A Qualitative Investigation on Multiport Converters for Renewable Energy Sourced DC Loads

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Received: 06.04.2022 Accepted:12.05.2022

Abstract: The global consumption of electrical energy is increasing, as is the demand for power generation. As a result, investment in alternative energy sources is becoming increasingly important nowadays. Renewable energy systems are quite unpredictable, and so they include both solar panels/wind turbines and batteries to smooth out variations in power generation. Solar PV systems have recently received a lot of attention due to the fact that they are more scalable, cost competitive, environmentally friendly, and safe renewable conversion. Solar energy conversion system involves combination of unidirectional and bidirectional converters. These converters have a greater number of magnetic components resulting in increased system complexity and cost. Hence to cover up the disadvantages of conventional power electronics converter, Multiport converters are introduced. As the name suggest multiport converters have many input ports and single output port. These converters are obtained by integrating multiple conventional converters. This paper presents a synoptic review of multiport converters for renewable energy applications.

Keywords: Multiport Converter, Photovoltaic Source, Battery Energy Storage, Maximum Power Point Tracking, DC Load

Nomenclature

MPC	Multiport Converter
RES	Renewable Energy Sources
MSMC	Multiple Source Multiple Converter
BDC	Bidirectional DC-DC Converters
HVS	High Voltage Side
PWM	Pulse Width Modulation
DAB	Dual Active Bridge
SOC	State of Charge
LCL	Inductor capacitor Inductor
CC	Constant Current
CV	Constant Voltage

1.Introduction

Electricity has been perceived as a fundamental requirement for human life existence. The economic development of a country has a greater dependency on the level of electric energy consumption. But unfortunately, over millions of people across the country has no access to electricity. In order to improve the prevailing scenario, several initiatives are taken by the researchers and among which generation of electricity by exploiting Renewable Energy Sources (RES) are becoming more prominent. Because of higher merits of solar energy and maximum utilization of solar energy, the Indian government has made reconciliation in Paris climate change conference, aiming to accomplish 450GW of sustainable energy by 2022. According the recent study, as of 2020 the installed capacity of India is about 175GW. Solar power accounts for around 100GW, 60GW of power is contributed by wind, biomass for about 9GW, an approximate of 5GW is contributed by hydropower, and waste-to-electricity is about1GW.The renewable energy share in India as of 2020 [101] is shown in Fig.1 from the Figure it is evident that solar and wind energy remain the top contributors to India's renewable energy market and so, there's a tremendous room for growth and expansion in the generation, storage and distribution of solar and wind energy.

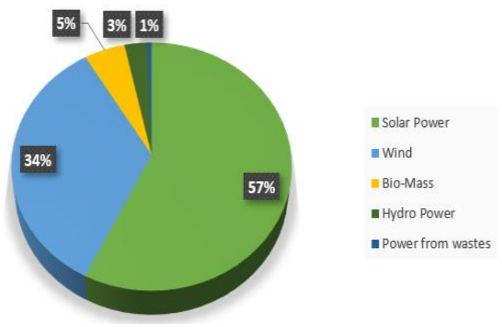

Fig.1. Renewable energy share in India - 2020.

Energy storage and power tapping are the challenges that the research face from these photovoltaic (PV) systems. Since, the energy storage mechanism is restricted by the size of battery, there is a necessity to extract surplus energy during its availability (i.e Day- time). Various maximum power tracking techniques are employed to control and optimize the power from PV systems. The power output of PV systems depends on the cell temperature, irradiation and nature of load connected to the system.[102]

Since, the availability of solar energy is periodic in nature and hence PV based systems requires an energy storage element which is achieved by utilizing a battery bank. Further, the system requires the service of power converters to form a bridge between the PV array, battery and load[3]. In the aforementioned system, many converters are required mandatorily to control each source individually, thus the complexity, cost of the system is increased. To minimize the number of converters, the concept of multiport converters was introduced where multiple converters are combined together in a single unit [1].

Based on the load requirement, the source parameters can be modified. The converters can process and control the flow of electric energy when power source is available. There are two ways of integrating power source with load;(1) Multiple sources with multiple converters (MSMC),(2) Multiport converters.

The MSMC is the traditional method where, the multiple power sources need multiple converters viz. unidirectional and bidirectional converters as shown in Fig.2(a).A PV system requires batteries for constant power supply, in those systems many DC – DC converters are required for PV panels as well as for the battery. A DC - DC converter is used to increase the power generation using PV panels by tracing maximum power point. Meanwhile, a bi-directional converter is used for battery regulation so as to attain the plain sailing power flow in PVsystems [7]. These converters have a greater number of magnetic components resulting in increased system complexity and cost [1]. There are some drawbacks with the traditional power converters, they are increased conversion steps, increased components and high cost.

