ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

A New Cascaded Three Port Converter Topology with Soft Switching and Small Inductor Currents

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ABSTRACT

A systematic method for deriving Modular three-port converters (TPCs) from the full bridge-converter (FBC) is proposed in this paper. The proposed method splits the two switching legs of the FBC into two switching cells with different sources and allows a DC bias current in the transformer. By using this systematic method, a novel full-bridge TPC (FB-TPC) is developed for renewable power System applications which feature simple topologies and control, a reduced number of devices, and single-stage power conversion between any two of the three ports. The proposed FB-TPC consists of two bidirectional ports and an isolated output port. The primary circuit of the converter functions as a buck-boost converter and provides a power flow path between the ports on the primary side. The FB-TPC can adapt to a wide source voltage range, and tight control over two of the three ports can be achieved while the third port provides the power balance in the system. Furthermore, the energy stored in the leakage inductance of the transformer is utilized to achieve zero-voltage switching for all the primary-side Switches. The FB-TPC is analyzed in detail with operational principles, design considerations, and a pulse width modulation scheme (PWM), which aims to decrease the dc bias of the transformer. Simulational results verify the feasibility and effectiveness of the developed FB-TPC. The topology generation concept is further extended, and some novel TPCs, dual-input, and multiport converters are presented.

Index Terms— ***PV System, Converters, DC micro grid, SEPIC, MPEI.***

I. INTRODUCTION

Renewable power systems, which are capable of harvesting energy from, for example, solar cells, fuel cells, wind, and thermo-electric generators, are found in many applications such as hybrid electric vehicles, satellites, traffic lights, and powering remote communication systems. Since the output power from renewable sources is stochastic and the sources lack energy storage capabilities, energy storage systems such as a battery or a super capacitor are required to improve the system dynamics and steady-state characteristics. A three-port converter (TPC), which can interface with renewable sources, storage elements, and loads, simultaneously, is a good candidate for a renewable power system and has recently attracted increased research interest. Compared with the conventional solutions that employ multiple converters [9-11], the TPC features single-stage conversion. Between any two of the three ports, higher system efficiency, fewer components, faster response, compact packaging, and unified power management among the port with centralized control. As a result of these remarkable merits, many TPCs have been proposed recently for a variety of applications. One way to construct a TPC is to interface several conversion stages to a common DC bus. But this is not an integrated solution for only a few devices are shared. Some TPCs are constructed from full-bridge as in fig. 1(a), half bridge, or series-resonant topologies as shown in fig. 1(b)by utilizing the magnetic

Cite this article as: Byagari Kanakaraju, Gubba Naveen & Ponaganti Rajendar, "A New Cascaded Three Port Converter Topology with Soft Switching and Small Inductor Currents", International Journal & Magazine of Engineering, Technology, Management and Research, Volume 6 Issue 7, 2019, Page 25-32.

coupling through a multi winding transformer. Power flow control and zero-voltage switching (ZVS) are achieved with phase-shift control between different switching bridges, whose principles are the same as the dual-active-bridge (DAB) topology. Isolation and bidirectional capabilities can also be achieved with these topologies.

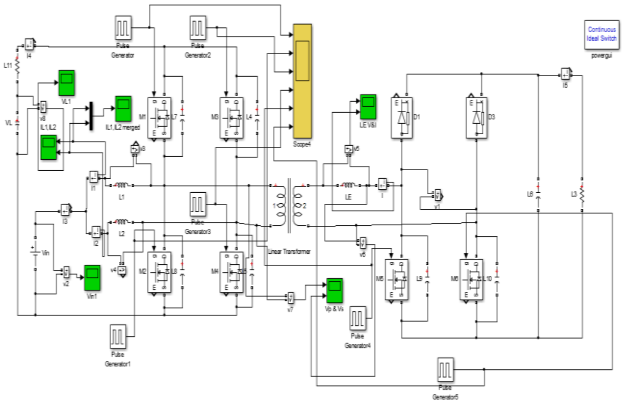

Fig.1. Proposed derivation of Full-bridge Three-port Converter

However, too many active switches have been used, resulting in a complicated driving and control circuit, which may de-grade the reliability and performance of the integrated converters. In a boost-integrated TPC is proposed based on the phase-shift full-bridge converter (FBC) and power flow control is implemented with pulse width modulation (PWM) plus a phase-shift control[17-18]. This principle is further extended to the three-phase FBC. A trimodal half-bridge converter is developed from a half-bridge converter to implement a three-port interface as shown in fig.1.

