Journal of Techniques, ISSN: 2708-8383, Vol. 5, No. 2, 2023, Pages 61-73
DOI: https://doi.org/10.51173/jt.v5i2.1227

JOURNAL OF TECHNIQUES

Journal homepage: http://journal.mtu.edu.iq

*RESEARCH ARTICLE - ENGINEERING*

# A Comprehensive Review of Multi-Port DC/DC Converters for The Off-Grid System Integration with Renewable Energy Resources

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**Article Info.**

*Article history:*

Received
23 January 2023

Accepted
14 May 2023

Publishing
30 June 2023

**Abstract**

Appropriate design of Multi-Port Converter (MPC) topology helps to overcome the difficulties of combining numerous renewable energy sources (RES). In this article, a comprehensive analysis of these MPCs in terms of their topologies, operating principles, various dependability, and overall efficacy is offered. There are two main types of MPCs which are non-isolated and isolated MPCs being coupled in parallel and series configurations to function as multi-input converters. These MPCs can flow the load power in one or both directions for the RES or BESS (battery energy storage system) applications. The non-isolated MPCs are most used in the latest years but they have some limitations such as small voltage gain, and failure in isolation. The isolated MPC is more effective than the non-isolated ones in terms of isolation between the input power stage and output but has some drawbacks such as the high cost, and large size of the high-frequency transformer (HFT). In this review paper, a high-efficiency voltage-regulator/battery energy storage system (VR-BESS) was presented as a multi-port DC-DC converter for the standalone PV (photovoltaic) array. This converter has fewer switches, is cheaper, and is more dependable than its counterparts.



Publisher: Middle Technical University

**Keywords**: DC/DC Converter; Multiport Converters; Isolated Converters; Non-Isolated Converters; Photovoltaic.

## 1. Introduction

As a result of their regeneration, safety, and environmental friendliness, renewable energy sources (RES) have attracted a lot of attention and made significant development across the globe [1]. The fast depletion of fossil fuels, climate change, and rising energy costs because of the petroleum crisis have all contributed to a rising interest in RESs in recent years. It's been established that the nations will work together to reduce carbon emissions during the next decades [2, 3]. The use of small-scale RES including wind and solar panels, as well as fuel cell (FC) energy systems, have been on the rise in recent years, notably in the context of power production [4-6]. FC power production units are currently more costly than wind and solar energy generation systems; nevertheless, they offer advantages such as continuous energy generation capabilities, high efficiency, quiet operating, and steady operation [7].

In addition, the growing awareness of the need to protect the environment, along with developments in technology and a concomitant reduction in the need for manual lab, has led to an increase in the usage of renewable sources such as solar photovoltaic (PV) and wind power [8]. However, these RES aren't widely used because of the inherent unpredictability of load demand and the nature of RES [9]. However, to overcome the challenge posed by the intermittent nature of RS and the unpredictability of the load demand [10, 11], the DC-DC converters integrated with energy storage systems (ESS) are generally used to share the electrical power from PV modules and BESS according to the demand output power or the load requirements. Also, the MPPT (maximum power point tracking) control was implemented to improve the PV system's power generation in both dynamic and steady-state conditions. However, a standard DC-DC converter used to regulate the RES with the load and a bidirectional DC-DC converters are used to connect the ESS with the load for charging and discharging process [12-15]. The most significant drawback of these conventional methods is the poor efficiency that is brought on by the employment of an extra converter for the ESS [16, 17]. Additionally, this design can provide an increased size, a lower power density, and a comparably higher cost.

Moreover, several applications require the integration of many forms of power input, such as FC, wind turbines (WT), and solar PV system, making a MPC a viable option [18, 19]. This sort of converter could be used to deliver the needed load power using a single-stage approach. When the output power is greater than the input power, however, these MPC may not be able to provide the necessary power production since they do not often feature an ESS. This can occur in FC operation if the chemical reaction of the FC is too slow to keep up with the abrupt rise in load. Similarly, solar PV applications may experience rapid variations in PV production due to factors such as passing clouds that reduce PV output below the load demand or lack of sunlight at night [20]. The production of WT power also varies with changes in wind speed. The requirement for applications with many inputs and outputs has increased the importance of MPCs. Further, in comparison to using numerous

| **Nomenclature & Symbols** | | | |
|---|---|---|---|
| MPC | Multi-Port Converter | CCM | Continuous Condition Mode |
| RES | Renewable Energy Sources | MPPT | Maximum Power Point Tracking |
| BESS | Battery Energy Storage System | D | Diode |
| WT | Wind Turbines | DAB | Dual-Active-Bridge |
| SC | Supercapacitor | L | Inductor |
| PV | Photovoltaic | n | Number Of Windings |
| FC | Fuel Cells | HES | Hybrid Energy Systems |
| ESS | Energy Storage Systems | η | Efficiency (%) |
| MG | Micro Grid | S | Electric Switch |
| PWM | Pulse Width Modulation | HFT | High Frequency Transformer |

single converters, MPC provides cost savings and boosts overall system performance. Electric vehicles (EVs) and grid applications benefit from MPC due to their ability to accommodate several input voltages. In addition, standalone power plants used in grid connected and EVs applications have drawn interest in MPC for their ability to interface with these sources [21, 22]. Additionally, MPCs need a smaller number of components and a more compact construction than several independent DC-DC converters. As a result, higher power density is achieved while converter complexity and overall cost are decreased. Therefore, grid-connected systems, RESs, and EV applications benefit from the use of MPCs. Overall, the use of MPC for off-grid power system applications is also an effective way to optimize the performance of these systems and make the most efficient use of renewable energy sources like solar and wind power, as shown in Fig.1. The MPC for the RES can be used for off-grid power system application [23, 24].

The outline for this paper looks like this: Section 2, describes the consisting of the multi-port DC-DC converter and explains the research approach in Section 3, these converters are compared. Section 4, it presents a converter that was selected as a recommendation for standalone systems. Section 5 describes areas for future research and the conclusion is presented in Section 6.

