A Brief Review on Partially Isolated Bidirectional Multiport Converters For Renewable Energy Sourced DC Microgrids

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Abstract- The increasing energy demand and the growing concern over the environmental effects of conventional sources augmented the integration of renewable energy sources as distributed generation units to the power grid. But integrating the renewable energy sources into the existing aged utility AC grids can introduce new difficulties such as an increase in voltage, synchronization, and protection issues. DC microgrids are becoming a solution to these problems by providing a reliable interface for connecting the renewable energy sources, storage, and the grid. Static power converters are required for matching the voltage levels of renewable energy sources and storages with that of the grid. Recently, multiport power electronic converters are gaining importance because of their compact size, centralized control and simple power flow management techniques. In renewable energy sourced micro-grid, it is required to have a battery back-up to overcome the on-off nature of renewable energy sources. For safety requirements, isolation is required between source and load side. And for interfacing storage , bidirectional power paths are required. In such a case, a multiport converter with bi-directional power flow capability and isolation becomes necessary in connecting various renewable energy sources with load and battery facilities. Among the different categories of multiport converters, partially isolated multiport converters combine the advantages of isolated and non-isolated circuits by providing required isolation while improving the power density by maintaining compact circuit size. In this paper, a brief overview of partially isolated multiport dc-dc converter topologies for harvesting renewable energy in DC microgrids is presented.

Keywords Renewable Energy, DC micro-grids, Multi-port dc-dc converters, Bidirectional converters.

1. Introduction

Harvesting electrical energy from renewable energy sources has become inevitable in these days to meet the increasing energy demand of both domestic and industrial sectors. Also, the depleting conventional sources of energy and their ecological effects on the environment shifted the focus towards the green sustainable energy sources. Thus, this demand and environmental concern increased the penetration of renewable energy sources as distributed generation units into the power grid. But the penetration of renewable energies into the existing utility AC grids will impose new challenges such as voltage rise, protection issues, grid safety, power quality, and reliability. To overcome the above-said challenges, a concept called micro-grid has been introduced and developed for supplying the local energy demands. In the micro grid setup, various distributed generation units are connected to the local substation units without extending the existing utility grid which is economically unfeasible [1]-[4]. Currently, most of the micro-grids are adopting the principles of AC power system (AC micro-grid). But the available renewable energy sources directly generate DC power or AC power with varying voltage and frequency. Further the developments in the area of power electronics increased the number of dc loads like LED lights, computers, mobile phone or laptop chargers etc. which operates on dc power. Thus, these devices for their operation requires conversion of available ac power to dc power and normally for that conversion, inefficient line frequency rectifiers are used. Moreover, the dc power from the renewable sources has to be converted to ac to feed the grid and again to dc, to supply these dc loads. This dc-ac-dc conversion stages increases the losses and complexity of the system and reduces the efficiency. DC micro-grids are emerging as a solution to these problems due to its natural interfacing capability with most of the renewable energy sources, modern dc loads and energy storage facilities [5]-[9]. The reliability and the efficiency of micro-grids can be improved cost-effectively by adopting dc distribution system (DC micro-grid). Further, by including some intelligent devices and by adopting intelligent energy management techniques it can be upgraded to a smart dc micro-grid with improved overall efficiency and reliability [10]-[12].

A recent statistics show that almost 70% of generated electrical power is transferred to the grid through the static power electronic converters. The static power electronic converters connect the source to the load/grid in such a way to match the parameters of the renewable energy sources with that of the load/grid [13]. The static power converters are extensively used in renewable energy systems for matching the source with the load/grid requirements, for maximum power tracking and to improve the static and dynamic characteristics. To overcome the on-off nature of the renewable energy sources, connecting renewable energy sources of different types to the grid or a stand-alone load along with a battery back-up becomes necessary to ensure uninterpretable power supply. For connecting different types of renewable energy sources along with the battery to supply load or grid, an individual converter for connecting each source to the grid or a multiport converter for connecting multiple sources to the grid can be used. A multiport converter is preferred for connecting different renewable energy sources to the load or grid because of their less expensive and high power density features [14]-[21]. The multiport power electric interface minimizes the losses and improves the efficiency by removing multiple conversion stages. Further, the effective sharing of passive and active devices in the multiport structure leads to circuit size reduction and power density improvement. The multiport interface also provides a centralized control and avoids the use of communication bus requirements [22]-[23]. A schematic of multiport converter set-up is shown in fig. 1.

Various topologies of multiport converters have been developed and applied for renewable energy sourced systems. The available topologies of multiport converters can be placed into any one of the following three categories: Non-isolated [24]-[28], fully isolated [29]-[33] and partially isolated [34]-[42] topologies. Non-isolated topologies use dc-link/electrical coupling whereas fully isolated and partially isolated topologies use magnetic coupling using a transformer for connecting different sources or loads. In non-isolated topologies, the ports are connected to other ports through direct connection without any isolation, thus resulting in a compact structure and high power density [37]. The dc linking or electrical coupling in non-isolated topologies allows, only sources with nearly equal operating voltages to be integrated. Mostly, these non-isolated converters are developed from the conventional buck, boost, and buck-boost converter fundamental topologies and its typical structure is shown in fig.2. These non-isolated multiport converters have a constraint over the voltage gain since it depends only on the duty cycle. Another limitation is, it can be applied only for systems that don't require galvanic isolation. Fully isolated topologies are derived from conventional full-bridge or half-bridge topologies or by combining both the topological structures. Fully isolated topologies use multi-winding high-frequency transformers for connecting different sources with the load, thus providing the advantage of integrating the sources of different voltage levels easily. The typical structure of the fully isolated multiport topology is shown in fig.3 Isolation and bidirectional power transfer feature and Zero Voltage Switching (ZVS) are inherent in these topologies.

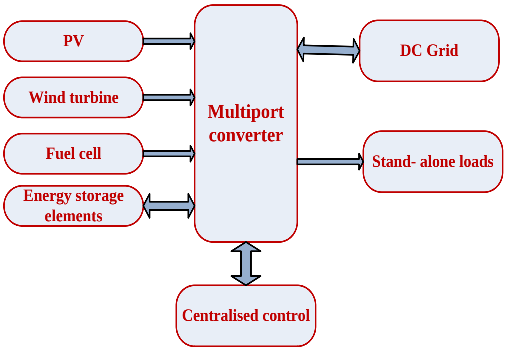

Fig. 1 Multiport converter-Schematic

Partially isolated topologies are derived by combining isolated and non-isolated topologies. The partially isolated topologies provide the required isolation for the load while maintaining the compact structure with high power density and flexible voltage levels. Partially isolated topologies use a single winding high-frequency transformer for providing necessary isolation between the source side and the load side. And dc-link/electrical coupling for combining more than one source or load at the primary and secondary side respectively. A typical structure of partially isolated multiport topology is shown in fig.4.

