Comparative Analysis of Non-Isolated Three port converters for Solar and Energy Storage Integration

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Abstract — *This paper provides a comparative analysis on various Non-Isolated topologies of three port converters. Nowadays, renewable energy resources are becoming inevitable to satisfy the energy demand. Solar energy is one among the renewable energy sources used to fulfil 10% of energy production. Non-Isolated DC-DC converters are very helpful to harvest the energy from solar panel with reduced losses and low cost. Multi-Port provisions in Non-Isolated topologies becoming most popular to reduce the number of DC/DC converters. When Bidirectional power flow introduced in Multi-Port Converter (MPC) that gives easy integration with energy storage devices (Battery). Three port converters (TPC) with Bidirectional and unidirectional power flow discussed here. Power ratings of TPC considered for important topologies. Finally, performance of TPC's are evaluated with merits and demerits directed to further interest of research.*

Keywords — *Three port Converters, Non-Isolated topologies, Multi-Port Converter, DC-DC Converters, Solar and Energy storage Integration.*

I. INTRODUCTION

According to Indian Ministry of Power Sector, 62.1% (fig.1) of electric power produced from thermal energy which includes coal, lignite, gas& Diesel.

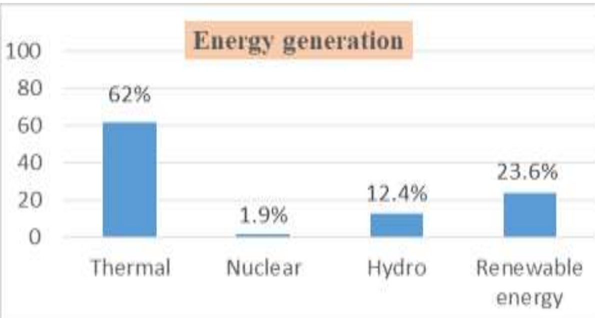


Fig 1. Energy Generation (upto march 2020)

1.9% produced from Nuclear energy, 12.4% from hydro and 23.6% from renewable energy sources (RES) such as small hydro project, Biomass, urban & Industrial waste power, Solar and wind [1].

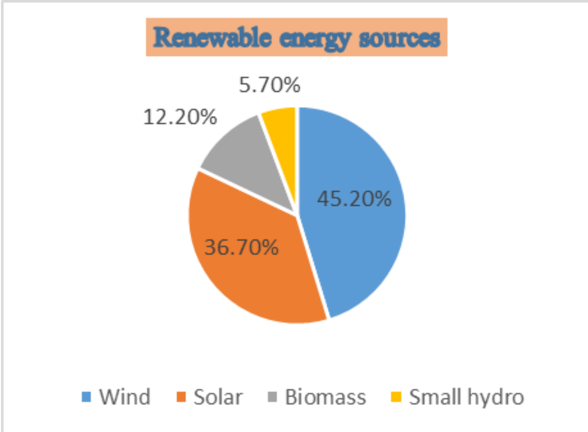


Fig 2. Installed grid interactive renewable power capacity in India as of June 30, 2019.

In this total amount of power generation using RES, solar power solely satisfies 36.7% of demand (fig.2). Green energy generation with the concentration of public health improves the growth of this country. So, researchers are interested in the improvement of power generation using solar power with low cost and reduced losses of associated devices. To reduce the losses, number of converters should be minimized. So that the use of energy storage elements (L&C) will reduce. When the project for reduction of converters takes place, cost of associated converters automatically decreases.

In general, Bidirectional converters are connected between DC link and Battery [2]. It allows power flow in both forward and reverse directions. It is used in electric traction, battery operated vehicles, etc. Buck-Boost converter is mainly preferred for designing bidirectional converters. In TPC, bidirectional power flow is often available for one port only. Scientists are interesting to provide more than one Bidirectional port based on requirements. In practical case (fig.2), one port is connected with solar panel, second port is connected with energy storage system (ESS) and the third port is connected with load / DC link.

Solar storage battery is chosen based on capacity and power. It is divided into two categories (i) A battery with High capacity and low power (ii) A battery with low capacity and high power. First one able to supply power to a number of key appliances for a long time. But second one will be able to power entire home for short amount of time. Lithium-Ion, Lead Acid batteries are mostly used as energy storage system in solar power. Li-ion batteries have longest life-span than Lead acid batteries. Isolated DC/DC converters require isolation between source and load. So, the cost of the system increases. When high power rating of solar energy installed, isolated converters may help. At the same time efficiency slightly affects due to magnetic losses of coils. So, Non-Isolated converters are the solution for low cost and high efficiency circuit design.