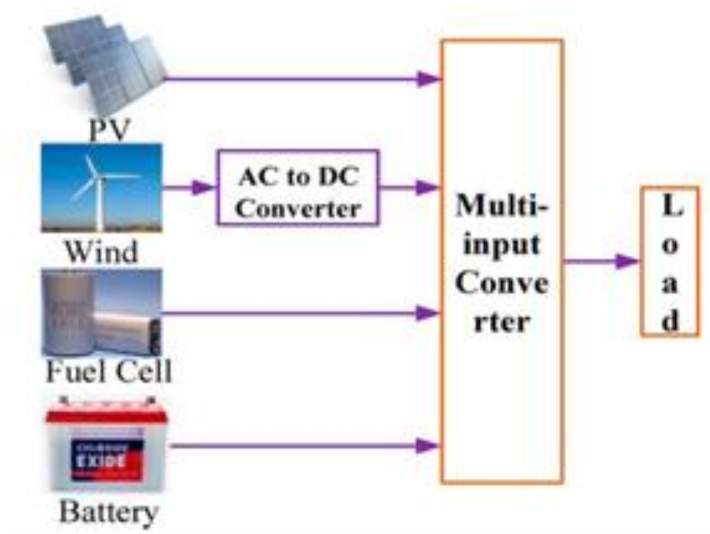


Fig. 1. Multi-port converter for off-grid power system application [23]

## 2. Multi-port DC/DC Converters

### *2.1. Non-isolated Multi-port DC/DC converters*

Fig. 2 depicts a bridge-type multi-port DC-DC converter that is implemented in [25]. This converter is intended for use with high/low voltage sources which represents the buck converter type with two ports on the input side. The energy is drawn independently from both of the voltage sources or both simultaneously and moreover, with the appropriate choice of switching method. Two voltage sources may be operated either in parallel with one another or in a series-parallel combination. On the other hand, it has problems with hard switching, and the flow of power in both directions could not be feasible. An innovative buck converter design for solar PV/battery systems is proposed in [26]. It refers to the capability of charging the battery when it is connected to a converter under conditions of low load or no load. The circuit of this converter is presented in Fig. 3.

An innovative non-isolated single-inductor multiple-input buck DC-DC converter with fewer components was proposed by the authors of [27], and is depicted in Fig. 4. In that study, a smaller number of components may lead to a reduction in the cost, mass, and size of the converter. The ability to transmit electricity from input sources either simultaneously or independently has been made available. Additionally, the ability of bidirectional power flow has been supplied via the use of a battery without the inclusion of any extra switches. Because of this, the design is optimal for a wide variety of uses involving hybrid HES (hybrid energy systems) as well as HEVs and EVs.

Using ESSs with varying electrical properties, the research in [28] offered a unique bidirectional non-isolated MPC architecture for application in EVs as seen in Fig.5. The proposed converter permits active power sharing, which allows ESSs to have their power regulated. Used ESSs may have input voltages that are more than or less than the load voltage. Since the converter's inductors are linked to a one switch, the element count is decreased since the converter needs just one more active switch for each input.

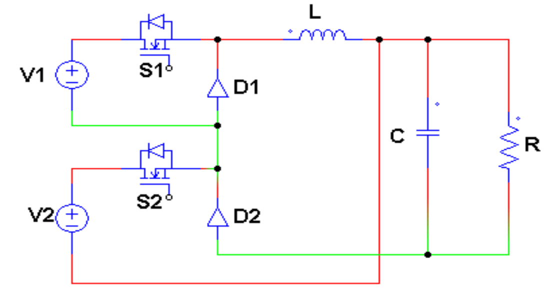


Fig. 2. Multi-port DC/DC buck converter in [25]

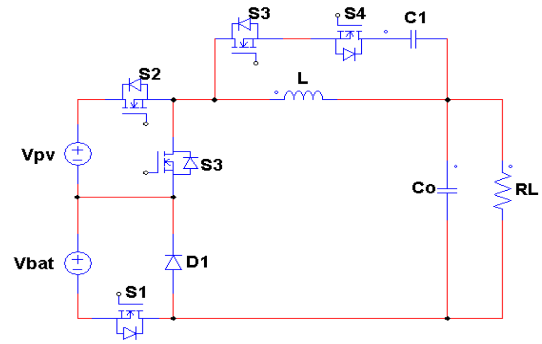


Fig. 3. DC/DC buck converter with dual input proposed in [26]

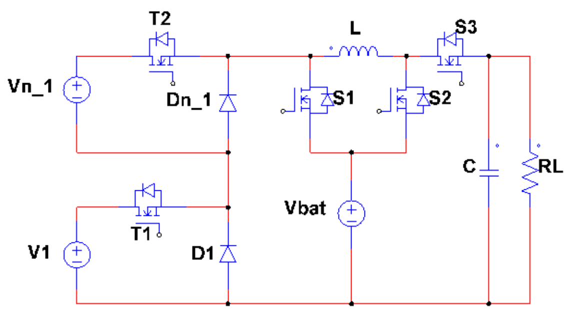


Fig. 4. DC/DC buck converter with multi- input proposed in [27]

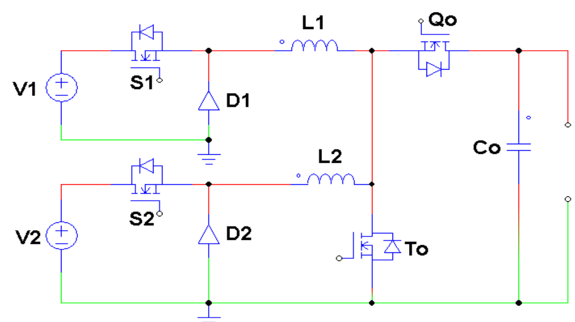


Fig. 5. MPC proposed in [28]

An actively regulated hybrid magnetic battery / ultra-capacitor-based ESS for automotive propulsion systems is the topic of the research in [29]. A linked inductor, rather than two individual inductors, as see in Fig. 6, is employed in this converter. Unfortunately, the linked inductor has a large size, which is represented the main issue of this converter. In [30] the authors examined the characteristics of a multi-port, non-isolated DC-DC boost converter, which is displayed in Fig.7. The single inductor used by the converter helps it adapt to tight spaces in a wide variety of uses. This work presents an MPC that converter that takes electricity from two independent inputs and distributes it to two separate loads. Because of its ability to provide output at a variety of voltages, the MPC is well suited for use in DC distribution systems and EV applications. The first port is represented by a FC renewable energy source while the second port of this converter is connected to a BESS. The converter may be coupled with future renewable DC sources for easier control.

