includes an auxiliary AC bus to guarantee compatibility with presently prevalent AC loads, which may be completely removed in the future with the adoption of a dc supply standard for consumer loads [25]-[27]. The plug-and-play capability of the dc linked EPDS, as well as the simpler interaction of the DGs and DESs, are major advantages. It offers a one-of-a-kind chance to use adaptable modular solutions, lowering weight and installation area, which is becoming more essential in residential construction. Because of the module-level maximum power point tracking, micro converters used in rooftop solar systems provide for greater system design flexibility, module-level monitoring and diagnostics, simpler installation, and higher energy output from the PV module [28], [29]. In contrast to conventional PV string inverters, the PV microconverters are linked in parallel at the HV dc-bus, making power scaling up more simpler and quicker. The home battery energy storage system (RBESS) [30] may use the similar modularity concept. A RBESS may be tailored to the requirements of a specific family by cascading tiny units in parallel [31]. RBESS between power and capacity is typically in the range of 0.25 W/(W•h) to 0.75 W/(W•h) [32], with 0.25 W/(W•h) providing the best economic performance [33]. This research focuses on LiFePO4 battery dc-bus interfacing, which is beneficial in residential applications owing to their extended lifespan, durability, and better safety [34]. The developed converter is intended for use with a 24 V LiFePO4 battery with a 1.2 kWh capacity and a nominal output of 300 W, resulting in a ratio of 0.25 W/(W•h), which is suitable for modular RBESS.

It may be comparable to commercial AC-coupled batteries as the Enphase AC battery, SOLARWATT My Reserve 500, and Solar World SunPac LiOn 2. Furthermore, the developed converter could be used for battery charging of small electric vehicles (electric bicycles, scooters, power assist wheelchairs, and so on) as well as the implementation of some service functions (for example, battery "refresh"), which are critical in the case of some battery technologies used in such vehicles. This article expands on the concepts given in [36], in which it was shown that the topology from [29] could be used to accomplish reverse energy transfer via a variety of control techniques, with topology reconfiguration by a relay demonstrating the greatest performance. Only feasible options for reverse energy transfer in the galvanically isolated quasi-Z-source full-bridge dc-dc converter were presented in previous findings [30]. As a consequence, the following are the contributions of this article to the findings presented in [25] and [15]. First, a closed-loop control theory appropriate for use in dc microgrids is developed based on a thorough examination of operating modes (charging and discharging) and a thorough assessment of their experimental performance. Second, the converter is experimentally justified for dc microgrid applications utilizing the same control system for both centralized and decentralized control, with excellent dynamics obtained via feed forward control. Both operational modes of this control system use the same modulator. Third, the modular RBESS technology is examined in the context of small residential dc microgrids, with the optimum size and power-to-capacity ratio established using existing research and industry solutions. Overall, this work adds to the fields of galvanically isolated impedance-source dc-dc converters and reconfigurable converters with topology morphing control. This article makes a practical contribution by proposing an open hardware solution for modular RBESSs that meets the requirements of the fast growing industry of technologies for near-zero energy buildings.

Bidirectional quasi-Z-source DC-DC converter

A galvanically isolated impedance-source dc-dc converter is proposed as a versatile power conversion technique for applications needing a wide range of input voltage and load management. Many of the important characteristics of the topology and its many variations have been demonstrated in renewable and alternative energy systems, where they have demonstrated such important characteristics as continuous input current, increased reliability due to inherent short- and open-circuit immunity, and high power conversion efficiency over a broad gain range [27]. Because ISCs combine the main features of voltage- and current-source converters, they may be regarded a new type of power converters that perform both buck and boost functions in a single switching stage, according to the findings of the technical research [30]. With its relative simplicity and high control flexibility, the quasi-Z-source full-bridge dc-dc converter (qZSC) [20] from the family of galvanically isolated ISC [29], which already includes more than 30 distinct topologies [24], appears to be the most promising due to its relatively simple structure. Because of the unique features of the quasi-Z-source (qZS) network, the full-bridge inverter could handle all possible switching states; as a result, multimode control (MMC) could be implemented, allowing for a ten-fold increase in input voltage regulation range [29]. Any shoot-through control method may be used in conjunction with phase-shift modulation [29], asymmetrical pulse-width modulation or variable frequency control to accomplish the MMC in the buck mode. The series resonant tank, which may be comprised of additional components [18] or fully integrated into the secondary side of the converter is often employed to assist the qZSC's ability to operate across a wide input voltage and load range. In order to reduce conduction losses in qZSC converters, it is highly recommended that they be connected to a synchronous qZS network, which may increase the overall efficiency of the converter by more than 2 percent depending on the operating point [20].