Block diagram of MPC with Bidirectional flow explained in Section II and various technique for Integration of solar and ES explained in Section III. In Section IV, important non-isolated MPCs are discussed. Section V and VI are explained about comparison of MPCs and Conclusion with future work.

II. Block Diagram of MPC

In fig.3, DC-DC converter with multi (three) port options drawn [4]. Port 1 connects Photo voltaic panel, Port 2 Connects DC link and Port 3 connects Energy Storage system.

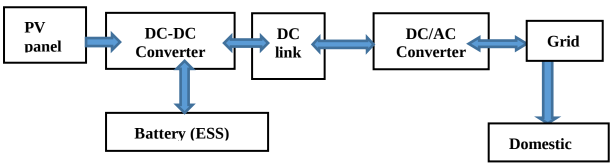


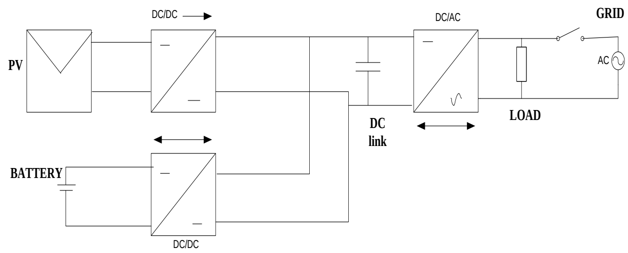
Fig 3. Block diagram of MPC with Bidirectional flow

Solar energy converted into electrical energy using PV panel sends to DC-DC converter. Buck-Boost converter used here. Bidirectional power flow offered between DC link with DC-DC converter and ESS with DC-DC Converter. Battery receives energy from DC link through Converter when solar energy is not sufficient. Grid receives AC power from DC link through DC to AC converter. Six modes of power flow obtained from the above block schematic.

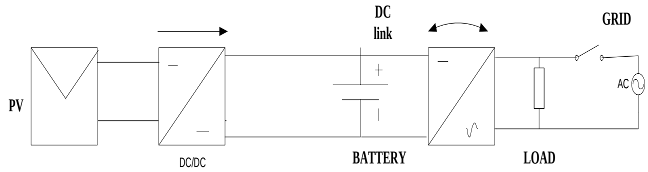
Mode 1: Solar Panel to DC link
Mode 2: Solar Panel to DC link
Mode 3: Solar Panel to Battery and DC link
Mode 4: Solar Panel and Battery to DC link
Mode 5: Battery (ESS) To DC link
Mode 6: DC link to Battery (ESS)

Mode 1 to 4 ensures unidirectional flow.
Mode 5 to 6 ensures Bidirectional flow.

III. Different types of Integration between PV and ESS



(a)



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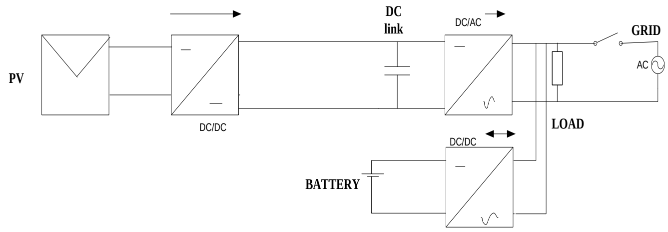

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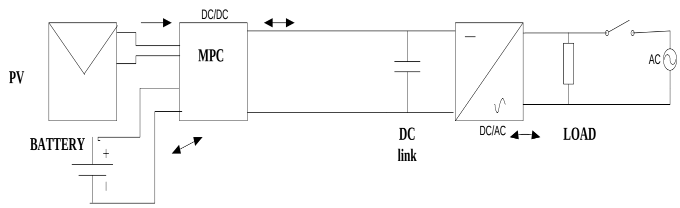


(d)

Fig4. (a) Separate DC-DC converter used [5], [6], and [7]. (b) Integration of Battery with DC link [8], [9]. (c) Integration of Battery with DC link through AC side [10], [11]. (d) Three port Converter [12], [13].