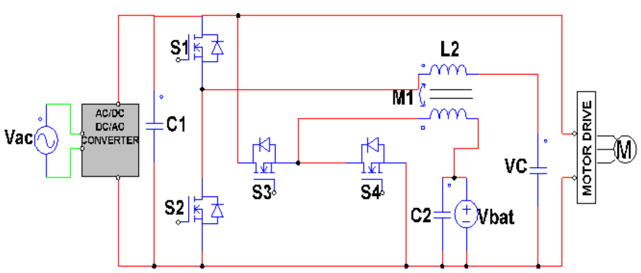


Fig. 6. DC/DC multi-port converter proposed in [29]

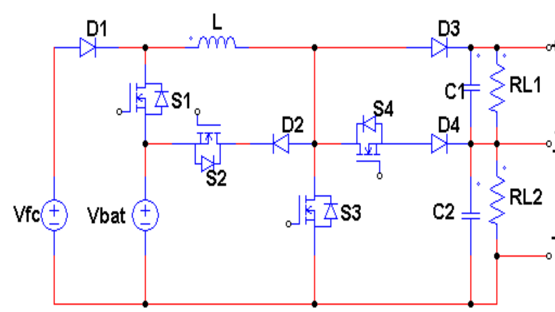


Fig. 7. Proposed boost converter in [30]

A novel multi-port DC-DC power converter that utilizes RESs, as presented in Fig. 8, is proposed in [31]. The suggested converter can be used in standalone micro grid (MG) or grid-connected MG. The FC, PV and WT are used in this converter as the renewable energy sources. The proposed circuit incorporates a variety of RESs in addition to the energy storage unit which is can be connected directly across the DC bus of the converter. Implications of RES's unreliable availability may be significantly mitigated by combining them with ESS. In addition, the problem of sluggish response that is inherent to renewable sources may be circumvented by combining these systems with energy storage devices [32-34]. It may either offer the extra energy that the load needs or absorb the surplus energy that is delivered by the power sources, greatly improving the system's dynamics.

A non-isolated DC-DC MPC with good output gain has been reported in [35]. The suggested circuit shown in Fig. 9 is made up of straightforward units that have high reliable gain. The ability to use input sources with varying voltage-current characteristics and continuous current from source inputs are two of the most significant benefits offered by the architecture that has been developed. The load on the switches can be decreased if more input units are used by selecting a lower duty ratio for each individual unit. This results in a decrease of stress for the switches. The suggested topology is also suitable for use with alternative or renewable sources of power.

In [36], a three-port DC-DC buck-boost converter for use in renewable energy systems' high-power step-up/step-down applications is described. It features two ports as well as one port that goes in both directions, so that the PV energy may be harvested and the battery can be charged as shown in Fig. 10. At port 1, a hybrid configuration of buck and buck-boost converters, together with a specific configuration of controlled switches and circuit inductors, is employed to convert electrical current. The ratio of voltage conversion between stepping up and stepping down is greater than that of a traditional converter, and the output voltage's polarity is maintained at a positive value.

In [37] a novel MPC is presented for use in the ESS or EVs applications. The suggested converter is equipped with the capability of operating in bidirectional step-up and step-down operation circuit, simultaneously. As a result, the wiring circuit structure of this converter was displayed in Fig. 11. Within the framework that is being suggested, there are three openings or ports through which the energy may transfer. The suggested converter has many notable advantages, the most notable of which are its low losses, simplicity, and a main switch with a low peak voltage. In addition, the suggested MPC utilizes just two power switches, which makes it simple to switch between different power sources. This facilitates the conversion process. Due to the fact that it is capable of step-up and step-down operating principles, the converter that has been presented is used for PV applications.

The authors in [38] proposed a new MPC for renewable energy application as seen in Fig. 12. The two inputs of PV array, and battery ESS were used in this system to test the performance of the converter. Within the scope of this investigation is a high-output voltage-gain boost DC-DC converter with two inputs. The converter that has been described offers a number of benefits, some of which include a high step-up capacity, continuous input current, bidirectional power flow from one of the ports, and a construction that is both straightforward and economical. The construction of the converter that is being given does not need the use of a coupled inductor or a transformer in order to accomplish a high-output voltage gain.

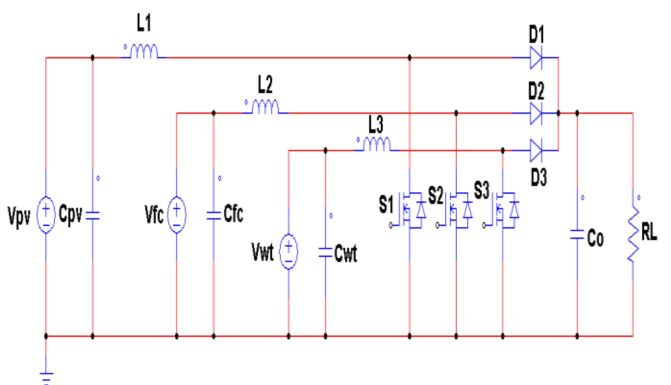


Fig. 8. D/DC MPC for renewable energy application proposed in [31]

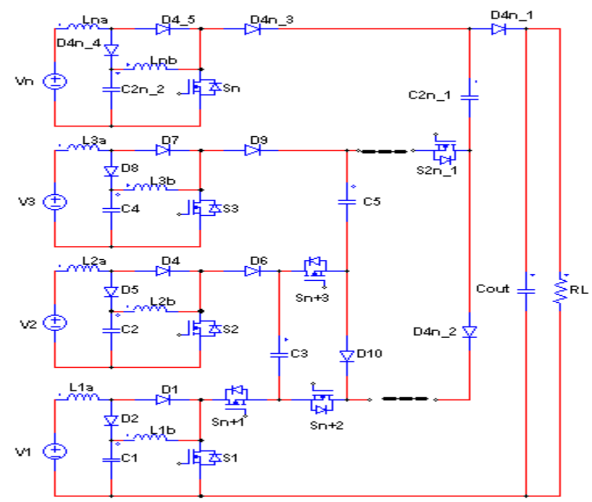


Fig. 9. High gain DC/DC MPC proposed in [35]

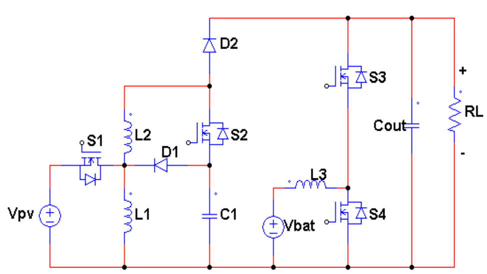


Fig. 10. Proposed dual input buck-boost converter in [36]

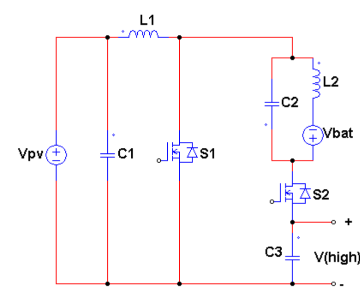


Fig.11. Multi-port converter proposed in [37]