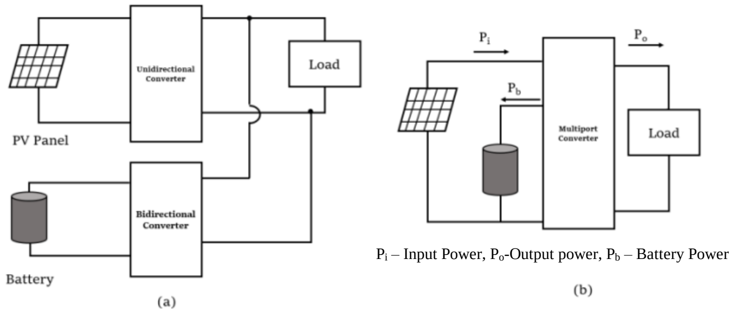

Fig.2(a). Traditional power system with multiple converters,**(b)** Multiport Converter

To decrease the count of converters in a power system, multiple converters can be integrated to form a Multiport converter is presented in Fig.2 (b). In MPCs, there are reduced components which imply the expense of converter will be lower than that of traditional system.

The aim of Multiport converter is to combine many ports into a power stage, allowing power to flow between each port.MPC proposed in [1] is shown in Fig 2.b has one unidirectional input port (V_i), one bidirectional port (V_b), and one output port (V_o). Power sources, like fuel cells, PV panels and generators are connected to the unidirectional input port, while batteries are connected to the bidirectional port. The power equation of the proposed MPCs is given by the Eq.(1),

$$P_i = P_o + P_b \quad (1)$$

where P_i, P_o, and P_b are the input, output and battery powers respectively. Based on the power equation, the multiport converter can operate in three modes (viz.) battery charging, discharging and hybrid mode. The output and battery voltages are regulated by Pulse Frequency Modulation (PFM) and Pulse Width Modulation (PWM) controls respectively, whereas in [13] the modulation scheme used is PWM and Phase Shift(PS) for the output and battery voltage regulation and the reported efficiency of [13] is 91% compared to [1] which is around 97%. The MPC proposed in [2] contains inductor – capacitor-inductor (LCL) resonant circuits to achieve ZVS and ZCS for the main switch. Frequency Modulation method is employed to maintain constant output voltage. The converter proposed in [13] employs phase angle shift and PWM to control output voltage and PV voltage respectively while providing a high step-up capability for power conversion. The control strategy as proposed in [35] involves three domain control method for PV battery power systems. In SUN domain and conductance control mode, the PV power generation is enough to supply load and to charge battery, the battery charging can be controlled according to design of battery management unit. In battery charge domain and MPPT control mode, the load voltage is regulated by varying the charge current. In battery discharge domain and MPPT control mode, the load voltage is regulated by varying the discharging current

A triple port converter is proposed in [12] for hybrid applications such as PV, Fuel cell, battery etc. The converter operates in three modes. First mode of operation is where power to the load is fed from two voltage sources V1 and V2, while the power is bypassed through the battery. The aim in this operation mode, is to track the maximum power point in PV and to regulate output voltage.

In second mode of operation, power is supplied to the load by the sources V_1 and V_2 and battery. In third mode of operation input sources V_1 and V_2 are feeding power to the load and battery.

Converter proposed in [3] is a transformer coupled converter which operates in four modes,(viz) MPPT mode , non-MPPT mode, battery-operated mode, shutdown mode. In MPPT mode, when the system is functioning in this mode, the greatest amount of energy is taken from the PV array. The power in this mode is given by Eq.(2)

$$P_o = P_M = (P_b + P_l) \quad (2)$$

Where P_o, P_M, P_b, P_l are output power, maximum PV power, battery power, load demand respectively. Innon- MPPT mode, the system cannot be used in MPPT mode since the battery will be overcharged. During this scenario, PV power extraction is limited to a value determined by Eq.(3)

$$P_o = (P_{bmax}+P_l) \quad (3)$$

Where P_{bmax} is the maximum power absorbed by the battery. When there is no PV power and the battery has the capacity to meet load demand without being overcharged, the system switches to battery-only mode. Shutdown mode is enabled when the PV power output is less than the load power and the battery is unable to provide, the system must be turned down to avoid the battery from being over depleted.

The main objective of this review article is to present intensive review of multiport converter emphasizing key factors like control of multiport converters, charge control techniques, MPC applications and problems associated with it, thus enabling the researchers to choose converter topologies with appropriate charge control methods for different batteries and suitable MPPT techniques for PV system so as to progress in the right direction. This paper first introduces the different topologies of multiport converter in Section 2. The battery charging methodology and control techniques are discussed in Section 3. Section 4introduces an overview of energy storage system along with jist of battery management system. Section 5 describes the MPC applications. Section 6 briefs about the MPC problems and future research directions, and the paper is concluded in Section7.

2. Multiport Converters

Various Multiport converters are proposed and are roughly classified into: i) *Isolated MPC* are the power converters that uses high frequency transformer to eliminate the DC path between its input and output. A multi winding transformer is utilized by multiple full bridge and half bridge converters to have multiple input and output ports [8]-[10] ii) *Non- Isolated MPC* has a DC path between its input and output. Non- Isolated three port converters are the derivations of buck, boost, buck-boost converter. And iii) *Partially Isolated MPCs* are based on the combination of non-isolated bidirectional PWM converter and an isolated converter have been proposed in [3],[11]-[13].Non isolated multiport converters are used in the applications where a low voltage regulation ratio is required. In contrary, isolated converters are used in applications requiring a high voltage regulation ratio.