A power MOSFET may also be used to replace the qZS diode in order to relieve some of the converter's instability problems while operating in the discontinuous conduction mode of operation (DCM). The behaviour of MOSFETs in the third quadrant allows the input current to go negative while still maintaining stable operation under low load conditions, which is advantageous. The performance of the qZSC may be improved even further by substituting controlled switches for the rectifier diodes on the secondary (high-voltage) side of the converter. Among the benefits are not just improved efficiency as a result of reduced conduction losses [21], but also the ability to control bidirectional power flow without requiring any other significant topological modifications. In reverse mode, the qZS-network behaves as a low pass LC-filter, which ensures that the output voltage remains stable within a specified regulatory range, as described in [20]. Despite the fact that the first bidirectional ISC concepts were proposed more than five years ago, their viability has been called into question due to the complexity of the power circuit (two qZS-networks are used) [28] or the efficiency and controllability issues that could arise from the use of the power switches' integrated antiparallel diodes as uncontrolled rectifiers ISC's reverse power flow control capabilities have recently been enhanced with the addition of two new techniques that take advantage of the resonant characteristics of the topology to ensure high efficiency in the power conversion process as well as linearity of control variables with little reliance on the operating power [28]. It is discussed in this article as a possible architecture for the modular RBESS's power electronic interface, namely the novel bidirectional qZS dc-dc converter shown in Fig. 2. In the battery discharge (forward) mode, the proposed converter works as a full-synchronous step-up impedance-source converter with shoot-through pulse-width modulation (PWM) (ST-PWM). In battery charging (reverse) mode, the qZS-network is reconfigured into an LC-filter, and the converter operates as a full-synchronous voltage-source step-down dc-dc converter with an appropriately adjusted PWM. The proposed converter, in contrast to the previous approach [32], does not have resonant properties. It has previously been proposed to use resonant features to either extend the voltage control range [29], which is not required in this application, or to use an inefficient alternate reverse energy transfer method [30]. Furthermore, whether or not the converter is resonant has no effect on whether form of reverse energy transfer is more efficient in terms of efficiency. Parallel to this, resonant operation places constraints on converter design by limiting the maximum quality factor Q 1, which in turn restricts the range of transformer leakage inductance values and, as a result, influences the selection of magnetising inductances. As a consequence, due to the relatively high shoot-through current required by the qZS network, resonant operation does not result in soft-switching of the front-end switches during operation. As a consequence, preventing resonance in converters is less difficult to design and maintain than before.

Principle of operation the converter proposed converter

Drawings and oscillograms of current directions indicate that the positive sign of the current corresponds to the directions illustrated in Fig. 2. More significantly, the modulation is the same for both modes, which makes its implementation easier since it is consistent. It is used in the battery charging mode as a component of a dissipative voltage overshoot clamping circuit, whereas it dissipates little power in the battery discharging mode because the qZS-network has inherent dc rail voltage clamping [30] and thus dissipates little power during the battery charging mode. The converter operates in this mode in the same way as the full-bridge qZSC [31]. When a high voltage (HV) side transformer winding is energised, parasitic oscillations may develop. The ST-PWM is achieved via the symmetrical overlap of active states in order to improve transformer utilization while simultaneously reducing losses. While the nature of voltage clamping is more complicated, it is shown in Fig. 5 via the use of simplifications to illustrate the concept.

Simulation results

The Matlab/Simulink implementation of the suggested system is shown in Fig. 3. Fig. 4 indicates the state of charge, Fig. 5 indicate the output current, Fig. 6 indicate the battery voltage, Fig. 7 indicate the transformer voltage, Fig. 8 indicate the output voltage and Fig. 9 is output current.

CONCLUSION

This article describes a bidirectional galvanically isolated dc-dc structure based on a quasi-Z-source. The idea surpasses any current rival in the area of impedance-source converters. It's designed for home battery energy storage systems that are modular. The proposed control system includes on-the-fly converter topology modification to provide acceptable efficiency in any of the energy transfer areas. For the nominal battery voltage, the efficiency is in the region of 95-96 percent, while the range of 20 V to 30 V is covered for the optimum battery usage. In the battery draining mode, the peak efficiency is 97.2 percent, however as the battery voltage lowers, the efficiency diminishes. In the battery charging mode, peak efficiency is lower, but efficiency is less reliant on battery voltage. For modular home BESS with modules cascaded in parallel, the new converter was designed, evaluated, confirmed experimentally, and justified. This method has been verified using MATLAB simulation and testing, and the results indicate that the proposed technique achieves its goal.