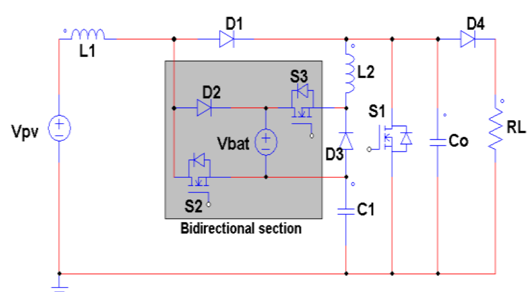


Fig. 12. Multi-port buck-boost converter proposed in [38]

*2.2. Isolated multi-port DC/DC converters*

All of the energy storage converters described in the aforementioned documents are non-isolated buck circuit, boost circuit or buck-boost circuits, which have the benefits of being inexpensive, lightweight, and having a straightforward design [39-41]. These types of converters are typically utilized in low-voltage applications that require high current. On the other hand, the non-isolated circuit, has a limited buck-boost range, making it inappropriate for applications that need significant voltage gain [42,43]. In addition, the absence of electrical isolation makes it impossible to ensure the distributed power system's level of safety. For these reasons, the isolated MPCs are the most used in EVs and RES applications due to they have more advantages over than the non-isolated converters such as isolation between the input and output stages, offer a high output voltage for the DC bus link especially in grid tied PV inverters applications [44, 45]. This kind of converter may be further subdivided into three subtypes based on the nature of the connection between the three ports: (i) non-isolated converters, (ii) partly-isolated converters, and (iii) isolated converters, as seen in Fig. 13; the non-isolated three-port DC-DC converters are shown in their typical design in Fig. 13(a). The lack of galvanic isolation between the converters of three inputs is indicative of this design. A design with less direct connection between the ports may not be as space-efficient, whereas one with more direct connections between the ports may have a greater power density. Moreover, the isolated converters shown in Fig. 13(d, b and c) display two possible topologies for connecting the partially isolated converters. Partially isolated converters and isolated converters both employ a high-frequency transformer (HFT) to fully separate the ports from one another, reducing the danger of electrical shock to the user. This is the standard procedure for autonomous converters. The transform also helps the converter achieve one of its goals by increasing the voltage at load side. Because of the large size and weight of a HFT, the converter's power density and efficiency will suffer as a consequence of its use. In contrast, in circuit of the non-isolated, the HFT did not used. Any of these three types of converters might be employed with the right PWM modulation techniques and power management plans in place. The end result should be suitable for a certain industrial use [44-48].

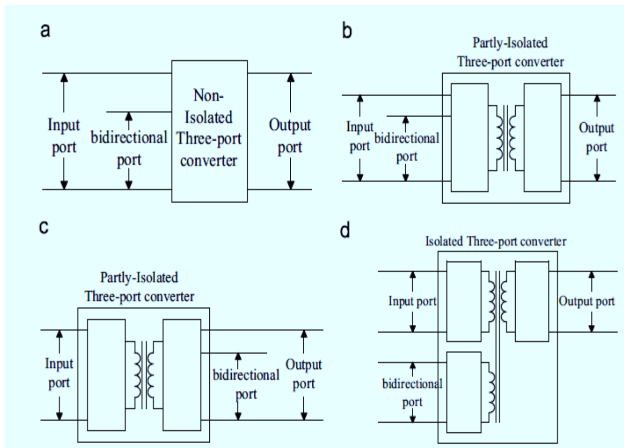


Fig. 13. Types of isolated MPC using HFT transformers [44]

The authors in [46] were developed a new quasi-Z-source converter integrated isolated MPC architecture for application of the PV systems associated with EV and ESS. As a result, the suggested technology is able to provide uninterruptible power to the EV's motor and recover the energy lost during braking, all while having the capacity to deliver power in both directions. The switch that is already in place is used as part of the system in order to incorporate quasi-Z-source and H-bridge converter. As a result, a four-port converter may be accomplished without the use of separate converters or any extra switches. In addition to this, it is now feasible to reduce the rated voltages of the SC packs and battery packs thanks to the high-gain quasi-Z-source converter, and it also makes it possible to use an HFT. The circuit configuration of this topology can be seen in Fig.14. However, as can be seen in Fig. 15 of [47], a unique bipolar converter is proposed that is based on the combination of an MPC dual active bridge (DAB) and a neutral point clamp topology. This design allows for the coordination of many RES, each of which may provide varying amounts of power and can be of a different kind, into a bipolar medium-voltage DC MG. When compared to the combination of the other converters, the recommended topology offers a number of advantages, the most prominent of which are its high-power density and its lowered number of switches.

An isolated MPC that is based on a HFT was presented in [48] as seen in Fig. 16. In this converter the DC sources controlled using four power switches and each H-bridge was connected to the HFT via an inductor and the primary winding which are (n1, n2, n3, and n4). As a result, voltages can change the power flowing into each one winding. This converter presents high output voltage with robust isolation process. Unlike, the main issue of this converter is the high cost of switches. For this reason, the authors in [49] proposed an isolated MPC for renewable energy sources (PV modules) and BESS with minimum number of switches. The H-bridge in [48] with four switches was improved by removing the right arm of the H-bridge and replace them by a capacitor as seen in Fig. 17. In this converter the first port is PV system while the second port source is represented by a BESS. The HFT with two winding in primary side and one winding in the secondary was used to raise the voltage of the sources and then controlled the voltage by adding a half bridge in the DC link side.

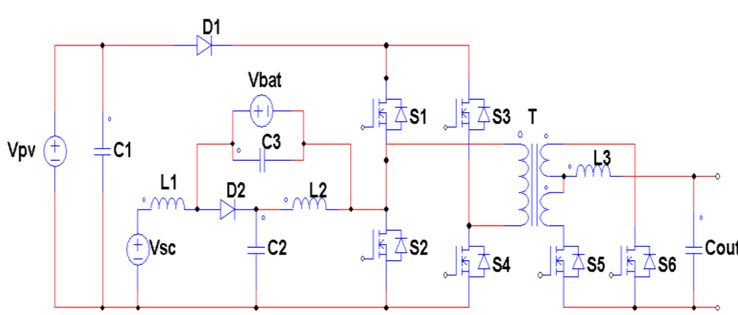


Fig. 14. Isolated MPC with quasi-Z-source converter proposed in [46]