2.1 Isolated Multiport Converters

Fully isolated multiport converters are developed from full bridge or half bridge topologies or combinations of both topologies. These converters are mostly preferred for integrating different sources of various voltage level. The basic structure of isolated multiport converter is shown in Fig 3.

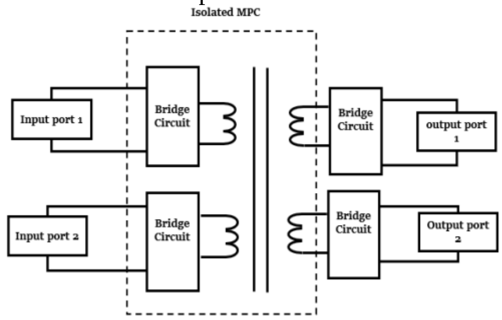

Fig.3. Isolated multiple converter

The ideology of isolated multiport converter with least number of switches is proposed in [2] [4] [5] [6], which uses multiport bidirectional DC-DC converters (BDCs). The most commonly used BDCs are full bridge topology that uses two controllable switches for each port as proposed in [4] and the other topology includes half bridge with four controllable switches proposed in [5].In some practical applications, energy storage element such as batteries are used so as to overcome the shortfall of solar energy during night time. However, the battery in [5] had to be charged and discharged for a high frequency, which reduces the life of battery. An isolated three port converter has been proposed for PV – battery system in [6]. The battery in the system can be charged using PV panel and discharged to the load through HVS of the transformer. This system is preferably used for stand-alone PV system and not for microgrids. Hence an effort is made to use the BDCs in [6] for DC microgrid applications by adding two extra controllable switches on the secondary of the transformer as proposed in [2]. Here the power flow is bidirectional and the solar power is used to charge the battery and to supply the DC microgrid. The proposed converter in [2] is operated in two modes with four operating scenarios for converters as depicted in Fig.4

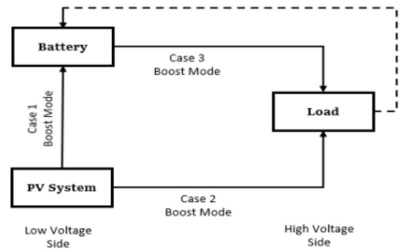

Fig.4. Power flow direction in the operating modes of converter.

2.2 Partially Isolated Multiport Converter

The partially isolated converter provides isolation between source and load also it maintains the small structure with greater power density and voltage level flexibility. Partially isolated converter requires high frequency transformer for isolating the source and the load and dc-link for integrating more than one source or load. The general structure of partially isolated topology is presented in Fig 5.

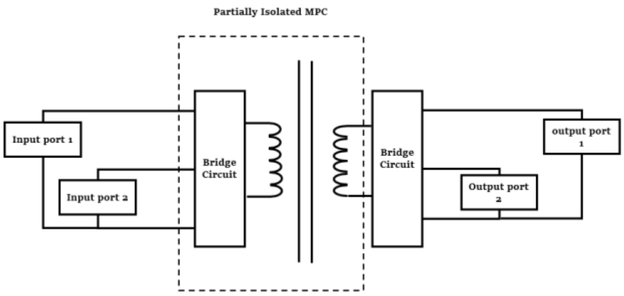

Fig.5. Partially Isolated multiple converter

On the other hand, in partially isolated MPCs sharing of switches between isolated and non-isolated converters helps in the reduction of the switch count [1],[11],[13],[27] – [34]. These multiport converters can be derived from isolated converter and a bidirectional converters, like full bridge or half bridge converter [13],[27]–[29] and resonant converter [1], [11]. Among various topologies, DAB based MPCs that achieve zero voltage switching as discussed in [30]–[34] is used for wide range of operation.

Though partially isolated MPCs are promising topology in regards with the component count, a large transformer is absolute necessity for isolation requirement. Hence for non-isolated applications such as PV system, non-isolated MPC is preferred.

2.3 Non- Isolated Multiport Converters

The non-isolated converters are the derivations of conventional buck, boost and buck boost converters. These converters are mainly preferred for those system which does not require galvanic isolation. The typical non isolated multiport converters structure is shown in Fig 6.

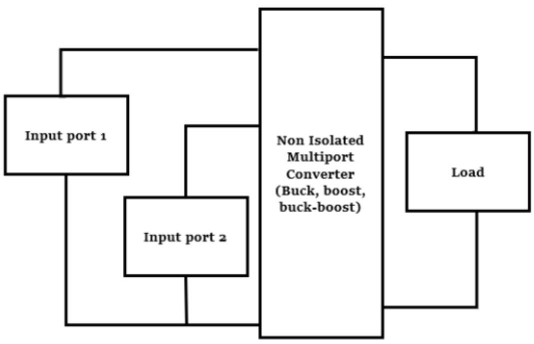

Fig.6. Non-Isolated multiple converter

Many researchers have proposed non-isolated MPCs in [7] [13]–[18]. All power sources share a single switching cycle in MPCs operating in a time division manner, resulting in a lower effective duty cycle, higher RMS currents, and lower power conversion efficiencies [14]. [15] proposes Multiport Converters based on bus sharing, which has lesser number of passive components. On the other hand, the topology described in [7],[16]–[17] can decrease the number of passive components and switches, resulting in lower costs and a simpler topology. Due to the requirement of more inductors, major issues with narrowed operation regions are associated with this topology [7], [16] and increased circuit volume [17]. A non-isolated MPC with a simplified topology, wide operation region, and common-ground that shares the switches of a PWM converter and a non-isolated DAB converter [18].