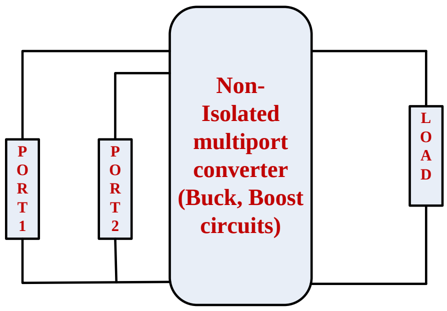

Fig. 2 Non-isolated multiport topology

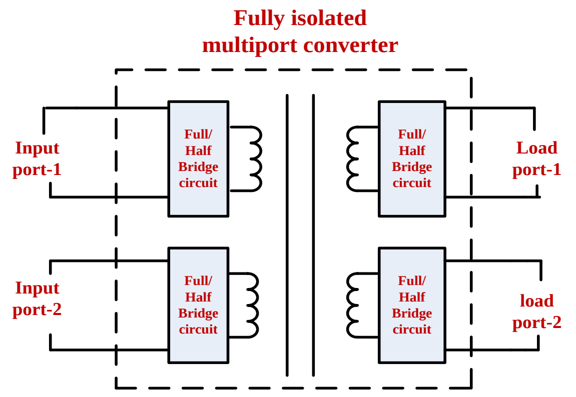

Fig. 3 Fully-isolated multiport topology

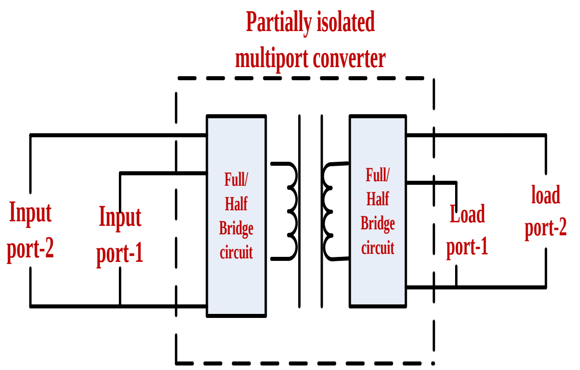

Fig. 4 Partially- isolated multiport topology

Because of the noticeable advantages, many partially isolated multiport converters have been developed for various applications [40]. Among the multiport structures it can be seen that partially isolated converters provides isolation and also circuit size reduction by sharing the devices and improving the power density. Most of the literatures reported three port partially isolated converters which depends on only one renewable energy source. Four port partially isolated topologies connecting two sources and a storage to load were reported in [37] & [42]. The limitation of partially isolated converter is that it does not allow widely varying voltage levels at the ports as that of a fully isolated converter. In the following sections, some of the partially isolated multiport converters reported in the recent literature are briefly reviewed.

2. Partially Isolated Multiport Converters

2.1. Multi-input bidirectional converter with combined direct link and magnetic coupling

In [34], a multi-input converter which uses direct link electrical coupling and magnetic coupling is developed and applied for fuel cell sourced application. In fig.5 the topology of the converter is shown and fundamental waveforms representing the operation of the converter are shown in fig.6. It uses six controllable semiconductor power switches (S_1-S_6) with a high-frequency transformer for isolating the load from the source. The current drawn from the fuel cell and supercapacitor is continuous. Switches S_1, S_2, and S_3, S_4 form two boost half bridges (HB2 and HB3) and switches S_5 and S_6 form a direct-connected bidirectional half-bridge (HB1) connecting the supercapacitor. The high-frequency isolation transformer not only provides required isolation but also increases the low input side dc voltage to a higher level at the output side. Transformer's leakage inductance is also used as an element for transferring energy.

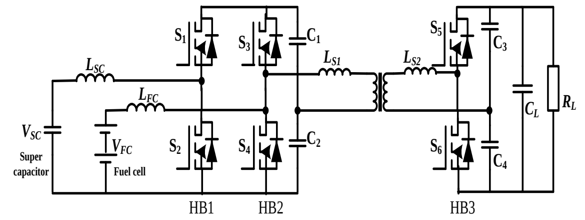

Fig. 5 Multi-input bidirectional dc-dc converter

The variations in voltage at supercapacitor port are corrected by appropriately varying the duty cycle of the first half bridge switches by PWM strategy. Other two half bridges are switched at fixed 50% duty cycle with a phase shift between them. A pair of complementary gate control pulses is used to drive the individual half bridges. Further, the PWM pulses for HB1 and HB2 are phase shifted by 180 degrees for interleaving. The power flowing to the load is given by equation (1) and can be seen that is bidirectional,

$$P = \frac{V_{in} V_0 \varphi}{n \omega L_x}\left(1 - \frac{\varphi}{\pi}\right) \quad (1)$$

where, V_{in} is the input side dc voltage, V_o is the output voltage, $\omega = 2\pi f$ (f is switching frequency) , n is the turns ratio of the transformer, φ is the angle of phase shift between the gating pulses and L_x is the leakage inductance referred to the primary side. The output power depends on the angle of phase shift and the leakage inductance for the fixed switching frequency. This topology can be used in medium power level fuel cell sourced applications.

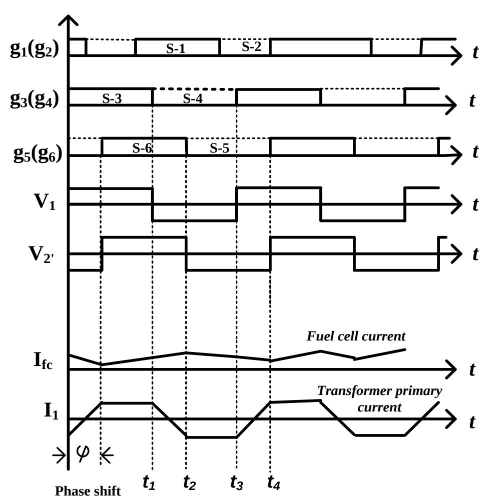

Fig. 6 Key waveforms of the multi-input bidirectional converter

2.2. Bidirectional partially isolated three port converter

The bidirectional converter proposed in [35] employs the lowest number of switching device among the available three-port bidirectional topologies (one switch for each port). In this converter, the PV source charges the battery and the battery discharges to feed the load. This can only be used for stand-alone applications and not for the micro-grid since power transfer from the output side to source side is not possible. For overcoming this limitation, in [36] two controllable switches (S_3 and S_4) are introduced at the secondary side of the high-frequency transformer and the resulting topology is shown in fig.7. This converter can be applied for tracking the peak power point of PV source and simultaneously for charging the battery from dc grid or PV.