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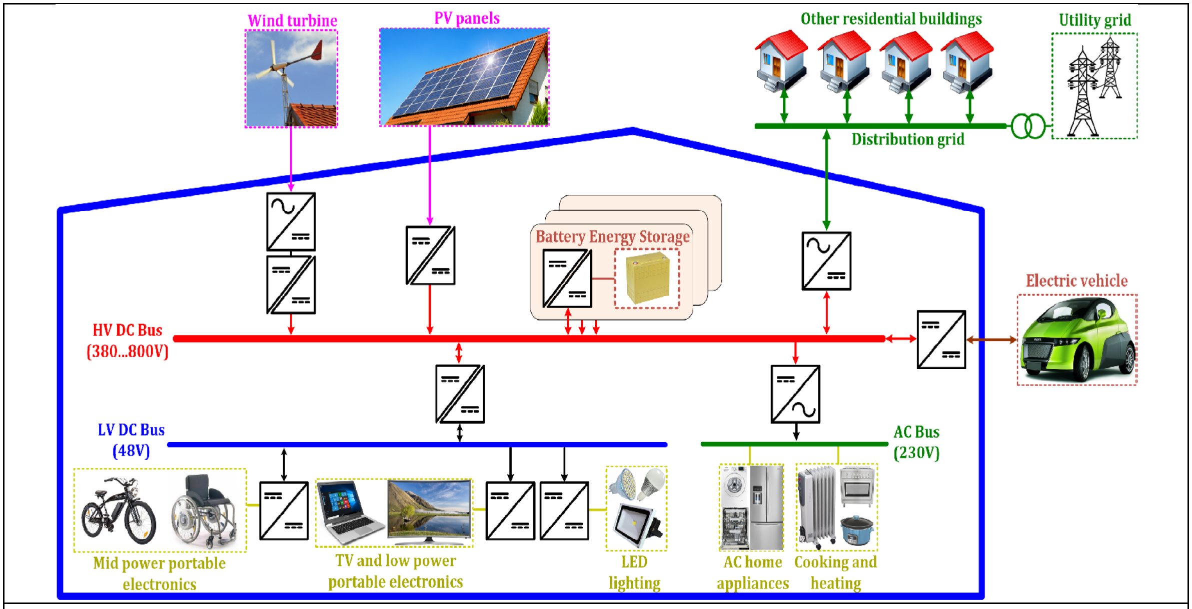

Fig. 1. DC Distribution system

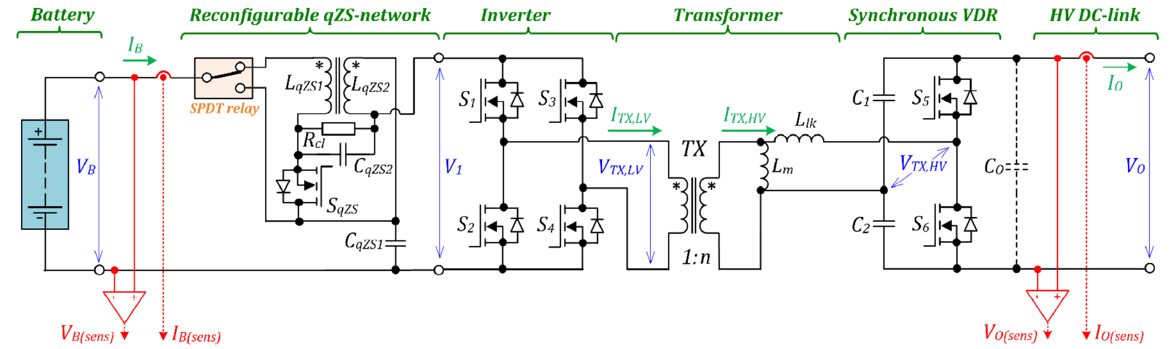

Fig 2: Quasi-Z-source dc-dc converter with the reconfigurable quasi-Z-source system