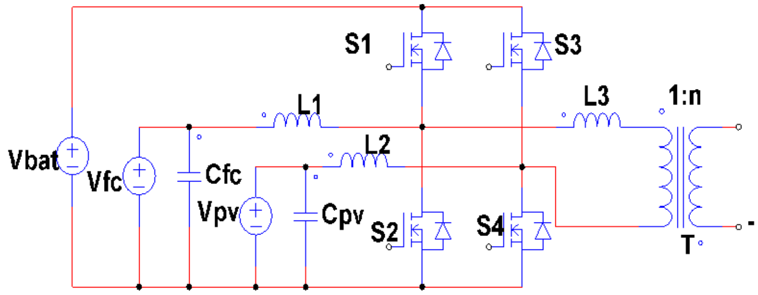


Fig. 15. Isolated MPC proposed in [47]

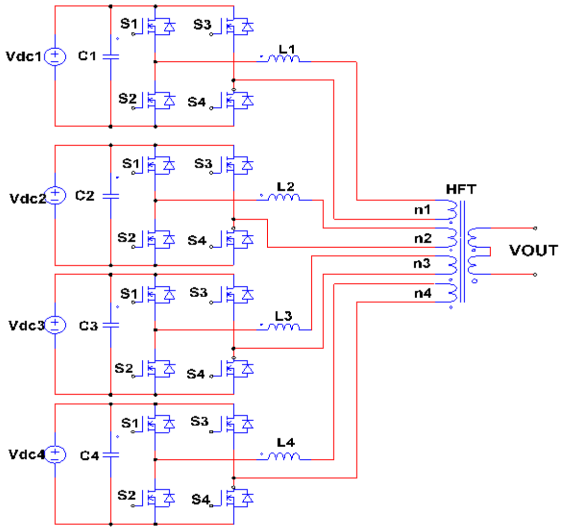


Fig. 16. An isolated MPC for EV application in [48]

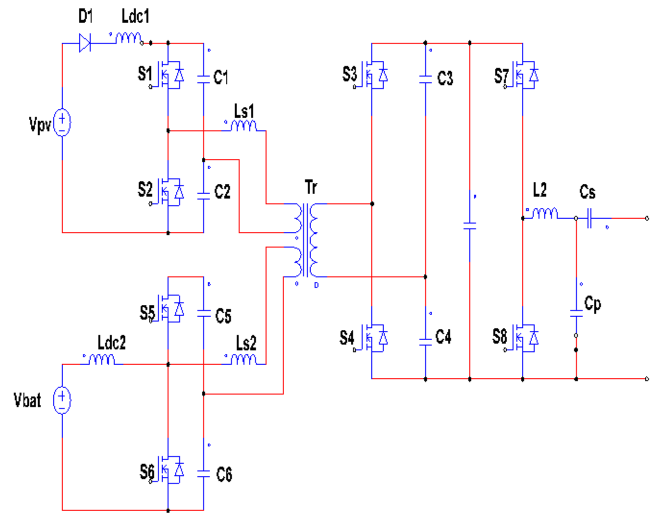


Fig. 17. An isolated half bridge MPC proposed in [49]

However, during periods of intermittent power production from the PV source, the load demand may be balanced off by the energy that is stored in the BESS. Furthermore, the charging of the depleted battery in absence of the PV power may cause a disruption in the system's general generation. Because of this, the authors in [50] have suggested a modified bidirectional converter to transfer the source power in the load output side and to make use of the available power for charging batteries as seen in Fig. 18. The converter's dependability was improved using a mode selection logic controller with optimum MPPT and PWM controllers. The use of more switches at the secondary side of the HFT may lead to an increase in the overall cost and reduce the system efficiency. For this reason, the author in [51] suggested a new isolated MPC for PV system applications with energy battery system using H-bridge of power diodes instead of controlled switches as displayed in Fig. 19. This study suggests using an architecture that has three inputs for a DC-DC converter, with one battery and two PV modules providing extra storage, respectively. If any one of the input units fails, the dependability of the converter is improved to the independent management of the input sources.

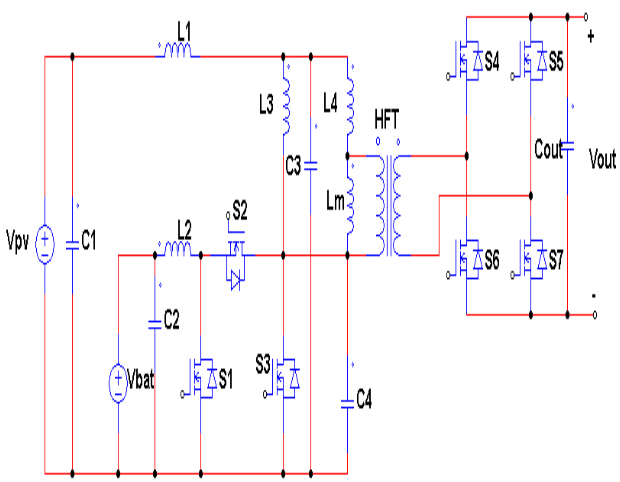


Fig. 18. Dual port DC-DC converter proposed in [50]

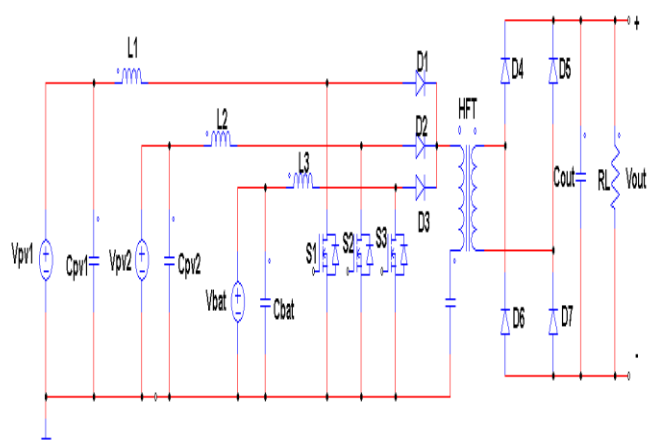


Fig. 19. Three port DC-DC converter proposed in [51]

The authors in [52-55] illustrates the MPC converter with the non-isolated section with many ports for RES or BESS applications. Non-isolated DC-DC converters are the ability to step up, the low voltage produced by PV panel and the capability to succeed load matching between PV panel and load is shown in reference [53]. Using a multiple-input converter with bi-direction, half-bridge, multiphase-converter topologies, and isolation, one may achieve diverse ranges of loads in [56-58]. This is made possible by combinational battery storage. When utilizing this converter, the power exchange may be carried out in either the independent mode or the combinational mode without any issues whatsoever. Additionally, since it operates in an independent mode, it improves its efficiency even when subjected to situations with a modest load. The voltage multiplier concept is combined at the output stage to increase the voltage gain and reduce the voltage stress across the switches and diodes. As seen in Fig. 20 of [60] the DAB was used on both side of the HFT transformer. It extends the increase of efficiency, which is the primary benefit of DAB, the peak current stress when compared with standard non-isolated MPC for the same power transfer. This is one of the ways that isolated MPC provides an advantage over classical DC-DC converters [59-60].