II. LITERATURE REVIEW

A. Review on Modeling and Control of Three-Port DC/DC Converter Interface for Satellite Applications

This paper presents the control strategy and power management for an integrated three-port converter [6], which interfaces one solar input port, one bidirectional battery port, and an isolated output port. Multimode operations and multiloop designs are vital for such multiport converters. However, control design is difficult for a multiport converter to achieve multifunctional power management because of various cross-coupled control loops. Since there are various modes of operation, it is challenging to define different modes and to further implement autonomous mode transition based on the energy state of the three power ports. A competitive method is used to realize smooth and seamless mode transition. Multiport converter as shown in fig. 2 has plenty of interacting control loops due to integrated power trains. It is difficult to design close-loop controls without proper decoupling method. A detailed approach is provided utilizing state-space averaging methods to obtain the converter model under different modes of operation, and then a decoupling network is introduced to allow separate controller designs. Simulation and experimental results verify the converter control design and power management during various operational modes.

The control strategy and modeling of the three-port DC/DC converter for satellite application that interfaces a solar input panel, a rechargeable battery port, and an isolated output port was presented in this paper. The converter has three circuit stages to allow two control inputs that are used to regulate two of the three ports. The output voltage is regulated at any given time, but either input port or battery port can be regulated depending on which is most urgently needed according to the available solar power and battery state of charge. The control design for multiport converter is challenging and needs to manage power flow under various operating conditions. Therefore, the control strategy must be “powerful” and “intelligent” enough to realize complicated control tasks, and should have different operational mode transition control [14-16]. A competitive method was Since matrices A and B are derived, transfer functions for output and input voltage to duty-cycle values can be extracted from the small-signal model, as shown in Fig. 3. The same decoupling network is adopted here as the battery regulation mode. In fact, the design of OVR is exactly the same, because no matter in which mode, the transfer function of $vo/d1$ should be the same even though different approaches are applied, and therefore, Bode plot of $vo/d1$ before and after compensation in this mode should be the same as the battery-regulation Mode utilized to realize autonomous mode transitions.

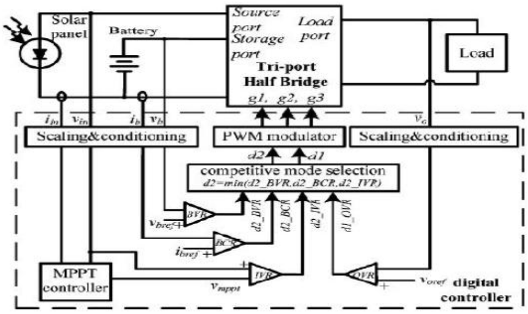

Fig. 2. Three-port modified half-bridge converter topology, which can achieve ZVS for all three main switches (S1, S2, and S3) and adopt synchronous rectification for the secondary side to minimize conduction loss.

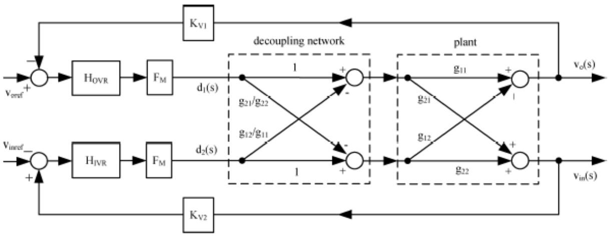

Fig. 3. Small-signal model of battery-balanced mode, control inputs and outputs are decoupled to enable separate controller design. *Vo* ref and *Vin* ref are the references for output voltage and input voltage, respectively. *H*OVR and *H*IVR are the compensators that need to be designed.