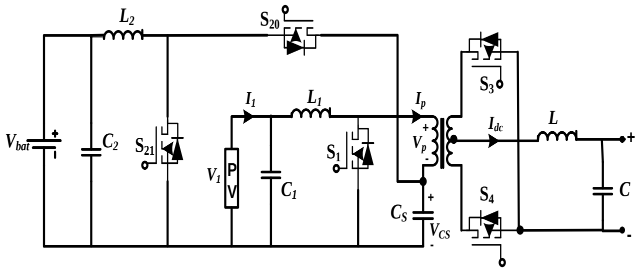

Fig. 7 Bidirectional partially isolated three-port dc-dc converter

The voltage generated from the PV is controlled by main switch S_1. The main switch S_1 also reverses the current flowing through the transformer. The high-frequency transformer has the turn ratio of n and for most of the applications, n is less than unity. The converter has two modes of operation: buck mode (power is transferred from load side to source) & boost mode (power is transferred from the source side to load side). Fig.8 shows the buck and boost mode operational waveforms of the converter.

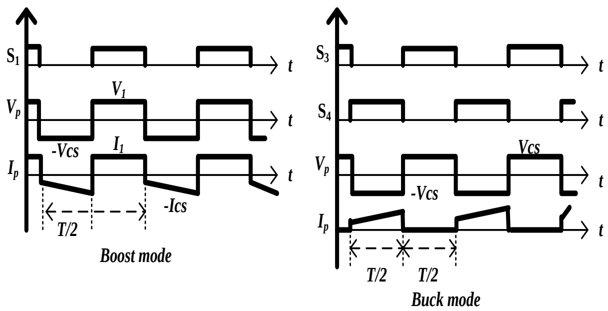

Fig. 8 Key waveforms of Three- port partially isolated bidirectional converter

2.3.Buck-Boost Four port Converter

In [37], a four-port converter with two PV sources of different ratings and a battery back-up for satellite application is proposed. The topology of the buck-boost four port converter is shown in Fig.9. Switches S_1 and S_2 and inductor L_1 are integrated to a boost converter and the switches S_3 and S_4 with inductor L_2 are integrated into another boost converter. These boost converters are used to connect the two PV sources to the storage element. From battery to the load the converter acts as a phase shifted bi-directional converter. Fig.10 shows the operational waveforms of the buck-boost four port converter.

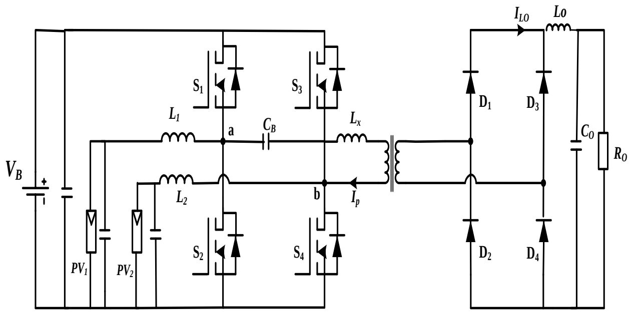

Fig. 9 Buck-Boost four port converter

The duty ratio of the boost converter switches are used for controlling the power transfer between the PV sources and the battery and also for tracking peak power of the sources. The shift between the phase angles of gate pulses of the boost circuits at the primary side is used to control the voltage at the output port. Voltages at the battery and the output are given by,

$$V_b = \frac{V_{PV1}}{1-D_{PV1}} = \frac{V_{PV2}}{1-D_{PV2}} \quad (2)$$

where, the battery voltage is V_b , V_{PV1} and V_{PV2} are voltages of sources PV_1 and PV_2 respectively, D_{PV1} and D_{PV2} are the duty ratio of the switches.

$$V_0 = \left\{ nV_b \left[\frac{\varphi}{2\pi}(1-\Delta D_{PV21}) + 2\Delta D_{PV21} - 2\Delta D_{PV21}^2\right], \quad \Delta D_{PV21} > 0, \right.$$

$$= \left\{ nV_b \left[\frac{\varphi}{2\pi}(1+\Delta D_{PV21})\right], \quad \Delta D_{PV21} < 0 \right. \quad (3)$$

where, the output voltage is V_0, n is transformer turns ratio, φ is the angle of shift between the switching legs of input side and ΔD_{PV21} is the difference between the duty ratio D_{PV1} and D_{PV2}.From the equation (2), it is clear that from PV sources to the storage battery, the converter works like a boost converter. Also from equation (3), it is clear that from battery and PV side to the load side the converter works as phase shifted converter.

2.4.PWM and Secondary side Phaseshifted Converter

In most of the boost integrated full bridge converters formed by interfacing the boost circuits with the primary side phase shifted full bridge circuits, the two control parameters (duty cycle and phase shift) are coupled. This coupling between these two control parameters will increase the complexity of the control system [38]. To overcome such complexities in control, secondary side phase shifting control technique was developed and reported in the recent literature. One such converter employing secondary side phase shifting is introduced in [39] and it is shown in fig.11. Here an interleaved buck-boost converter is combined with a secondary side phase shifting converter. An inductor with high operating frequency is employed for power transfer from primary side to secondary side.

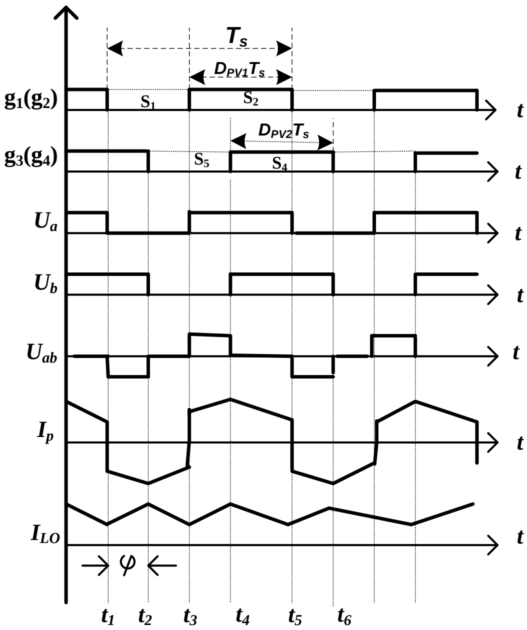

Fig. 10 Key waveforms of Buck-Boost four port converter

Duty cycle adjustment of the switches S_1, S_2, and S_3, S_4 are used for peak power tracking and for the battery charge and discharge control. Further, the shift between the phase angles of the source side and load side switches is used to control the voltage at the output. Key waveforms representing the converter operation are shown in Fig.12. This converter provides decoupled power flow control by separating the control parameters, the duty cycle of the switches and the phase shift between them. It tracks the maximum power point of sources while reducing the circulating current. Current ripples are also minimized due to interleaving.