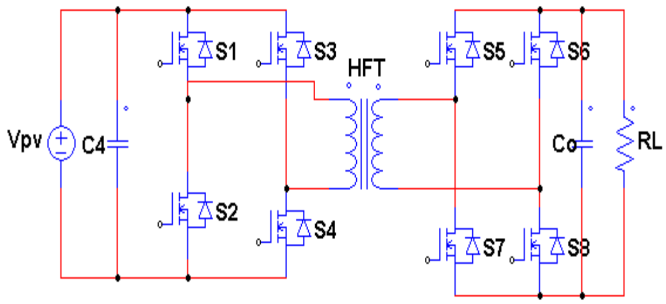


Fig. 20. Isolated DAB DC-DC converter in [60]

For a RES application without the need for an additional power grid, a technique is given to construct 3-port half-bridge converters (TPHBCs) between a PV module, a BESS, and an isolated DC load [61]. With the addition of a DC bias current in the HFT, the main circuit of this converter can act as a synchronous buck circuit, allowing for the configuration of a current flow path between the PV module and the BESS. The circuit configuration of this converter can be seen in Fig. 21.

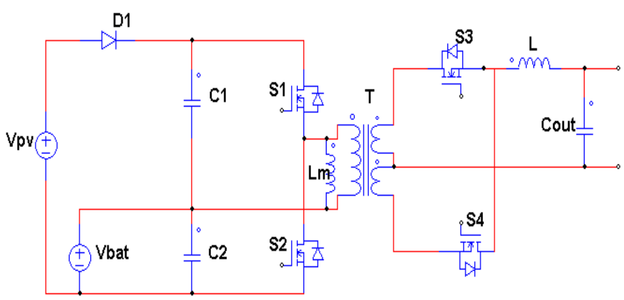


Fig. 21. The converter presented in [61]

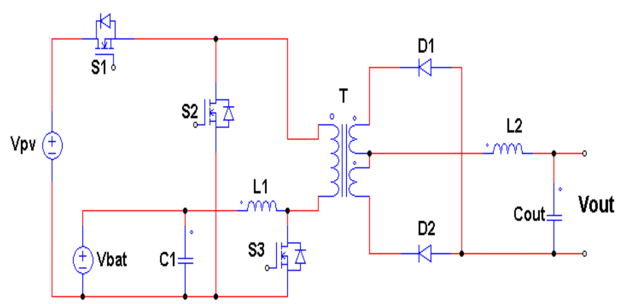


Fig. 22. The converter presented in [62]

The study proposed in [63] was presented a PV isolated DC-DC converter with three ports as an integrated solution to both the power system's cost and power density problems as shown in Fig. 23. By including two power switches on the input side and one controlled switch with three power diodes in the load side conversion. In the topology, the criteria of the zero current switching are possible for the diodes and MOSFETs. For this reason, this can increase the conversion efficiency. In addition, the robust method for controlling the PV module based MPPT battery charge management was proposed with the foundation being the energy-balancing element.

The authors in [64] presented a DC-DC converter that uses the Cuk topology with three input ports as shown in Fig. 24. The suggested converter was made with three ports: one input and two output ports. Due to the zero-ripple quality, the suggested design requires just three power switches and eliminates the need for output capacitors on the output ports. There are three power operating modes for the converter, each optimized for a certain battery use stage. Simulation results for various operating situations are used to validate the proposed converter's characteristics.

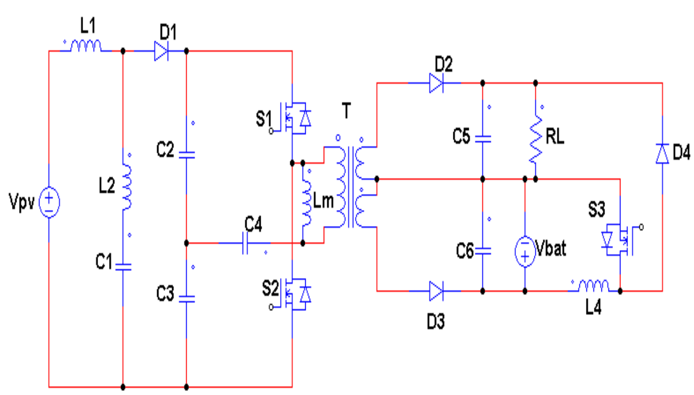


Fig. 23. The converter presented in [63]

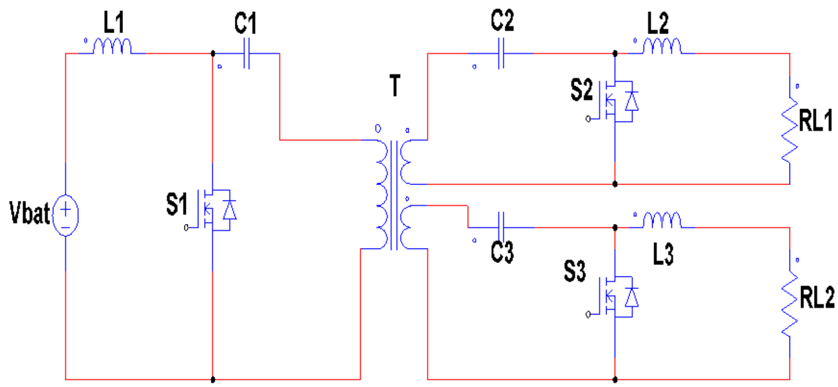


Fig. 24. The converter presented in [64]

### 3. Comparison Between the Non-Isolated DC/DC Converters

The purpose of this comparison is to demonstrate the differences between the DC/DC converters that have been evaluated in terms of voltage, gain, the number of components, and rated power as seen in Table 1. The number of semiconductors includes diodes (D), and switches (S). The conventional boost, buck, and buck-boost converters are presented with a low voltage gain, but they have a simple circuit configuration. Compared with these converters, the MPCs [25], [27], and [28] considers a more efficient and have high voltage gain.