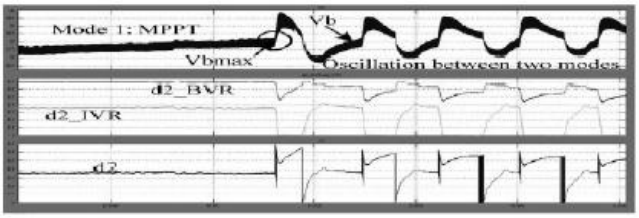

Fig.4.Oscillation between modes 1 and 2 because of the instant switching of duty-cycle value.

avoids possible system oscillations due to elimination of instant duty-cycle value change is shown in fig. 4. This paper also presented a general modelling procedure specially tailored for three-port converters. Since there are many control inputs and state variables for multiport converter, converter model derivation adopts matrix-based averaged state-space method.

Moreover, the small-signal models for different operational modes were obtained separately, while the model derived for each model includes two ports' dynamic characteristics other than one for two-port converters.

Then, a decoupling network was adapted to solve the problem of control-loop interdependence, so that each port can be treated as an independent subsystem. With proper decoupling, it is then possible to analyze each port's control loop separately. Control-loop design examples in all operational modes were presented in detail. Operation of this converter for satellite application was experimentally verified using a 200-W prototype.

B. An Integrated Three-port Inverter for Stand-alone PV Applications

This paper presents a novel concept of integrated three-port interface for stand-alone photovoltaic applications[7]. The three-port topology interfaces one solar panel input port and one bi-directional battery port to an isolated output port which generates a rectified sinusoid voltage. Then an unfolding circuit can be adopted to generate an AC wave with very high efficiency because it operates at very low frequency (50/60Hz). Therefore, this proposed structure uses only one switch-mode conversion stage to replace several independent converters and inverters in order to reduce component count and save the cost, making itself a valuable choice for low cost low power standalone PV system. The circuit operation and control architecture of the three-port interface are presented. It can achieve maximum power harvesting for the solar port, battery charge control for the battery port, while keeping a regulated rectified sinusoid output. The experiments of the three-port interface confirm the topology operation and its ability to achieve the multi-functional power

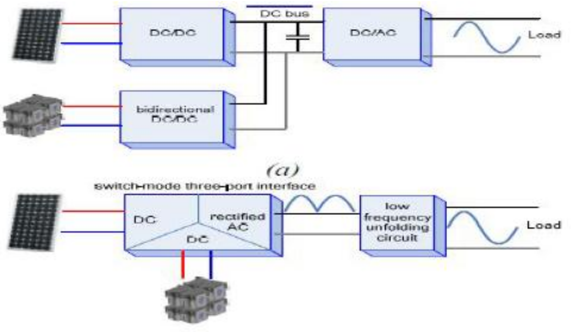

Fig.5.Two PV stand-alone structures, (a) conventional independent converter structure; (b) new integrated structure

Sunshine is an abundant resource, while PV technology is clean, quiet, and suitable for both grid-tied and stand-alone applications[7,8]. For remote areas where the AC mains are not available, the stand-alone PV system provides power to the local user behaving as an ac voltage source. Because of the intermittent nature of PV Source, a battery backup is necessary to store the excess energy during the high insolation period and source the load when the PV energy is not available or just not sufficient to support the full load. For the safety issue, isolation is normally required for such application of inverters. Due to the PV characteristics of nonlinearity, the inverter will have a wide input voltage range, which is undesirable. Conventionally, as in Figure 5(a), a DC/DC pre-conditioning converter is needed to boost the PV output to a constant voltage, provide proper isolation, and also achieve maximum solar power harvesting.

In order to control the battery charging and discharging rate, a bidirectional DC/DC converter[12] or two unidirectional converters will be required. Then a switch-mode DC/AC inverter will chop this DC bus voltage into a sinusoidal voltage by SPWM (Sinusoidal Pulse Width Modulation) method. This conventional structure has three or four switches-mode conversion stages, therefore the component count and cost are high and the power density is low.