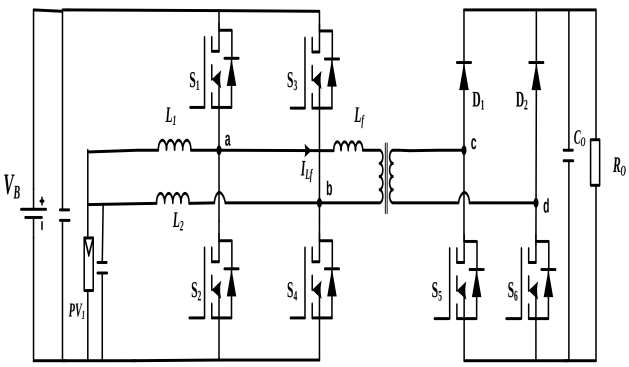

Fig. 11 PWM and secondary side phase shifted converter

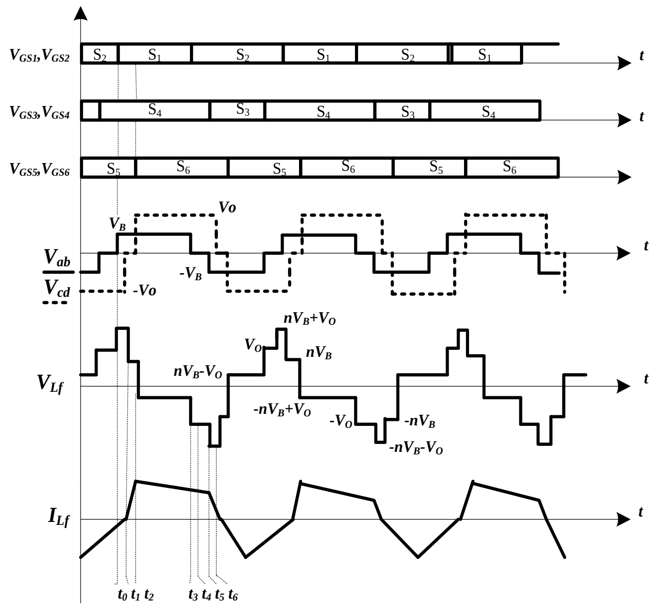

Fig. 12 Key waveforms of PWM and secondary side phase shifted converter

2.5. Secondary side regulated converter with bridgeless boost rectifier

In [40], a full bridge three port converter is derived by interfacing an interleaved bi-directional converter with a boost rectifier and it is shown in fig.13. The key waveforms depicting the operation of the converter is given in fig.14. It employs secondary side regulated control strategy for decoupled power flow management. Input current ripples are minimized by interleaving. A bridgeless boost rectifier is employed at the secondary side to convert ac to dc more efficiently by reducing the number of semiconductor components and their conducting losses. Unlike the bridgeless conventional boost rectifier circuits (which works in line-frequency), this converter works in high frequency. The normalized voltage conversion ratio of this converter is given by,

$$G = \frac{V_0}{2n V_{pv}} \tag{4}$$

where, V_{pv} is the voltage of PV source, the output voltage is V_0 , and transformer turns ratio is n.

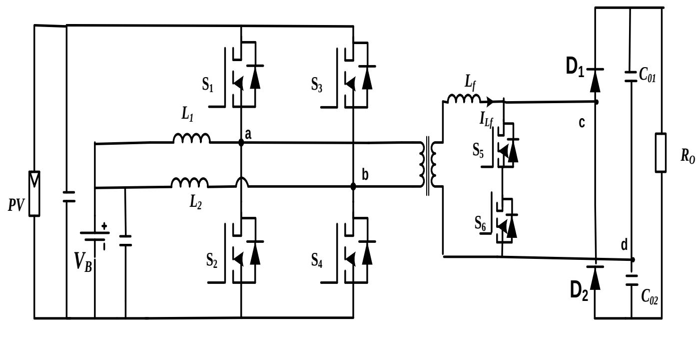

Fig. 13 Secondary side regulated converter

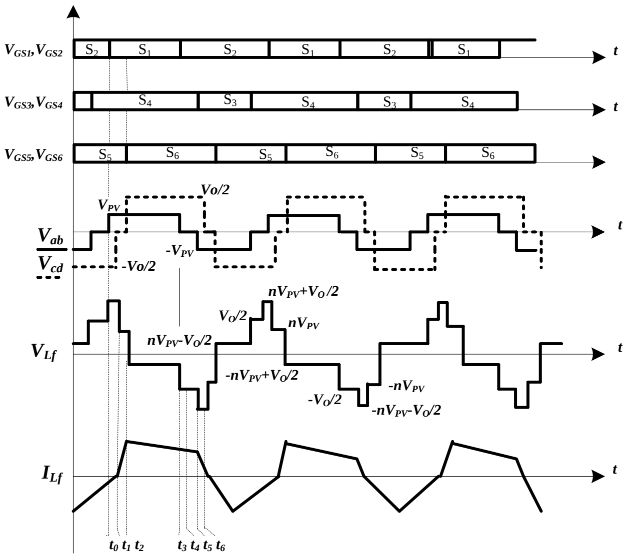

Fig. 14. Key waveforms of secondary side regulated converter

2.6. Three port full bridge bidirectional PWM with phase shifted secondary side control

The partially isolated converter reported in [41], is the integration of non-isolated buck-boost converter and the isolated dual active bridge (DAB) converter. The switches S_1, S_2, S_3 and S4 with inductors L_1 and L_2 form the bidirectional interleaved buck/boost converter and is shown in fig.15.

The two full bridges formed by switches S_1-S_4 and S_5-S_8 are interconnected through a high-frequency transformer to form a dual active bridge converter. The switches S_1-S_4 are shared by both the buck/boost converter and DAB converter. This device sharing increases the power density of the converter.