Table 1. Comparison between the non-isolated DC/DC converters

| Converter | No. of D and switches | No. of C and L | Voltage gain | $\eta$ (%) |
|---|---|---|---|---|
| Boost converter [13] | 1 D, 1 S | 1C, 1 L | $V_o = \frac{1}{1-d} V_{in}$ | 94.5 |
| Buck converter [14] | 1 D, 1 S | 1C, 1 L | $V_o = d\ V_{in}$ | 80 |
| Buck-boost converter [15] | 1 D, 1 S | 1C, 1 L | $V_o = \frac{-d}{1-d} V_{in}$ | 98.5 |
| [25] | 2 D, 2 S | 1C, 1 L | $V_o = \frac{d_1}{1-d_2} V_1 + \frac{d_1}{1-d_2} V_2$ | N.A |
| [26] | 1 D, 5 S | 2 C, 1 L | $V_o = d_1 V_{pv} + d_2 V_{bat}$ | N.A |
| [27] | 2D, 4 S | 1C, 1 L | $V_o = \frac{(-d_1)\ V_{bat} + (d_3)\ V_1 + (d_3 - d_2)\ V_2}{(1-d_1)}$ | 96.8 |
| [28] | 2 D, 4 S | 1C, 2 L | $V_o = \frac{d_1}{1-d_T} V_1 = \frac{d_2}{1-d_T} V_2$ | 97 |
| [29] | 0 D, 4 S | 1C, 2 L | $N.A$ | N.A |
| [30] | 4 D, 4 S | 2C, 1 L | $N.A$ | N.A |
| [31] | 3 D, 3 S | 4C, 3 L | $V_o = 2\ d_1 V_{pv}$ , for one-port | N.A |
| [32] | 4 D, 2 S | 3C, 2 L | $\frac{V_o}{V_{pv}} = \frac{1}{1-d_1}, \frac{V_{bat}}{V_o} = \frac{1}{1-d_2}$ | N.A |
| [33] | 2 D, 2 S | 3C, 3 L | $V_o = \frac{V_{pv} - rL - (d_1 - d_3) V_{bat}}{1-d_2}$ | N.A |
| [35] | 9 D, 7 S | 5C, 6 L | For n=2, $V_o = \frac{1}{(1-d_1)^2} V_1 + \frac{1}{(1-d_2)^2} V_2$ | N.A |
| [36] | 2 D, 4 S | 2C, 3 L | $V_o = \frac{d_1}{(1-d_1)^2} V_{pv} + \frac{1}{(1-d_1)} V_{bat}$ | 93.6 |
| [37] | 0 D, 2S | 3C, 2 L | $V_{o,high} = \frac{d_1 + d_2}{d_2} V_{pv} + V_{bat}$ | 94.11 |
| [38] | 4 D, 3 S | 2C, 2 L | $V_o = \frac{V_{pv}}{(1-d_1)^2} + \frac{[(d_1 - d_2) + (1-d_1)(d_3 - d_2)] V_{bat}}{(1-d_1)^2}$ | 96 |

In order to show the features of the presented MPC, Table 2 was listed here to present the comparison between the isolated and non-isolated DC-DC converters. Moreover, the non-isolated converters presented high efficiency and low cost because there is no a high frequency transformer (HFT) in their structures. In same time, these converters may be failed due to the high voltage gain where there is no isolation between the input and output sides. This represents the main issue in the non-isolated converters. The partially isolated or the isolated DC-DC converters has more safety due to the HFT winding. The main disadvantage of these converters is the high cost of the HFT and the size of the circuit which may decrease the converter efficiency.

Table 2. The comparison between the non-isolated and isolated converters

| Reference | Type of converter | No. of winding | $\eta$ (%) | Capacity (W) | Features |
|---|---|---|---|---|---|
| [27] | Non-isolated | N. A | 96.8 | 152 $W$ | -small size and low cost<br>- low components count<br>- Its ability for power to flow in both directions |
| [28] | Non-isolated | N. A | 97 | 1000 $W$ | -the ability of controlling the power of battery storage by allowing active power sharing<br>- Only one additional active switch is needed for each input to the converter. |
| [35] | Non-isolated | N. A | N. A | 210 $W$ | - high output voltage gain<br>- The possibility of using input sources with different voltage-current characteristics. |
| [36] | Non-isolated | N. A | 93.6 | 200 $W$ | - It has two unidirectional ports<br>- The higher voltage is achieved by attaching an extra inductor at the drain of the switch |
| [37] | Non-isolated | N. A | 94.11 | 150 $W$ | -having the capability of operating in both step-up (boost) and step-down (buck) modes.<br>-low components count |
| [38] | Non-isolated | N. A | 96 | 300 $W$ | -simple and low cost<br>-high output voltage gain<br>-continuous input current |
| [46] | Partially-isolated | 3 | 96 | 9000 $W$ | -combining four ports with a reduced switch converter architecture<br>- high output voltage gain |
| [47] | isolated | 2 | 95 | 2000 $W$ | - It is consisting of a combination of a neutral point clamp and a multi-port DAB topology.<br>-high power density, as well as a decrease in the total number of switches |
| [49] | isolated | 3 | $N.A$ | 150 $W$ | -high voltage gain<br>- low components count |
| [51] | isolated | 2 | $N.A$ | 500 $W$ | - The converter can be employed to control the electricity that is generated by a variety of RES.<br>-simple configuration and high output voltage gain |
| [60] | isolated | 3 | 91.5 | 10000 $W$ | -it has three ports designed with a symmetrical duty cycle control.<br>- minimum coupling factor between the duty ratio control and phase shift control |
| [61] | isolated | 3 | $N.A$ | 120 $W$ | - Fewer devices are used, and a single-stage power conversion was accomplished between any two of the three ports.<br>-power flow path between the PV module and the battery |
| [62] | isolated | 3 | $N.A$ | 60 $W$ | -The power flows from the two input sources and the load voltage are controlled individually.<br>- constant output voltage with high voltage gain |
| [63] | Partially-isolated | 3 | 94.8 | 500 $W$ | -low cost and high-power density<br>-zero current switching (ZCS) for diodes and switches are achieved |
| [64] | isolated | 3 | 95 | $250\ W$ | -One unidirectional input source with two bidirectional outputs<br>-designed with minimum power switches |

**4. Selected DC/DC Multi-Port VR-ESS Topology**

The suggested MPC for standalone PV system application can be shown in Fig. 25. The proposed converter consists of two input ports. The first port is supplied by the PV array which is a voltage regulator (VR), and the other can supply battery energy storage (BESS). As result, this converter is called VR-BESS which is designed with minimum number of switches to reduce the circuit's size and improve the efficacy under different work conditions such as variable load or weather conditions. Results of a PV system equipped with a VR-BESS in a standalone configuration are shown in this figure are two switches, three diodes, two inductors, two capacitors, and a battery pack make up this system. The VR-BESS in a standalone PV system may be divided into three distinct converters, each of which performs a unique yet essential role. The mode of operation of this converter can be description in Figs. 26-28. The three modes are represented in this converter based on the continuous condition mode (CCM). In first mode, to control the voltage at the load, a regulator made up of the load, capacitor Co, diode D3, inductor Ls, and PV voltage Vpp is used. When the switches S1 and S2 are set up in this manner, they toggle on and off simultaneously. Fig. 26 depicts the input boost converter of this mode.