The performance comparison of various topologies of multiport converter is tabulated in Table 1.

Table 1. Comparison between various topologies of Multiport Converter

Type	TOPOLOGY	COMPONENT COUNT					Modulation Scheme	Efficiency %
		Switch	Diode	Capacitor	Inductor	Transformer		
Partially Isolated MPC	[1]	2	4	4	0	1	PWM and PFM	73–97%
	[3]	2	2	5	1	1	PWM	73–94%
	[11]	4	4	4	2	1	PWM and PFM	90–96%
	[13]	4	2	4	0	2	PWM and PS	86–91%
	[28]	3	2	3	1	1	PWM	
	[29]	4	4	3	2	1	PWM and PS	91–97.5%
	[50]	4	2	3	0	1	PWM and PS	75–90%
	[52]	4	4	3	0	2	PWM and PS	87–91%
	[53]	6	2	3	3	1	PWM and PS	93–97%
Isolated MPC	[4]	12	0	1	3	1	Phase Shift	91.7%
	[49]	6	0	7	4	1	Phase Shift	91-93%
	[6]	3	4	4	4	1	Frequency	94.5%
	[10]	12	0	4	2	1	Phase Shift	91%
	[34]	8	0	2	5	1	Phase Shift	
Non-Isolated MPC	[17]	3	1	4	3	-	PWM	94-96%
	[56]	6	0	2	2	-	Duty Ratio	91-94%
	[64]	6	4	5	2	-	PWM and PFM	94%
	[14]	4	3	2	1	-	Duty Ratio	
	[48]	4	0	1	2	-	Duty Ratio	96-97%

3. Charge Control Techniques

A charge controller is a system to control voltage or current. Controlling the voltage or current helps to charge the battery and keep the electric cells from overcharging. A battery is an essential part of renewable power systems as it helps in storing the electric charge, thereby facilitating the power to the load in case of circuit failure. Hence, it is necessary to understand the charging methods of a battery so that a suitable charge controller can be designed. This article discusses about the various charging methods and charge controller techniques.

3.1 Traditional Charging Methods

The various charging methods are; Constant Voltage Charging, Constant Current Charging, Mixed constant current / constant voltage charging method, Pulse charging method, Float charging method.

Constant Voltage Charging (CC)

During the charging process, the charging voltage is maintained constant. When the battery is discharged, the charging current is high. As the battery charges, the current value gradually decrease, causing an increase in back emf.

Constant Current Charging (CV)

In this method, the charging current is maintained constant as the battery voltage rises by reducing the circuit resistance. Here, the charging current is roughly about 12.5% of its ampere rating. The series resistance should have a current carrying capacity greater than or equal to the charging current required; otherwise, the opposition will overheat and burn out.

Mixed constant current / constant voltage charging method (CCCV)

It is a combination of CC and CV methods, it can efficiently reduce charging time with a constant voltage charging method and also self-regulate current, ensuring that the battery does not overcharge.

Pulse charging method

In this method the battery is charged by delivering a periodic pulse to the battery cell. Since there is a charge – off time, this method has the capability to make the electrolyte of the battery more uniform during this period of time. As the chemical energy is completely converted to into electrical energy by the energy of charging, the charging efficiency is greater than that of the methods discussed above.

Float charging method

This method is best applied where the battery discharge is not often, hence it is used in battery backup applications. The load, charger and battery must be connected in parallel during float charging. The charger is powered by a standard power supply, which supplies current to the load while it is in use.

Trickle charging Method

Trickle charging is the technique of charging a fully charged battery at a rate equal to its self-discharge rate, hence maintaining the battery's charge. As a result, trickle charging only occurs when the battery is unloaded. The charge rate varies depending on how frequently the battery is discharged.

Multistage charging Method (MSC)

This method employs several stages of constant current, with the current gradually decreasing as the terminal voltage approaches a preset threshold voltage. The charging procedure is repeated until the battery reaches terminal charge. The charging strategy like constant current charging (CC), constant voltage charging (CV) and pulse charging methodology is implemented in [109],[110],[111]

A constant voltage charging is proposed in [104] with current limitations to restrict temperature variations in battery. A fast constant voltage charging method is implemented in [105], where the control scheme is based on internal impedance value of battery.

A CCCV charging method is implemented in [106],[117] with MPPT technique to decrease battery charging time thereby high accuracy and less steady state oscillation error is achieved.

A CCCV method and multi stage charging are the most effective charging methods. Typically, researchers concentrate on improving these approaches' charging performance. one such optimization is proposed in [105]. where zero computational based control algorithm is used. A control algorithm is proposed in [112] where the charging speed, temperature and energy loss of battery is optimized. Many researchers have suggested various optimization techniques for Multi stage current charging profile. Fuzzy logic algorithm for five stage current charging profile was proposed in [113]. Another optimization technique named Taguchi based method fasten the process of charging and increases the battery life was proposed in [114]

From the literature study, a comparison between various traditional charging methods is presented in Table 2.