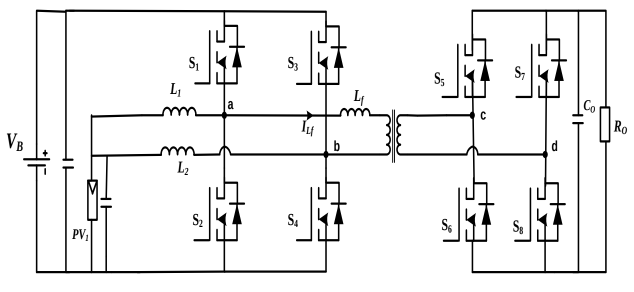

Fig. 15 Full bridge three port bidirectional converter

The power transfer between the source and the energy storage device is controlled through the duty ratio adjustment of switches at source side and the duty ratio adjustment of the switches are also used for maximum power tracking of the renewable source. The shift between the phases of gate pulses of primary and the corresponding secondary switches is used for controlling the load voltage. Key waveforms given in fig.16 depicts the working principle of the converter. The switches at the secondary side attain ZVS naturally without any constraints. The presence of inductors in the primary side limits the ZVS range of the switches. The soft switching range of the switches at the input side is determined by the inductor current values. The output power flowing to the load is given by equation (5),

$$P_O = \frac{N_1 V_b V_O}{2N_2 L_f f_{sw}}\left((m-2)D^2 + (1-m)D - m\left(\frac{\varphi}{\pi}\right)^2 + m\frac{\varphi}{\pi} + \frac{m}{4}\right) \quad (5)$$

where, N_1 and N_2 are the number of primary turns and secondary turns, L_f is value of the ac inductor, f_{sw} is the device switching frequency, V_b is voltage of the battery, V_O is the value of load voltage, φ is the shift between the phase angle of gating pulses of the primary switches and secondary switches and m is the voltage gain of the converter given by the relation, $m = \frac{N_1 V_O}{N_2 V_b}$.

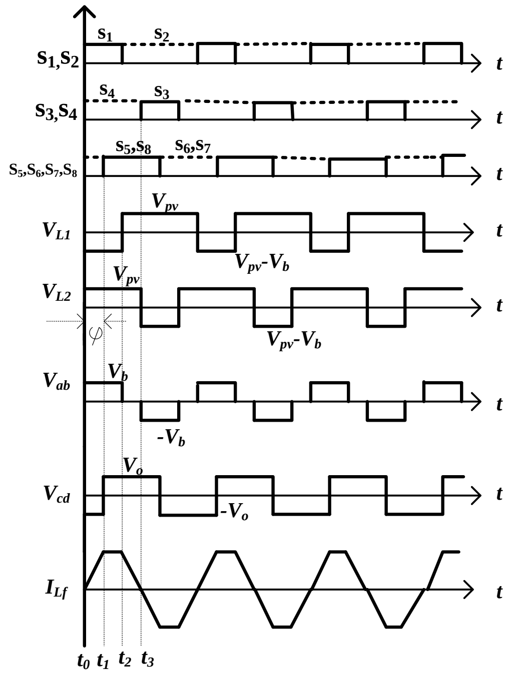

Fig. 16 Key waveforms of Full bridge three port bidirectional converter

3. Comparative Study and Assessment

Table-1 summarizes the comparison of partially isolated converters based on their component count. From the table it can be seen that the three port converter reported in [36] uses least number of active and passive devices but the reported output voltage of the converter is very less when compared with the other converters listed in the table. The converter reported in [37], for handling power among the four ports uses only four controllable switches and four diodes. This converter also utilises two sources and ensures a reliable power supply to the load i.e. even if power generation from one source drops, the other source along with battery will provide supply to load. The converters reported in [39], [40] and [41] eliminates the use of filter inductor at the load side thus reducing passive component count and related inductor losses. The absence of unidirectional diodes in converters presented in [34], [36] and [41] provides a way for bidirectional power transfer between battery and load port. Except the converters presented in [34] and [36], other converters are developed by integrating non-isolated converter circuits into isolated converter circuits. This integration results in sharing of active and passive devices among the different ports of the converter which in turn reduces the component count and improves the power density. Particularly in the converter reported in [37], four active switches in the primary side are shared by two boost converter sections and phase shifted full bridge section providing high level of integration. But in conventional cascaded structure, for integrating two boost converters and phase shift converter eight active switches are required which increases the circuit size and reduces the power density.

Features of the converter like soft switching performance, current ripple at the input ports and bidirectional power transfer capability are compared for reviewed partially isolated converters in table-2. It can be observed from the table that for most of the converters, ZVS performance is limited by the presence of boost inductors. Hence selecting proper inductor values is important for providing an extended range of ZVS operation at the primary side. The switches in the secondary side of most of the converters attains ZVS naturally due to the absence of boost inductors. And it can also be noted that the converters using bridge circuits like the converter in [41], shows better ZVS performance than the other converter structures. The switching legs of converters presented in [39], [40] and [41] are operated in interleaved manner which results in reduced current ripple at the input ports. The converter reported in [37] uses phase shifting of primary side switching pulses to regulate the output, and doesn't allow interleaving operation of primary side switching legs. Because of which it has higher current ripple at the input side when compared to the other converters. The absence of diodes in converters presented in [34], [36] and [41] allows bidirectional power transfer from source side to battery side and vice-versa. But other converters listed in the table have bidirectional power flow between source and storage ports only. And between source and load, they allow only unidirectional power flow because of the presence of diodes.

Table 1. Comparison of Components Count of Partially Isolated Converters

Converter	**No. of Ports**		**No. of semiconductors**		**No. of passive devices**		**Degree of integration**
	Input	**Output**	**Switches**	**Diodes**	**Inductors**	**Capacitors**	
Multi-input bidirectional dc-dc converter[34]	2	1	6	-	4	5	Low (No sharing of devices among ports)
Bidirectional three-port dc-dc converter[36]	2	1	5	-	3	4	Low (No sharing of devices among ports)
Buck- Boost four port converter[37]	3	1	4	4	4	4	Very high(primary side devices are shared by three ports)
PWM and secondary side phase shifted converter [39]	2	1	6	2	3	3	High(primary side devices are shared by two ports)
Secondary side regulated converter[40]	2	1..n	6	2	3	2	High(primary side devices are shared by two ports)
Three port full bridge bidirectional PWM and secondary side phase shift controlled converter[41]	2	1	8	-	3	3	High(primary side devices are shared by two ports)

Table 2. Features of Different Partially Isolated Converters

Converter	Soft switching	Current ripple at input side	Bidirectional power transfer
Multi-input bidirectional dc-dc converter[34]	Primary side switches attain ZVS for all conditions. Secondary switches ZVS performance depends on transformer current and fuel cell current	Low due to current source structure at input side.	Allows Bidirectional power flow between battery and load side.
Bidirectional three-port dc-dc converter[36]	Not mentioned	Not mentioned	Allows Bidirectional power flow between battery and load side.
Buck- Boost four port converter[37]	ZVS operation of switches is limited by the values of inductor currents of boost converter section.	High (since primary side switches don't work in interleaved manner)	Unidirectional from battery to load side.
PWM and secondary side phase shifted converter [39]	Secondary side active switches attain natural ZVS, but the presence of boost inductors limits the ZVS range in source side	Very low (since primary side switches work in interleaved manner)	Unidirectional from battery to load side.
Secondary side regulated converter[40]	Secondary side active switches attain natural ZVS. The ZVS range of source side switches depends on the inductor currents	Very low (since primary side switches work in interleaved manner)	Unidirectional from battery to load side.
Three port full bridge bidirectional PWM and secondary side phase shift controlled converter[41]	Secondary side switches attain natural ZVS. Presence of boost inductors at the limits the soft switch range of switches at the primary side	Very low (since primary side switches work in interleaved manner)	Allows Bidirectional power flow between battery and load side.