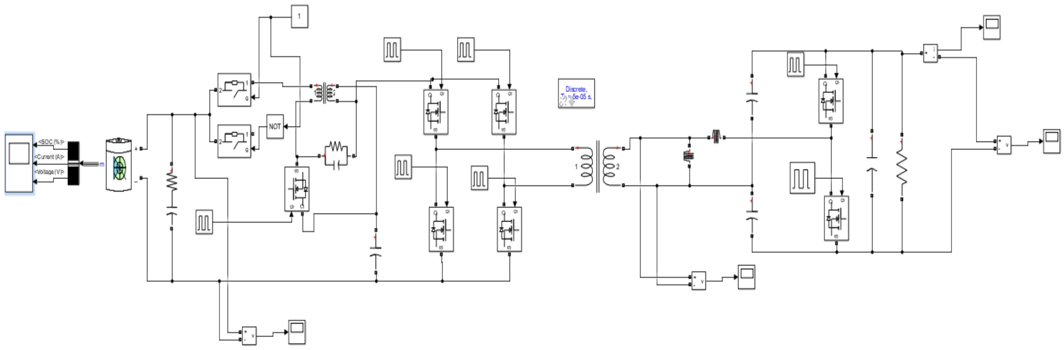

Fig 3: Simulation circuit

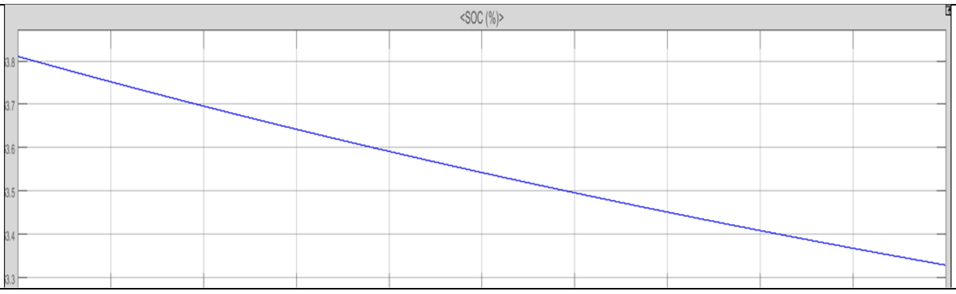

Fig 4: State of charge

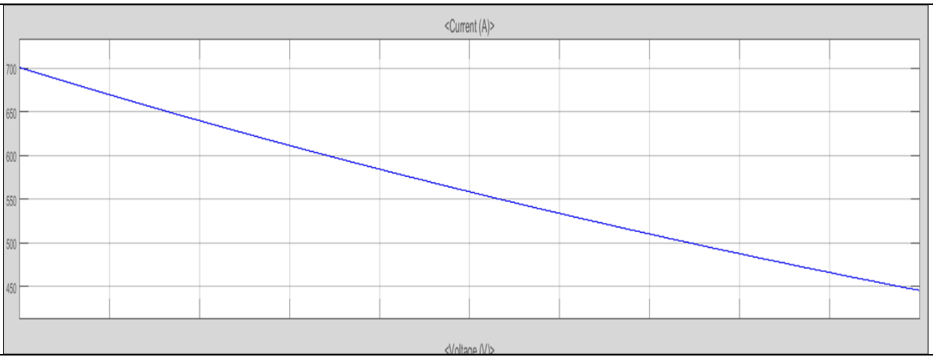

Fig 5: Output current

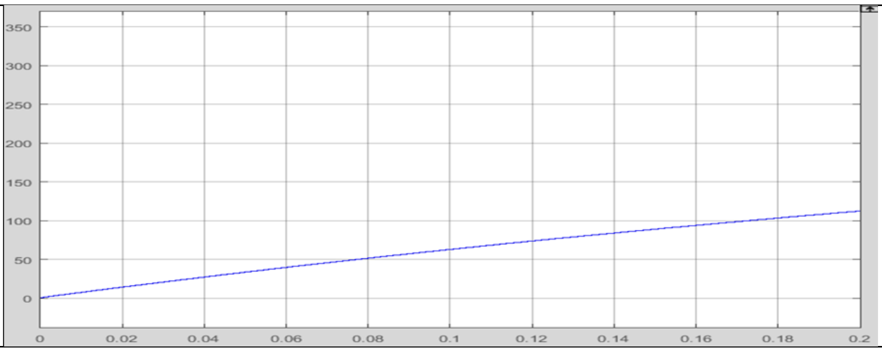

Fig 6: Battery voltage