Table 2. Comparison between various traditional charging methods

Criteria	CC Method	CV Method	CCCV Method	MSC Method
Basic parameters	Rate of charging current	Rate of charging voltage	Charging current rate in Constant current mode Rate of charging voltage in constant voltage mode	Rate of charging current at each stage
Advantages	Easy impleme ntation	Easy implementat ion	Terminal voltage is stable Capacity utilization if more	Easy implementati on Fast Charging
Disadvantag es	Capacity utilizatio n is less	Disintegratio n of battery framework	Difficulty in maintaining steadiness of charging speed, temperature.	Difficulty in maintaining steadiness of charging speed, capacity utilisation and battery life

3.2 Charge controller techniques

A Charge controller is a vital component of PV System that is used to interface PV panel with the battery. The purpose of charge controller is to prevent battery from over charging and over discharging below its threshold limit, thereby increasing the life of battery. The three types of charge controller are Voltage regulator-based charge controller, charge controller based on Pulse width modulation, MPPT based controller.

The voltage regulator-based charge controller is a simple on / off charge controller that uses an IC LM317 voltage regulator [107]. In PWM based charge controller, the charging is controlled by controlling the duty cycle (i.e ON time) of signal. The duty cycle is adjusted based on the battery's SOC and the panel voltage [71]. MPPT based controller ensures that maximum power is tracked by constant monitoring of voltage and power change.

A charge controller is made up of a unidirectional DC-DC converter for regulating solar panel voltage and a bidirectional DC-DC path for charging and discharging of batteries with optimized system and power management in various irradiance levels and charge states [108]. This review paper focuses much on MPPT based controller, as MPPT is efficient technique to maximize the power output of PV panel and increases charging current of the storage element [118].

For maximum power extraction from the solar panel a DC-DC booster converter [70] is connected to the panel and it is operated using MPPT algorithm [73]. The MPPT algorithm defines the duty ratio of the booster converter switch which boosts the output voltage of the converter as presented in Fig 7.

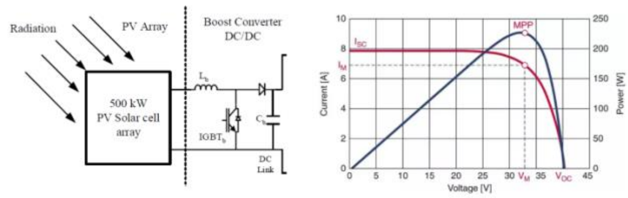

Fig. 7. Solar panel connected DC-DC booster converter for maximum power extraction

The maximum power point is achieved at the highest power peak point which is achieved at I_M (maximum power point current) and V_M (maximum power point voltage). In the above MPP Figure Voc is open circuit voltage of the panel and Isc is short circuit current of the panel [75]-[78]. There are different types of MPPT techniques in which P&O, hill climbing, incremental conductance methods are considered as basic conventional algorithms. In modern power systems new advanced adaptive MPPT algorithms are developed for faster reaction rate extracting maximum power from the panel.

Many researchers have contributed their ideas for maximum solar power tracking and few them are listed in Table 3.

Table 3. Comparison of different MPPT techniques [20]

S.No	MPPT Technique	Control Strategy	Control Variable	Complexity Level	Applications	Converter Used (DC/DC or DC/AC)
1.	Curve-Fitting Technique	Indirect Control	V	Simple	Stand Alone	DC/DC
2.	Fractional Short-Circuit Current (FSCI) Technique	Indirect Control	V or I	Simple	Stand Alone	DC/DC
3.	Fractional Open-Circuit Voltage (FOCV) Technique	Indirect Control	V or I	Simple	Stand Alone	DC/DC
4.	Look-up Table Technique	Indirect Control	V,I	Simple	Stand Alone	DC/DC
5.	Differentiation Technique	Sampling Method	V or I	Complex	Stand Alone	DC/DC
6.	Feedback Voltage or Current Technique	Sampling Method	V or I	Simple	Stand Alone	DC/DC or DC/AC
7.	Feedback of Power Variation With Voltage Technique	Sampling Method	V,I	Complex	Stand Alone	DC/DC
8.	Feedback of Power Variation With Current Technique	Sampling Method	V,I	Medium	Stand Alone	DC/DC
9.	Perturbation and Observation (P&O) And/Hill Climbing Technique	Sampling Method	V,I	Complex	Stand Alone	DC/DC
10.	Incremental Conductance (Inc-Cond) Technique	Sampling Method	V,I	Complex	Stand Alone	DC/DC
11.	Forced Oscillation Technique	Modulation Method	V or I	Complex	Stand Alone	DC/DC
12.	Ripple Correlation Control (RCC) Technique	Modulation Method	V or I	Complex	Stand Alone	DC/DC
13.	Parasitic Capacitance Technique	Sampling Method	V,I	Simple	Stand Alone	DC/DC
14.	Load Current/Load Voltage Maximization Technique	Modulation Method	V	Medium	Stand Alone	DC/DC
15.	Linearization-Based MPPT Technique	Sampling Method	Irradiance	Medium	Stand Alone	DC/DC
16.	Intelligence MPPT Techniques	Intelligent Control	V or I	Medium	Grid or Stand alone	DC/DC or DC/AC
17.	Sliding-Mode-Based MPPT Technique	Sampling Method	V or I	Complex	Grid or Stand alone	DC/DC or DC/AC
18.	Gauss-Newton Technique	Sampling Method	V or I	Simple/Medium	Stand alone	DC/DC
19.	Steepest-Descent Technique	Sampling Method	V or I	Medium	Stand Alone	DC/DC
20.	Analytic-Based MPPT Technique	Indirect Control	V or I	Medium/Complex	Stand Alone	DC/DC
21.	Hybrid MPPT (HMPPT) Techniques	Sampling Method	V or I	Medium/Complex	Grid or Stand alone	DC/DC or DC/AC
22.	MPPT Techniques for Mismatched Conditions	Intelligent Control	V or I	Medium	Grid or Stand alone	DC/DC or DC/AC