Two DC/DC converters are used in fig.4 (a). PV panel is connected with first one in unidirectional flow and battery is connected with another DC/DC converter in bidirectional power flow. Inverter connected between DC link and grid also provided with bidirectional power flow.

Fig.4 (b) consists only one DC/DC converter with unidirectional flow. Here battery is combined with DC/DC link. Hare also inverter connected between DC link and Grid with bidirectional flow.

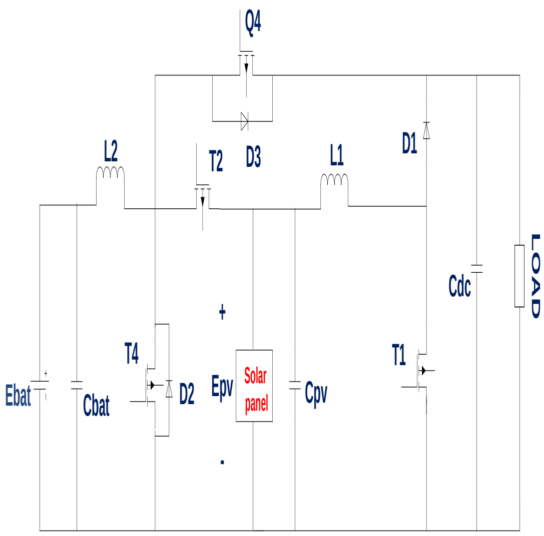
Fig.4(c) consists one DC/DC converter with unidirectional flow connected directly with PV panel. Two inverters are used. One with unidirectional and other with bidirectional flow. Inverter with Bidirectional flow connected between battery and grid. When Battery fully discharges, grid helps to charge the battery due to bidirectional flow. Inverter with unidirectional flow connected between DC link and Grid.

Fig.4 (d) shows only one DC/DC converter with multi-port options. In this three ports are provided. In the first port, PV panel is connected and it is unidirectional port. Second port is Bidirectional port connected with DC link. Third port also bidirectional connected directly with battery. In this type, we use only one inverter between DC link and Grid. This inverter is Bidirectional flow. Battery charges from DC link when PV panel receives insufficient solar power.

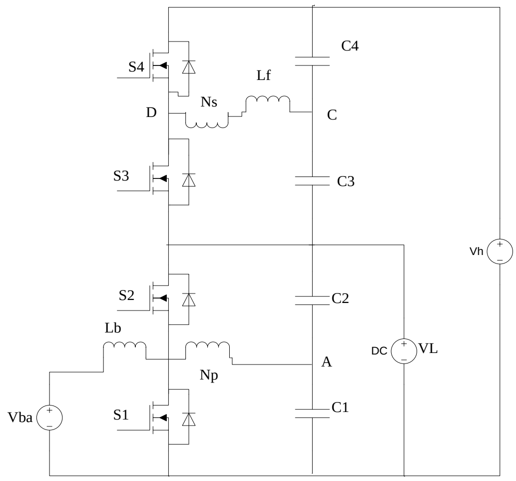
From all the above types, DC/DC converter with multi-port options provides the following merits.

(i) Number of DC/DC converter reduces.
(ii) Losses associated with L&C also reduces.
(iii) Cost is low

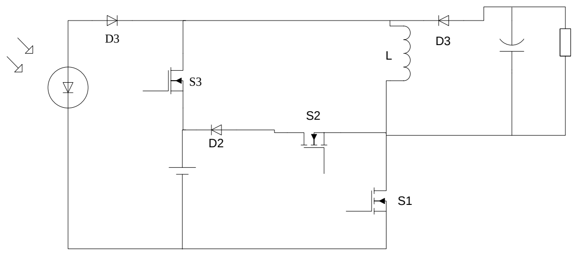
IV. Non-Isolated Topologies of Multi Port Converters



(a)



(b)



(c)

Fig.5 (a) Non-Isolated TPC [4]. (b) Non-Isolated TPC with high voltage conversion ratio [16]. (c) Integrated Non-Isolated TPC [12].

Non Isolated MPC topologies are basically divided into three [2]. They are combined Input/ output ports, Reconfigurable ports, Magnetic/Capacitive Coupled ports. Here we discussed these topologies except Reconfigurable ports. Because, this type has more losses due to large number of inductors. Fig5 (a) shows Non- Isolated TPC having two bidirectional ports.