C. Quantitative Evaluation of DC Microgrids Availability: Effects of System Architecture and Converter

Topology Design Choices

This paper presents a quantitative method to evaluate the DC microgrids availability by identifying and calculating minimum cut sets the occurrence probability for different micro grid architectures[1] and converter topologies. Hence, it provides planners with an essential tool to evaluate downtime costs and decide technology deployments based on quantitative risk assessments by allowing to compare the effect that converter topologies and micro grid architecture choices have on availability. Conventional architectures with single-input converters and alternative configurations with multiple-input converters (MICs) are considered. Calculations yield that all micro grid configurations except those utilizing center Conve- writers achieve similar availability of 6-nines. Three converter topologies are used as representatives of many other circuits. These three benchmark circuits are the boost, the isolated SEPIC (ISEPIC), and the current-source half bridge. Marginal availability differences are observed for different circuit topology choices, although architectures with MICs are more sensitive to this choice. MICs and, in particular, the ISEPIC, are identified as good compromise options for DC micro grids source interfaces. The analysis also models availability influence of local energy storage, both in batteries and generators' fuel. These models provide a quantitative way of comparing DC micro grids with conventional backup energy systems. Calculations based on widely accepted data in industry supports the analysis.

This paper presents a quantitative framework based on mcs theory that allows evaluating how dc–dc converters circuit topologies and system electrical architecture design choices influence dc micro grids availability. The impact on availability of both conventional architectures with SICs is shown in fig. 6 and alternative configurations with MICs are evaluated. Calculations indicate that power architectures with MICs seem a good compromise approach suited for highly available micro grids because they enable source diversity—an essential need in order to achieve high availability—and achieve with fewer circuit component availability only marginally below that of SIC modules.

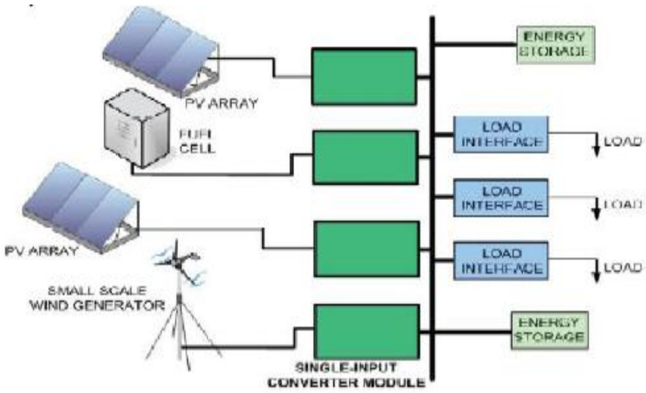

Fig 6 Possible dc microgrid architecture with SICs.

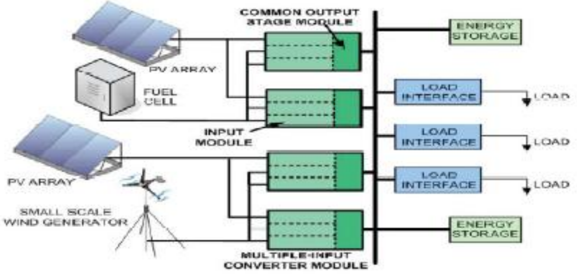

Fig 7. Possible DC microgrid architecture with MICs.

Configurations with center converters have availabilities of about 5-nines with redundant DG sources and 4- nines without redundancy. These values are an order of magnitude worse than those calculated for modular SICs or MICs is shown in fig. 7. Three converter topologies are considered as benchmarks because they are representative of other possible suitable alternatives: boost, ISEPIC, and CSHB. Although the ISEPIC has availability only marginally below than the highest one achieved by the boost, the ISEPIC provides more operational flexibility because it can achieve high-voltage conversion ratios and track the entire Output range of sources in search of a maximum power point. Availability models for battery energy storage and discontinuous fuel delivery are included in the discussion. These models provide a way of quantifying the impact of locally added energy storage and of tradeoffs between battery storage and local fuel storage.

D. Multiport Power Electronic Interface Concept, Modeling, and Design

The continuous effort to improve efficiency, reduce particle, and greenhouse gas emissions leads to the emergence of the concept “more electric.” This concept helps to boost the performance as well as the flexibility of the domestic and vehicular applications; however, on the other hand, it excessively burdens current power networks (including vehicle power systems). In order to remedy this problem, simultaneous usage of renewable sources and energy storages is encouraged. A multi converter system is commonly adopted to process the renewable power in a form of distributed generation.[2-5]. However, due to the discrete structure of such systems, power flow and load regulation are coordinated via communication channel, which inevitably reduces the reliability and dynamic response of the system. This paper presents the concept of the multiport power electronic interface (MPEI) for renewable energy sources and storages. With a unified modular topology and highly integrated digital control system, controlled quasi-current source is achieved for each input port in both steady-state and transient powersharing modes. MPEI analysis, modelling, design is shown in fig. 8, and system operation is treated in a systematic manner in this paper. Both power stages and digital control system are implemented for a five-port MPEI. Experiments are conducted under meaningful operation scenarios. The results are presented to prove the feasibility of MPEI concept and system design methodology.