Summary of the rated output voltage, power and power transfer efficiency of the partially isolated converters taken for review is provided in table-3. It can be seen from the power handling capacity of the mentioned converters, that they can be utilized in a wide range of dc power requirements (from low voltage dc grids to high voltage dc grids). Thus, the partially isolated multiport converters can be used for harvesting renewable energy in both residential and commercial dc micro-grids, in which the power demand varies from few watts to kilo watts. It can also be inferred from table-3 that the converters employing secondary phase shift control provides better efficiency than the primary side phase shifted partially isolated converters.

Comparison of control strategies employed by the various partially isolated multiport converters is provided in table-4. Multiport converters exhibits coupled control loops [43]-[44], hence decoupling of control loops is important regarding the control of multiport converters. Partially isolated converters reported in most of the literatures used PWM and Primary side phase shift control [45]-[48].

Table 3. Comparison of Output Voltage, Power and Efficiency

Converter	**Reported output voltage**	**Reported output power**	**Reported power transfer efficiency**
Multi-input bidirectional dc-dc converter[34]	400 V	1 kw	-
Bidirectional three-port dc-dc converter[36]	24 V	-	-
Buck- Boost four port converter[37]	100 V	500 w	92.3%
PWM and secondary side phase shifted converter [39]	100 V	600 w	95%
Secondary side regulated converter[40]	300 V	500 w	95.3%
Three port full bridge bidirectional PWM and secondary side phase shift controlled converter[41]	7000 V	250 kw	-

Table 4. Comparison of Control Strategies of Partially Isolated Multiport Converters

Converter	**Control strategy**	**Storage device power management**	**MPPT tracking**	**Output regulation**	**Control complexity**
Multi-input bidirectional dc-dc converter[34]	PWM & phase shift	PWM	PWM	Phase shift	Less (decoupled duty cycle & phase shift control variables)
Bidirectional three-port dc-dc converter[36]	PWM	PWM	Not mentioned	PWM	Complex (duty cycle adjustment of one port affects other port's)
Buck- Boost four port converter[37]	PWM+ Primary phase shifting	PWM	PWM	Primary phase shifting	Complex (coupled duty cycle and phase shift control variables)
PWM and secondary side phase shifted converter [39]	PWM + secondary phase shifting	PWM	PWM	secondary phase shifting	Less (decoupled duty cycle & phase shift control variables)
Secondary side regulated converter[40]	PWM + secondary phase shifting	PWM	PWM	secondary phase shifting	Less (decoupled duty cycle & phase shift control variables)
Three port full bridge bidirectional PWM and secondary side phase shift controlled converter[41]	PWM + secondary phase shifting	PWM	PWM	secondary phase shifting	Less (decoupled duty cycle & phase shift control variables)

The primary side phase shift control has some demerits like idling power loss, limited soft switching range etc. Generally to overcome these demerits, secondary side phase shift control is introduced and applied for some two port and three port converters [49]-[50]. For maximum power tracking and battery management, PWM control is widely used. For regulating output voltage, primary or secondary phase shift control is used. From the comparison, it can be seen that the converters employing PWM plus secondary side phase shifting reduce the control complexity by decoupling the control variables of duty cycle and phase shift.

4. Challenges and Future Scope

From the review, it is clear that the multiport converters have gained a lot of research interest in the area of power electronics. Many topologies of the multiport converter are developed and applied in the areas like electric vehicles, satellite applications, fuel cell based power source applications, uninterruptible power supply applications and renewable energy sourced micro-grid applications etc. But still, optimization of the existing structures and development of new ones is required in multiport power electronics field. Further, the following issues also have to be addressed in the area of multiport converters.

1. Different three port topologies for connecting the renewable source and battery to the load are developed and implemented recently. Work can be conducted in developing four port topologies, which can be used to integrate more than one source along with a battery to the load/grid to ensure continuous power supply.

2. Development of multiport topologies that are able to supply both dc and ac loads simultaneously at varying voltage levels is required.

3. The voltage gain of the partially isolated multiport converters is the function of duty cycle and turns ratio of the high-frequency transformer. But wide variations in duty cycle during light and heavy load conditions results in reduced voltage gains. Voltage gain improvement techniques that are applied to two port converters can be extended to multiport topologies too.

4. Work can be conducted in overcoming the limitations caused by the boost inductors on the soft switching range of the partially isolated converters.

5. In most of the partially isolated multiport converters, the charging and discharging operations of the battery are done within one period of the switching pulse itself. This frequent charging and discharging reduce the lifetime of the batteries. Hence, attention is required in developing efficient battery management techniques.

6. Distributed simultaneous maximum power point tracking techniques for multiport converters with different renewable sources under varying conditions (Eg. PV with varying irradiance) have to be developed.

7. Digital modulation and power management strategies which are less complex, have to be developed for four-port converters.

8. Accurate modelling of multiport converters is necessary for enhancing the static and dynamic performance of the converters.

9. Intelligent devices with intelligent energy management and optimization techniques can be incorporated to make the system compatible with the smart grid technology.

10. Controller design and control loop decoupling which is essential in reducing the complexity of this multivariable control system is an important research aspect in enabling efficient and stable operation of these converters.

5. Conclusion

This paper briefly reviewed the topologies of partially isolated multiport converters reported in the various literature. From the review, it is evident that partially isolated multiport converters gained increasing interest in the research of connecting various renewable energy sources along with storage element to the load/grid. Comparison of the partially isolated converter has been done in terms of their component count, ZVS performance, power transfer efficiency and control strategies. The general operation of the converters is also reported briefly. It can be seen that these partially isolated multiport converters combine the advantages of both isolated and non-isolated converters by providing necessary isolation and the circuit size reduction simultaneously with the use of a single winding transformer. Also the reported power rating of these converters proves that it is suitable for wide range of applications that require dc power from 500 W to 250 KW. Thus, these partially isolated topologies prove to be worthy candidates in the competitive run of integrating more than one renewable sources along with the battery to the stand-alone load or dc-grid.

References

[1] K.R.Bharath, M.KrishnanMithun, and P. Kanakasabapathy," A Review on DC Microgrid Control Techniques, Applications and Trends", International Journal of Renewable Energy Research (IJRER), vol.9, No.3, pp.1328-1338, Sep 2019.