The configurations are, P_{rated} = 4000W, V_{pv} = 200V, V_{bat} = 150V, V_{load} = 600V, f_s = 20 KHz. Port 1 of DC/DC converter is connected with solar panel. Supply from panel directly sends to load in one mode. Similarly Supply from panel directly sends to charge the battery in another mode due to port 2. Port 3 connects load and battery and it makes bidirectional flow. Zero Voltage Switching and Zero Current Switching techniques are used to control signals. This circuit is not suitable for high switching frequency applications.

Fig5 (b) shows Non-Isolated TPC with high voltage conversion ratio [16]. Three ports are connected with battery, Low voltage bus and High Voltage bus. All are Bidirectional Ports. This circuit is introduced to get high voltage conversion ratio between ESS and load. Soft switching technique is applied using Pulse width modulation and phase control. This helps for effective power management in the whole circuit. The operation of this circuit consists three modes. They are single input single output mode, Single input double output mode, Double input single output mode. Two inductors L_f, L_b are used here which are doing very important role to get boost stage. But the drawback here is, coils N_s & N_p which are leading to losses. The configurations are, P_{rated} = 1000W, V_{bat} = 30V to 42V, V_{low}= 72V, V_{high} = 400V, f_s = 100 KHz. Though this circuit has the advantage of phase shift technique coil losses are inevitable.

Fig 5(c) shows Integrated Non-Isolated TPC [12]. One port is Bidirectional out of three. Remaining two ports are unidirectional. System efficiency becomes low when bidirectional ports are enabled. The main advantage of this circuit is the use of single inductor. Cost of the system is very low compared with other structures. The configurations are, P_{rated} = 200W, V_{pv} = 15V to 21V, V_{bat} = 23V to 25V, V_{load} = 30V, f_s = 80 KHz. Pulse width modulation technique is used to control the signal.

V. Table 1
Parameters of MPC for various topologies

Ref. No.	Power Rated (W)	Panel Voltage (V)	Voltage of ESS (V)	Load Voltage (V)	No. of Switches (MOSFET/ IGBT)	No. of Diodes	Switching frequency (KHz)	Efficiency (%)	Bidirectional flow
4	4000	200	150	600	4	1	20	98.7	ES - load
12	200	15 to 21	23 to 25	30	3	3	80	95	-
16	1000	-	30 to 42	V_L = 72V V_H = 400V	4	0	100	96	ES - load

V. Comparison of MPC's:

In [4], Bidirectional flow allowed between Battery (ES) to load. Experimental section was performed for 200V PV panel, 4KW rating. Voltage of Battery and Loads are 150V and 600V. Switching frequency is 20KHZ. Four numbers of IGBT's and only one number of Diode are used. IGBT works under low switching frequencies. Efficiency of the circuit is 98.7%.

In [12], there is no Bidirectional power flow. It has been designed for low power applications. Experimental section was performed for the range of 15V to 21V PV panel, 200W rating. Switching frequency is 80KHZ. Voltage of Battery and Loads are 25V and 30V. Three numbers of MOSFET's and three number of Diodes are used. Efficiency of the circuit is 95%.

In [16], Bidirectional flow allowed between Battery (ES) to load. Experimental section was performed for 1KW rating. Voltage of Battery is 30-42V. Load is divided into two voltage ranges V_{Low} = 72V, V_{High} = 400V. Four numbers of MOSFET's are used. There is no diode. Efficiency of the circuit is 96%.

Ref [4], [16] are supports bidirectional power flow. But [12], has only unidirectional power flow. Also it has been designed only for 200W power rating. At the same time, Ref. [4], [16] helps to operate the circuit in KW ranges. In overall, Ref [4] seems better but its switching frequency is not satisfied. So, we may try the same circuit using MOSFET switches with few modifications in the circuit.

VI. Conclusion

This paper gives a detailed comparison on three port converters using Non-Isolated topologies. The circuit configuration, working, merits and demerits of three different DC/DC converters have been discussed here. Comparison of TPC's in Table 1 provides the detail of various parameters of TPC which helps to get the advantages from each reference. It is very clear that Non-Isolated topologies are the only solution to reduce the cost of the converters in solar energy. But, when Bidirectional power flow introduced to reduce the number of converters, system efficiency slightly reduces during that particular mode. So, it is essential to concentrate research on Bidirectional mode of MPC to improve system efficiency.

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