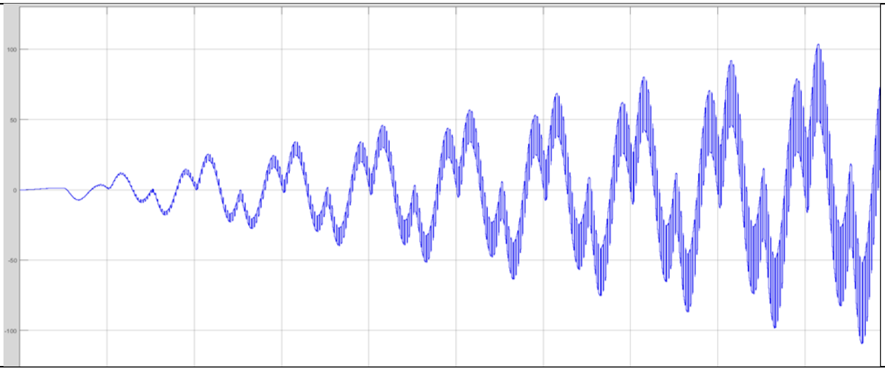

Fig 7: (a) Transformer voltage

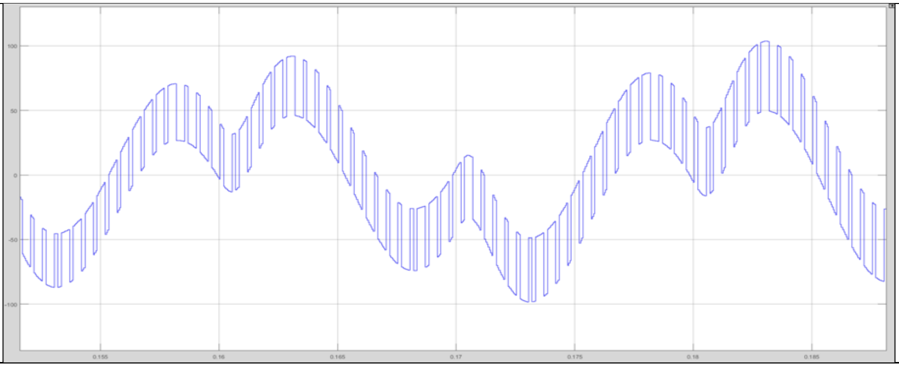

Fig 7: (b) Transformer voltage

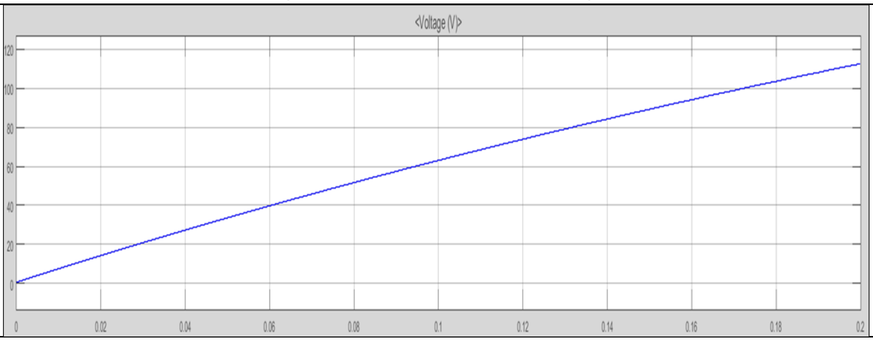

Fig 8: Output voltage

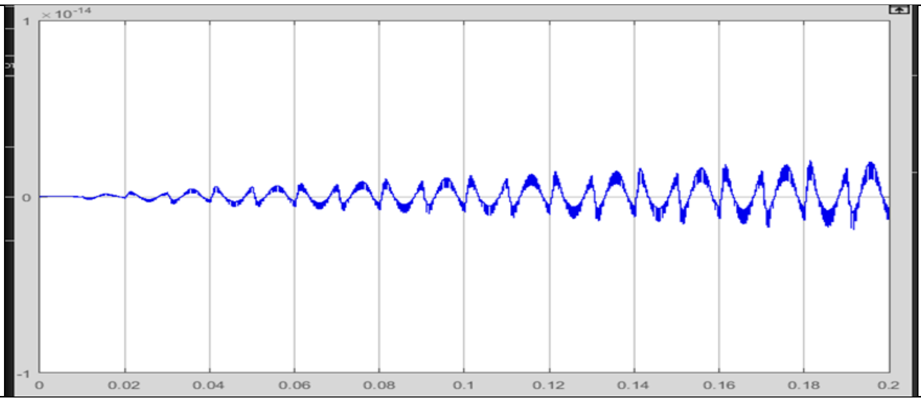

Fig 9: Output current