The MPPT presented in Table 3. is compared based on parameters like types of (i) control strategies, (ii) number of control variables, (iii) level of complexity and (iv) making cost.

There are two types of control strategies (viz). *a) Indirect control* where a database is used that includes data such as characteristics curves of PV panel for different temperature and irradiance which are used to estimate maximum power point through an empirical formula *b)Direct control method*, the maximum power point is estimated directly by considering the variations of the PV panel operating points without any précised knowledge of the PV panel characteristics. Direct control method is sub classified into sampling methods and modulation methods. In sampling methods, first a sample is made from panel voltage and current. The sample includes parameters like power (P), dP/dV and dI/dV. The location of maximum power point is traced by collecting the previous and present data of the sample [116]. In modulation methods, maximum power point can be traced by producing oscillations instantly by the feedback control [115].

There are many practical applications of MPPT techniques, including solar water pumping systems [21], solar vehicles [22], satellite power [23], off-grid [24], and small electronics equipment [26].

4. Energy Storage System

In recent years, the solar photovoltaic system has grown in popularity as one of the most promising renewable energy sources. Since PV power is sporadic in nature, PV-based stand-alone systems require an energy storage portion, which is implemented by various energy storage element like super capacitors, Ultra capacitors, fuel cells and batteries. Among these elements battery bank is preferred and is implemented by various researchers in [65]-[66].

The storage device considered for power storage during excess power generation from the solar panel module is battery unit [91]-[95]. Battery storage unit is chemical combination of different acids which can store power in the form of acidic concentration. There are different types of batteries with different material combinations and the mostly used battery types are given as

i) Lead-acid batteries
ii) Nickel – Metal Hydride batteries
iii) Nickel - cadmium battery
iv) Lithium-ion batteries

In the above types of batteries for large storage capacity lead-acid batteries are used. They are highly reliable and have higher charging and discharging times. However, they have a small disadvantage is that they cannot charge or discharge at faster rate. The charging time is very high and it cannot discharge high currents if required. Therefore, they cannot be used for heavy duty applications like electric vehicles, traction, high power storage units etc [67]. They are only utilized to operate small electronic equipment and for low rating electrical loads operated through inverter.

The other two categories of batteries which are regularly used for domestic and commercial purpose are Nickel-metal hydrate and nickel-cadmium batteries. These are regularly called as dry batteries as they don't have any liquid material in them. Nickel-metal hydrate batteries are rechargeable and nickel-cadmium batteries are non-rechargeable. These are regularly used by domestic users for regular house hold equipment as they can be manufactured with small and miniature capacities [69]. They are also considered as the safest batteries as they don't have any leakage material during or after usage. The main drawback is they cannot be utilized for high capacity and fast charging applications. The output current rating if these batteries are very low, which can operate only low rating electronic equipment.

The most efficient battery is considered to be Lithium-ion battery can store more energy for less volumetric size as compared to lead-acid battery. This battery has faster charging capability and higher discharge rate which can operate heavy loads. This battery has both acidic and metal materials which can be used only for commercial purpose. The main disadvantage of this battery is it generates very high heat during charging and discharging. There is also risk of explosion if untreated or operated in high temperatures. The cost of the battery is also very high and the reliability [114] is less as compared to other batteries. If the lithium-ion battery is completely discharge it can never be charged again, considering it as dead battery. Therefore, these types of batteries are ideal fit for electrical drive applications which can charge faster and operate heavy loads like traction motors.