Fig. 27 depicts second mode operation which is charging mode, or the buck converter made up of the PV voltage, the inductor $L_s$, the switch S1, the inductor $L_{bat}$, the diode $D_2$, the capacitor $C_{bat}$, and the battery system. This converter feeds the additional power harvested from the PV system into the BESS.

In Fig. 28, the battery bank, capacitor of battery, inductor of battery, switch $S_2$, diode $D_1$, output capacitor, and the load make up a boost converter that increases the battery voltage to the output DC bus. Whenever there is not enough sunlight to power a load, this converter steps in to help the load when the solar irradiation is low.

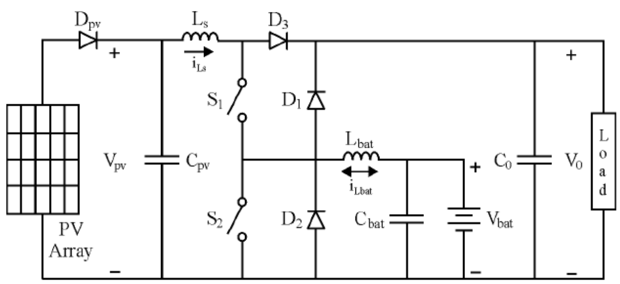


Fig. 25. The suggested VR-BESS converter [32]

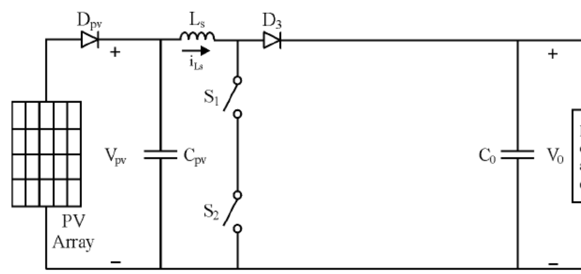


Fig. 26. First mode as input boost converter [32]

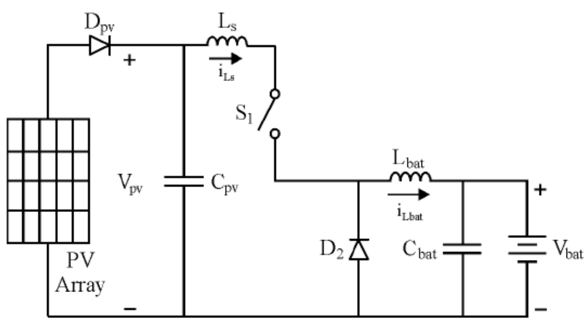


Fig. 27. Charging the BESS in second mode circuit [32]

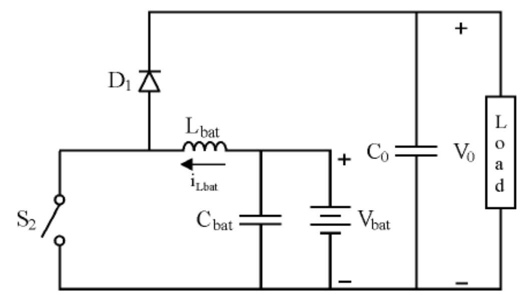


Fig. 28. Delivering the required load by BESS [32]

The main features of the suggested converter are listed as below:

- The suggested converter is a straightforward implementation of a DC-DC converter coupled with BESS.
- Depending on the requirements of the load, the DC-DC converter will keep the output voltage stable.
- The battery storage system can absorb or supply the extra power produced by the PV system to the load.
- The number of semiconductors, inductors, capacitors are low.

## 5. Future Scope of MPC Development

The development of RES systems, such as PV and WT energy installations, has recently attracted widespread interest. Many PV arrays are linked in a cascading or parallel fashion to meet the energy demand brought on by population growth. In addition, several port converters are linked together such that the electricity from these PV panels into BESS. These MPCs demand cutting-edge innovations from the realm of applied research. So that electricity or power flow may be delivered effectively to the load terminals. The following are some directions that researchers should go in the future if they want to create effective MPCs:

- In general, the efficiency of a system for transmitting power is diminished by the presence of phases in which that power must be converted. Therefore, the total efficiency of the system may be improved by decreasing the number of power conversion stages in these converters.
- Microgrids and residential grids are seeing a rise in popularity of new loads like EVs and novel storage devices like supercapacitors, Li-ion battery, and FC. Therefore, modern MG with MPC designs need to account for the unique load characteristics of these emerging loads and storage components.
- Incorporating renewable generation systems into the grid is hampered by power quality issues including sag, swell, and line-line failures. To address these power quality concerns, the development of MPCs is warranted.
- Switches made from novel materials like GaN, metal oxide semiconductors, are designed to increase the efficiency of MPCs. Because of this, better semiconductor devices must be used in the design of MPCs to enhance the system's overall performance.
- By redesigning the optimal controllers, this makes the resulting converters simpler to use and lower the switching complexity of their operation epically in PV system based MPPT controllers.

## 6. Conclusion

In conclusion, the goal of this review paper is to investigate the modern technologies of DC-DC converters type MPC for renewable energy applications. Moreover, the non-isolated and isolated MPC are discussed in this work in terms of configuration, number of components, and their benefices. Based on the number of diodes, switches, and the voltage gain at the output, the MPC are compared, and they have all shown to be significant problems in the converter research. In addition, the research has shown how different switching methodologies and designs give high interfaces, better efficiency, minimal components, reliability, cost optimization, and minimal power loss. After looking at a few different circuits, it became clear that a built converter was required to fix the problems identified. Therefore, the purpose of this work is to create a circuit for future demands in renewable energy sources. In this article, a VR-BESS for the off-grid PV system with energy storage system is presented. The main advantage of this converter is the low cost, small size, less components count, and higher efficiency.

**Acknowledgement**

I would like to express my deepest appreciation to Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq, for the encouragement and support for disseminating the engineering research paper.

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