[2] D.Kumar, F.Zare and A.Ghosh," DC Microgrid Technology: System Architectures, AC Grid Interfaces, Grounding Schemes, Power Quality, Communication Networks, Applications, and Standardizations Aspects", IEEE Access, vol. 5, pp. 12230-12256, June 2017.

[3] M.Lakshmi, S.Hemamalini, "Non isolated high gain DC-DC converter for DC microgrids," IEEE Transactions on Industrial Electronics", Vol.65, No.2, pp.1205-1212, July 2017.

[4] E.Unamuno, and J.A. Barrena,"Hybrid ac/dc microgrids-Part II: Review and classification of control strategies",

Renewable and Sustainable Energy Reviews, Vol.52, pp.1123-1134, Dec 2105.

[5] J.J.Justo, F.Mwasilu, J.Lee, J.Jung, “AC-microgrids versus DC-microgrids with distributed energy sources: A review”, Renewable Sustainable Energy Reviews, Vol.24, pp. 387–405, August 2013.

[6] X.Lu, K.Sun, JM.Gurrero, JC.Vasquez, and L.Haung, “State-of charge balance using adaptive droop control for distributed energy storage systems in DC microgrid applications,” IEEE Transactions on Industrial electronics, Vol.61, No.6, pp.2804-2815, August 2013.

[7] S. Ikeda and F. Kurokawa, “Isolated and wide input ranged boost full bridge DC-DC converter for improved resilience of renewable energy systems,” IEEE 6th International Conference on Renewable Energy Research and Applications (ICRERA), pp. 290-295, Nov 2017.

[8] E.Planas, J.Andreu, JI.Garate, IM.DeAlegria, and E.Ibarra, “AC and DC technology in microgrids: A review”, Renewable and Sustainable Energy Reviews, Vol.11, No.43, pp. 726-749, March 2015.

[9] AT.Elsayed, AA.Mohamed and OA.Mohammed, “DC microgrids and distribution systems an overview”, Electric Power Systems research, Vol.119, pp.407-417, Feb 2015.

[10] V.Monteiro, TJC. Sousa, MJ. Sepulveda, C.Couto, A. Lima and JL. Afonso, "A Proposed Bidirectional Three-Level dc-dc Power Converter for Applications in Smart Grids: An Experimental Validation," International Conference on Smart Energy Systems and Technologies (SEST), pp. 1-6, Sep 2019.

[11] M.Nakamura, K.Takeno, R. Hisamitsu and M. Shoyama, "Bi-directional Multiport Converter for Utilizing Green Base Stations as Virtual Power Plant," 8th International Conference on Renewable Energy Research and Applications (ICRERA), Brasov, Romania, pp. 137-141, Nov 2019.

[12] LI.Yunwei, and F.Nejabatkhah,” Overview of control, integration and energy management of microgrids”, Journal of Modern power systems and clean energy, Vol.2, No.3, pp.212-222, Sep 2014.

[13] M. Mihai, "Multiport converters - a brief review", 7th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), pp. 27-30, June 2015.

[14] BG. Dobbs and PL. Chapman, “A multiple-input DC-DC converter topology”, IEEE Power Electronics Letters, Vol.1, No.1, pp. 6–9, March 2003.

[15] W. Jiang and B. Fahimi, "Multiport Power Electronic Interface—Concept, Modeling, and Design", IEEE Transactions on Power Electronics, Vol. 26, No. 7, pp. 1890-1900, Nov 2011.

[16] T.Ishiyama, "Output Characteristics of Energy Harvesting Using Multiple Energy Sources," 8th International Conference on Renewable Energy Research and Applications (ICRERA), Brasov, Romania pp. 224-228, Nov 2019.

[17] H.Wu, J.Zhang and Y.Xing, “A family of multiport buck-boost converters based on DC-link-inductors (DLIs)”, IEEE transactions on Power Electronics, Vol.30, No.2, pp.735-746, Feb 2015.

[18] FS. Alargt, AS. Ashur and AH. Kharaz, "Parallel Interleaved Multi-Input DC-DC Converter for Hybrid Renewable Energy Systems," 54th International Universities Power Engineering Conference (UPEC), Bucharest, Romania, pp. 1-5, Sep 2019.

[19] ND .Benavides, and PL. Chapman, “Power Budgeting of a multiple-input buck-boost converter”, IEEE Transactions on Power Electronics, Vol.20, No.6, pp. 1303-1309, Nov 2005.

[20] FS. Alargt, AS. Ashur and AH. Kharaz, "Analysis, Simulation, and Comparison of Multi-Module Interleaved DC-DC Converter for Hybrid Renewable Energy Systems," 54th International Universities Power Engineering Conference (UPEC), Bucharest, Romania, pp. 1-6, Sep 2019.

[21] N.Zhang, D.Sutanto, and KM.Muttaqi, “A review of topologies of three-port DC-DC converters for the integration of renewable energy and energy storage system”, Renewable and Sustainable Energy Reviews, vol.56, pp. 388-401, April 2016.

[22] A. El Shafei, S. Ozdemir, N. Altin, G. Jean-Pierre and A. Nasiri, "A Complete Design of a High Frequency Medium Voltage Multi-Port Transformer," 8th International Conference on Renewable Energy Research and Applications (ICRERA), Brasov, Romania, pp. 761-766, Nov 2019.

[23] J. Zeng, W. Qiao, L. Qu, and Y. Jiao, "An Isolated Multiport DC-DC Converter for Simultaneous Power Management of Multiple Different Renewable Energy Sources", IEEE Journal of Emerging and Selected Topics in Power Electronics, Vol. 2, No.1, pp. 70-78, Nov 2013.

[24] KP.Savitha and P. Kanakasabapathy, "Multi-port DC-DC converter for DC microgrid applications", IEEE 6th International Conference on Power Systems (ICPS)-New Delhi, pp. 1-6, March 2016.

[25] H. Matsuo, W.Lin, F. Kurokawa, T. Shigemizu and N. Watanabe, "Characteristics of the multiple-input DC-DC converter", IEEE Transactions on Industrial Electronics, vol. 51, no. 3, pp. 625-631, June 2004.

[26] H. Wu, Y. Xing, Y. Xia and K. Sun, "A family of non-isolated three-port converters for the stand-alone renewable power system," IECON 37th Annual Conference of the IEEE Industrial Electronics Society, Melbourne, pp. 1030-1035, Nov 2011.

[27] VAK.Prabhala, P.Fajri, VSP.Gouribhatla, BP. Baddipadiga, and M. Ferdowsi, “A DC-DC converter with high voltage gain and two input boost stages”,

IEEE Transactions on Power Electronics, Vol.31, No.6, pp. 4206-4215, Sep 2016.