The comparison of various types of batteries are compared in Table 4

Table 4. Comparison table of various batteries [72]

Characteristics	Lead Acid [67]	Nickel Cadmium [68]	Nickel-Metal Hydride [69]	Lithium Ion
Energy Density (Wh/kg)	30-50	45-80	60-120	110-160
Power Density	180	150	250-1000	1800
Nominal Voltage	2V	1.25V	1.25V	3.6V
Operating temperature	-20 - 60ºC	-40-60 ºC	-20-60 ºC	-20-60 ºC
Life cycle	200-300	1500	300-500	500-1000
Charge efficiency %	79	-	-	100
Energy efficiency %	70	60-90	75	80
Overcharge tolerance	Good	Average	Poor	Least
Self-discharge	Poor	Average	Good	Least
Thermal stability	Poorly Stable	Poorly Stable	Poorly Stable	Highly stable
Life time in years	5-15	10-20	10-15	2-7

Battery energy storage system is generally preferred for obtaining smooth output of PV power and the technique includes PV ramp rate control, where the battery energy storage system charges and discharges based on the preset value of ramp output of PV power. The preset value can be fixed based on the irradiance data. Other techniques for attaining smooth PV output power includes algorithm where the power with the help of low pass filter and BESS is controlled to trace the power calculated[74]-[76].

Besides PV smoothing, additional features such as frequency regulation, compensation of harmonics, Voltage regulation, facilitating spinning reserves can enhance the working of power system and also the cost of equipment is deferred [77]. As discussed in [79]– [80] besides energy storage, the battery energy storage system is used for assisting multiple features such as frequency and voltage regulation. A Battery Energy Storage System(BESS) is incorporated to grid through its dedicated transformer – inverter setup where the output power of the PV system is smoothened [81]. Also, the BESS mentioned earlier is capable of performing auxiliary functions like frequency regulation. The design of battery energy management system plays a significant role in grid integration and size selection of battery of an PV power plant. To minimize the size of energy storage, an EMS with energy storage is proposed in [82] for PV plants. However, the system proposed in [82] does not exhibit any of economic analysis. An ideal energy management system is incorporated in [83] with storage, exclusively used for grid connection of PV power systems. The aim of the system is to help in depth perforation of PV power into grid by enabling peak shaving aid at lesser cost. Likewise, cost-based energy management system was adapted for PV system with battery installed at roof top for local load [84]. The PV output and battery system are programmed depending on time variant price signals corresponds to electricity demand. Anoptimization technique is proposed in [85] for control scheme and battery sizing of PV plant. Optimization is done based on the cost of operation and maintenance versus market penalty cost. An energy management system in [86] is developed to subsidize peak load and to sustain constant generation of power. In [86], the diminished line losses are investigated based on energy management system design and different size of battery.

Researchers have proposed various energy systems incorporated with suitable energy storage and algorithms. The issues that are unavoidable are handled by any of the approaches mentioned further, determines the convolution of the system that can be controlled. In nonlinear models, dynamic programming [87] are used as nonlinear optimizer. Other researchers have proposed reduced computational power with linear [88] and quadratic [89] algorithms to optimize design models with less complexity.

On the contrary, heuristic [90] and metaheuristic algorithms are proposed for non-deterministic problems. Metaheuristic algorithms such as particle swarm [91], [92], ant colony [93], or ant-bee colony [94]; the genetic algorithms [95] or the taboo search algorithms [96] are proposed. Other than these Metaheuristic optimizations, many authors have proposed fuzzy logic [97], model predictive control [98], game theory [99], even multi-agent systems [100] for energy management system with energy storage systems.

Battery Management Systems (BMS) are designed to monitor and optimise the battery's performance. Additionally, the BMS is utilised to monitor battery charging as well as the management of energy sources and loads. Battery's performance must be monitored so that the battery may be replaced if its storage capacity and energy delivery fall below threshold level. State-of-charge (SOC) and state-of-health (SOH) describes battery's performance. The SOC is the total amount of charge remaining in the battery, given as a percentage of the maximum charge that the battery can retain in its current state. The SOH is the proportion of a fully charged new battery's total charge that a fully charged battery in its present state can store. Battery management systems include main functions as mentioned in Fig 8.

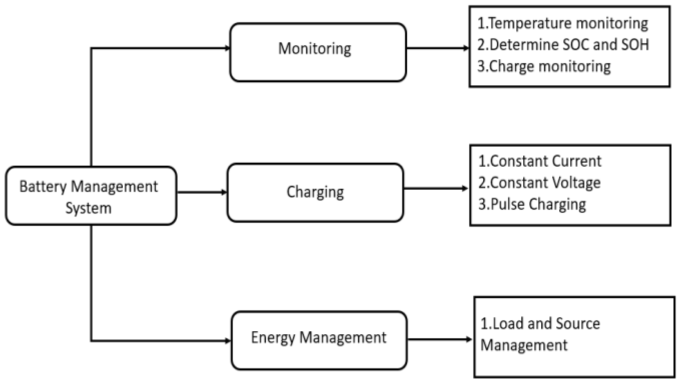

Fig.8. Overview of BMS

5. Applications of MPC

The MPC proposed in [1] is best suited for low power applications where simplicity and size of the circuit is of higher importance, such converters are used in standalone PV systems. Meanwhile, topologies proposed in [11],[13],[29],[50]-[54] uses more than four switches for interleaved PWM converters whose current capability is double in comparison with simple PWM converters, hence such type of converters are highly suitable for large power applications.

The power flow in [50] is controlled independently in each loop and hence such systems are suitable for PV applications where single converter is integrated with PV array, battery and load. A multiple port DC- DC converter has been proposed in [46] whose application is on the regulated satellite power bus. These converters share common power devices there by leading to high power density, and has good modularity by using conductance current control.