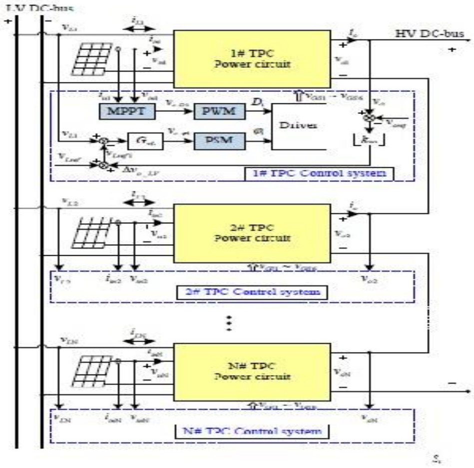

Fig.8. MPEI circuit topology

Considering the multiple roles of a generator, power conditioner, and energy storage interface, a multiport converter is expected to offer a direct interface to different sources, storages, and loads, which means that the voltage/current waveforms at output port are readily usable. The concept of MPEI is addressed here: A multiport power electronic interface (MPEI) is a self-sustainable multiple-input/output static power electronic converter[13], which is capable of interfacing with different sources, storages, and loads. The integrated control system of MPEI enables excellent dynamic and steady-state performance, which renders optimal renewable energy harvesting, optimal energy management, and optimal and economical utility grid interactions in a deregulated power market This paper introduces the concept of MPEI for multisource power processing applications. Circuit topology, integrated digital control structure, and modes of operation are proposed for the source interface of a five-port MPEI. The local control loops are designed to achieve relieved stress on renewable sources, steady state as well as dynamic load sharing between different renewable sources and energy storages, and mitigated subsystem interactions. The experimental work is conducted in the selected meaningful mode of operations is shown in fig. 9; the resulted performance proves the feasibility of the MPEI concept and control system design methodology[19-20].

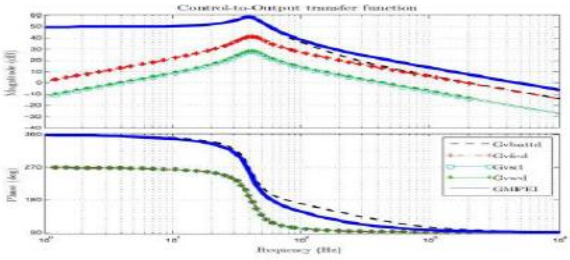

Fig 9 Disturbance injection under multi port operation

III. SIMULATION USING MATLAB

For simulating the proposed circuit using MATLAB simulink & simpower system blocks are used.

A. Simulation of .Proposed topology

In the fig. 10 shows the simulation model of the proposed topology in Matlab-Simulink. In order to verify the performance of the proposed converter, simulations have been done in all three operating modes of MATLAB software. A resistive domestic load *R* with the peak power of 1kW and the average power of 0.75kW is supplied at the dc link by the proposed system.