[28] E.Babei, Z. Saadatizadeh and P. Chavoshipour Heris, “A new topology for non-isolated multiport zero voltage switching dc-dc converter”, International Journal of Circuit Theory and Applications, Vol.46, No.6, pp. 1812-1836, June 2018.

[29] H. Tao, JL. Duarte, and MAM. Hendrix, "Three-Port Triple-Half-Bridge Bidirectional Converter With Zero-Voltage Switching", IEEE Transactions on Power Electronics, Vol. 23, No. 2, March 2008.

[30] H. Krishnaswami and N. Mohan, "Three-Port Series-Resonant DC-DC Converter to Interface Renewable Energy Sources With Bidirectional Load and Energy Storage Ports", IEEE Transactions on Power Electronics, Vol.24, No.10, pp. 2289-2297, August 2009.

[31] A. Ajami, and PA. Shayan, "Soft-switching method for multiport DC/DC converters applicable in grid-connected clean energy sources", IET Power Electronics, Vol. 8, No. 7, pp. 1246-1254, April 2015.

[32] Y.Jiang, F. Liu, X. Ruan and L. Wang, “Optimal Idling control strategy for three-port full-bridge converter”, Power Electronics International Conference -Hiroshima IEEE, pp.458-464, May 2014.

[33] M.Phattanasak, R. Gavagsaz-Ghoachani, JP. Martin, B. Nahid-Mobarakeh, S. Piefederici and B. Davat, “ Control of a hybrid energy source comprising a fuel cell and two storage devices using isolated three-port bidirectional DC-DC converters”, IEEE transactions on Industry applications, Vol.51, No.1, pp.491-497, July 2015.

[34] H. Tao, A. Kotsopoulos, JL. Duarte and MAM. Hendrix, "Multi-input bidirectional DC-DC converter combining DC-link and magnetic-coupling for fuel cell systems", Fourtieth IAS Annual Meeting. Conference Record of the Industry Applications Conference, Vol.3, pp. 2021-2028, Oct 2005.

[35] J. Zeng, W. Qiao, and L. Qu, "An isolated three-port bidirectional DC-DC converter for photovoltaic systems with energy storage", IEEE Industry Applications Society Annual Meeting, pp.1-8, Feb 2013.

[36] J. Zeng, W. Qiao, and L. Qu, "An isolated multiport bidirectional DC-DC converter for PV-battery-DC microgrid applications", IEEE Energy Conversion Congress and Exposition (ECCE), Pittsburgh, pp. 4978-4984, Sep 2014.

[37] H. Wu, P. Xu, H. Hu, Z. Zhou, and Y. Xing, "Multiport Converters Based on Integration of Full-Bridge and Bidirectional DC-DC Topologies for Renewable Generation Systems", IEEE Transactions on Industrial Electronics, Vol. 61, No. 2, pp. 856-869, March 2014.

[38] W. Li, J. Xiao, Y. Zhao and X. He, "PWM Plus Phase Angle Shift (PPAS) Control Scheme for Combined Multiport DC/DC Converters", IEEE Transactions on Power Electronics, Vol. 27, No.3, pp. 1479-1489, Aug 2012.

[39] J. Zhang, H. Wu, X. Qin, and Y. Xing, "PWM Plus Secondary-Side Phase-Shift Controlled Soft-Switching Full-Bridge Three-Port Converter for Renewable Power Systems", IEEE Transactions on Industrial Electronics, Vol. 62, No. 11, pp. 7061-7072, June 2015.

[40] H. Wu, J. Zhang, X. Qin, T. Mu, and Y. Xing, "Secondary-Side-Regulated Soft-Switching Full-Bridge Three-Port Converter Based on Bridgeless Boost Rectifier and Bidirectional Converter for Multiple Energy Interface", IEEE Transactions on Power Electronics, Vol. 31, No. 7, pp. 4847-4860, Aug 2016.

[41] MA. Moqaddam and M. Hamzeh, "PWM plus secondary-side phase-shift controlled full-bridge three-port bidirectional converter for application in MVDC distribution networks", 8th Power Electronics, Drive Systems & Technologies Conference (PEDSTC), pp. 178-183, Feb 2017.

[42] P. Kolahian, H. Tarzamni, A. Nikafrooz, and M. Hamzeh, "Multi-port DC–DC converter for bipolar medium voltage DC micro-grid applications", IET Power Electronics, Vol. 12, No. 7, pp. 1841-1849, March 2019.

[43] C. Zhao, SD. Round, and JW. Kolar, "An Isolated Three-Port Bidirectional DC-DC Converter With Decoupled Power Flow Management", IEEE Transactions on Power Electronics, Vol. 23, No. 5, pp. 2443-2453, Nov 2008.

[44] Z. Qian, O. Abdel-Rahman, H. Al-Atrash, and I. Batarseh, "Modeling and Control of Three-Port DC/DC Converter Interface for Satellite Applications", IEEE Transactions on Power Electronics, Vol. 25, No. 3, pp. 637-649, Oct 2010.

[45] Z. Zhang and MAE. Andersen, "Interleaved boost-half-bridge dual-input DC-DC converter with a PWM plus phase-shift control for fuel cell applications", 39th Annual Conference of the IEEE Industrial Electronics Society-Vienna, pp.1679-1684, Nov 2013.

[46] H. Wu, Y. Lu, T. Mu and Y. Xing, "A Family of Soft-Switching DC–DC Converters Based on a Phase-Shift-Controlled Active Boost Rectifier", IEEE Transactions on Power Electronics, Vol. 30, No. 2, pp. 657-667, Feb 2014.

[47] H. Xiao and S. Xie, "A ZVS Bidirectional DC–DC Converter With Phase-Shift Plus PWM Control Scheme", IEEE Transactions on Power Electronics, Vol. 23, No. 2, pp. 813-823, March 2008.

[48] H. Al-Atrash, and I.Batarseh, “Boost-integrated phase-shift full-bridge converter for three-port interface”, IEEE Power Electronics Specialists Conference proceedings , pp. 2313-2321, June 2007.

[49] W. Li, S. Zong, F. Liu, H. Yang, X. He, and B. Wu, "Secondary-Side Phase-Shift-Controlled ZVS DC/DC Converter With Wide Voltage Gain for High Input

Voltage Applications", IEEE Transactions on Power Electronics, Vol. 28, No. 11, pp. 5128-5139, Feb 2013.

[50] T.Mishima and M. Nakaoka, "Practical Evaluations of a ZVS-PWM DC–DC Converter with Secondary-Side Phase-Shifting Active Rectifier", IEEE Transactions on Power Electronics, Vol.26, No.12, pp.3896-3907, March 2011.