The bidirectional converters proposed in [19] consists of six ports (i.e.) three ports in both input and output sides which is mostly used in battery charging applications.

The topology proposed in [55] has a bidirectional configuration and can be used in low and high-power applications with power levels varying from 100 W to 10MW. Via module voltage and current sharing capabilities, the MIMO-modular MMC's configuration allows for efficient component utilization. On the other hand, the topology proposed in [56] is most realized in electric vehicles where the converter can be employed for boost mode as well as buck mode with bidirectional control. Also, independent control of power flow is possible between the multiple power sources which are intently transmitting power in one of two directions.

An isolated multiport converter proposed in [57] employs a single controllable switch in individual port on the input side, thereby adding an advantage of reduced number of switches. Also, the proposed topology can be applied for controlling the hybrid power generation system comprises of single wind turbine generator and double PV panels through simultaneous MPPT logic.

6. MPC Problems and Future Research Directions

In order to extract non-isolated and isolated multiple-input converters from single-input models, general rules were followed in [35]-[37], to define the feasible input cell that complies with certain conditions and assumptions.

A cost-effective approach on buck boost topology is proposed in [38]-[40]. Though the converters are simple, these converters lack a power flow path for charging batteries, making them unsuitable for PV-battery systems.

The topology proposed in [41], [42] uses two bidirectional boost converters with parallel outputs. This topology contributes high efficiency, lesser components and has two bidirectional current flowing ports. Even so, the voltage of PV and battery port is lower than that of load port, the output current seems to be discontinuous, thus making controlling and sharing of output current very difficult. A three-switch bidirectional topology is introduced in [43], where the current in all the three ports is continuous and fewer switches are used, thus compact design is achieved but the topology faces power safety issue as the PV, battery and output port do not have common ground.

Two unidirectional input power ports and bidirectional port for storage element is interfaced by the researcher as proposed in [44]. These converters utilize two power inductors, eight MOSFET and power diodes thus increasing the switching losses. A methodical approach has been proposed in [45] to develop non isolated three port converters, that undergoes single stage conversion resulting in high efficiency. However, the right half plane zero (RHPZ) of boost converter reduces its dynamic performance and AC characteristic and current of the port is discontinuous.

Converter proposed in [46] has battery port voltage greater than the bus voltage, thus making the battery design impossible and unsafe. Also, the dual stage conversion of power from PV to bus reduces the converter efficiency. In [47], a high voltage gain three port converter is proposed where the converters port current is continuous in the low voltage side. However, the system design is complicated as the seven power devices are utilized.

The isolated multiport converter proposed in [10] uses triple active bridges which power controllability and zero voltage switching. The performance of switching in such converters can be improved by implementing dual series resonant module. An improved modulation technique is implemented in [9] which includes phase shift and Pulse width modulation. The triple active bridges proposed in [10],[9] has increased circuit complexity and reactive power circulation leads to power loss. Hence a three-port network in half bridge is integrated using buck boost converter in [50]. Also, controlling of multi variable is achieved by individual single loop subsystems. By doing so the current passes through a minimum of five inductors in each energy transfer state, thereby increasing the power loss and also the power capacity is restricted by the transformer size.

For non-isolated application, the obvious choice of converters are non-isolated MPCs. Anon-isolated multiport converter employing PWM controlling technique utilizes a DC link bus to integrate multiple converters into one unit [56]. Despite of using limited circuit elements among multiple converters, their assistance of integration is confined. Though many non-isolated multiport converters are introduced, diminished duty cycle is observed in [58]. Concurrently, PWM based multiport converters are proposed in [17],[59] – [60] shares switches and passive components among the converters and can overcome the issues of decreased duty cycle and unshared common grounds. Voltage equalizers are essential to integrate converters for Photovoltaic panels and batteries to overcome the demerits of partial shading as proposed in [61]-[63], Also cost reduction can be achieved. An PWM and PFM based switched capacitor converter is proposed in [63] that achieves independent control of load and battery voltages, while partial shading issues can be avoided by the voltage equalizer along with switched capacitors.

7. Conclusion

A detailed review of multiport converter for renewable energy application is presented in this paper. The main aim of multi-port converter is to reduce the number of switches, complexity of the systems and power conversion in one stage without barging the characteristic of PV system, such as battery capability while charging and discharging. From the discussion, it is evident that for power system less than 600W (i.e) low power system, non-isolated topologies can be used, whereas for high power system isolated topologies are the better choice. A desired charge controller is required to have a watch on battery charging and discharging, ensuring the battery's health also for tracking the maximum power from PV, sampling method is best suited as for standalone DC -DC system as the method is simple and cost effective also besides PV power smoothening, it is required to incorporate Voltage regulation, facilitating spinning reserves so as to improve the working of the PV based power system. The lead acid batteries have high power output capability and highly robust. For the Energy storage system, suitable algorithm must be derived for the optimizing the battery performance. The discussions presented in the paper, facilitates the researchers to choose different multiport converter topologies to integrate various renewable energy sources to power the loads that are present in the remote locations.

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