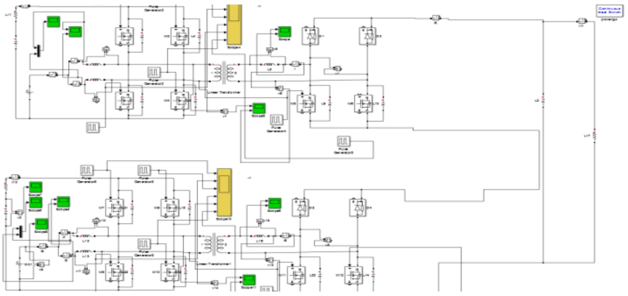

Fig 10. Simulation Result

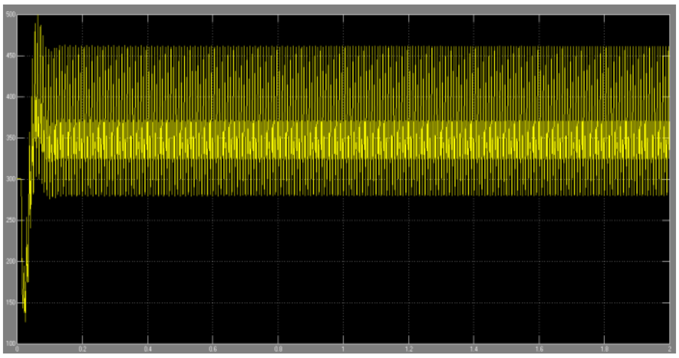

Fig 11. Input electrical condenser VL Voltage

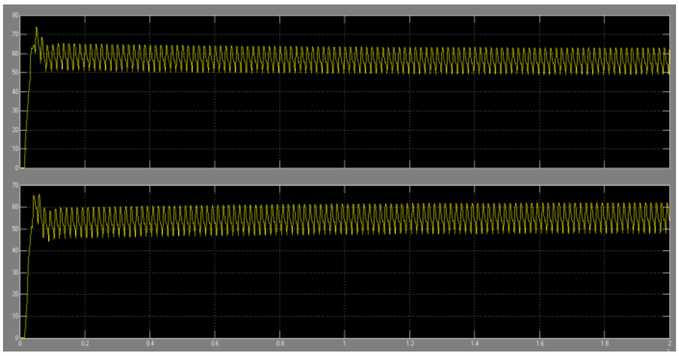

Fig 12. L1, L2 inductance currents

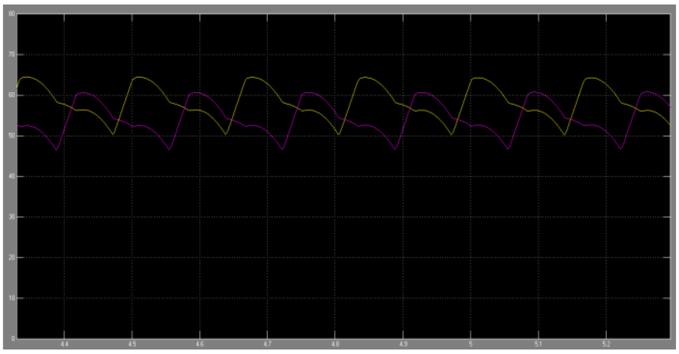

Fig 13 L1,L2 inductance currents incorporate

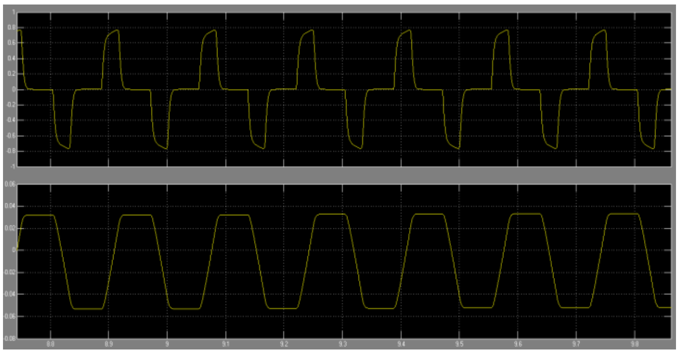

Fig 14 Vp & Vs Voltages

IV. CONCLUSION

Novel FB-TPCs have been proposed and investigated in this paper. The FB-TPCs are rooted in the FBC and generated by splitting the two switching legs of the FBC into two switching cells, connecting the two cells to different sources, and utilizing the magnetizing inductance of the transformer as a filter inductor. A buck-boost converter is integrated in the FB-TPC and used to configure the power flow path between the two ports on the primary side of the converter, which is aimed to handle a wide range of source voltage. ZVS has been achieved for all the primary-side switches by utilizing the energy stored in the leakage inductance of the transformer. This results in high conversion efficiency.

The topology generation concept is further extended and some novel TPCs and multiport converters are derived. The proposed converters offer the advantages of simple topologies and control, reduced number of devices, and a single-stage power conversion between any two of the three ports. They are suitable for renewable power systems that are sourced by solar, thermoelectric generator, etc., with voltages vary over a wide range. The analysis of the operating principles and the experimental results of the FB-TPC is given, with the modulation proposed, to verify the proposed topology derivation method.

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