A Survey on Two Port DC-DC Converter Topologies for Energy Preservation

D.C. Kumaresan and Dr.P. Selvan

Abstract--- The renewable sources to convert the power by using power electronic converters, that is to match the load demand and grid requirement to improve the dynamic and steady-state characteristics of the green generation systems, to provide the Maximum Power Point Tracking (MPPT) control, to integrate the energy storage system to solve the challenge of the intermittent nature of the renewable energy and the unpredictability of the load demand. In order to improve the efficiency and the power density of the overall circuit, the use of a two port High Gain buck boost based DC-DC converter, which includes one for the renewable sources and another for the energy storage system is used. In recent years, many two port DC-DC converters have been proposed and reported in the literature. Each of these converters has its own topology and operating principle, which results in different complexities, different numbers of components, different reliability and efficiency. This work also explains the potential research extension of the basic topologies of DC-DC converters and how the voltage gain of the two-port DC-DC converter can be improved.

Keywords--- Power Electronic Converters, Maximum Power Point Tracking (MPPT) Control, Two Port DC-DC Converters.

I. INTRODUCTION

The extensive use of dc power supplies inside most of electrical and electronic appliances which leads to an increasing demand for power supplies that draw current with low harmonic content & also have power factor close to unity. Dc power supplies are extensively used inside most of the electrical and electronic appliances such as in computers, audio sets, televisions, and others. The presence of non linear loads results in low power factor operation of the power system. The basic block in many power electronic converters are uncontrolled diode bridge rectifiers with capacitive filter. Due to the non-linear nature of bridge rectifiers, non-sinusoidal current is drawn from the utility and harmonics are injected into the utility lines. The bridge rectifiers contribute to high THD, low PF, and low efficiency to the power system. These harmonic currents cause several problems such as voltage distortion, heat, noises etc. which results in reduced efficiency of the power system. Due to this fact, there is a need for power supplies that draw current with low harmonic content and also have power factor close to unity.

Isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters in that their output voltage is often (but not always) the same as the input voltage. A current-output DC-DC converter accepts a DC power input, and produces as its output constant current, while the output voltage depends on the impedance of the load. In many industrial applications, it is required to convert a fixed-voltage dc source into a variable-voltage dc source. A dc-dc converter converts directly from dc to dc and is simply known as a dc converter. A dc converter can be considered as dc equivalent to an ac transformer with continuously variable turns ratio. Like transformer, it can be used to step down or step up a dc voltage source [1].

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DC converters are widely used for traction motor in electric automobiles, trolley cars, marine hoists, and forklift trucks. They provide a smooth acceleration control, high efficiency, and fast dynamic response. Dc converter can be used in regenerative braking of dc motor to return energy back into the supply, and this feature results in energy saving for transportation system with frequent stop; and also are used, in dc voltage regulation. There are many types of DC-DC convertor which are buck (step down) converter, boost (step-up) converter, buck-boost (step up-step-down) converter. DC conversion is of great importance in many applications, starting from low power applications to high power applications.

The goal of any system is to emphasize and achieve the efficiency to meet the system needs and requirements. Several topologies have been developed in this area, but all these topologies can be considered as a part or a combination of the basic topologies which are buck, boost and flyback [2]. For low power levels, linear regulators can provide a very high-quality output voltage. For higher power levels, switching regulators are used. Switching regulators use power electronic semiconductor switches in on and off states. Because there is a small power loss in those states (low voltage across a switch in the on state, zero current through a switch in the off state), switching regulators can achieve high efficiency energy conversion.

II. STUDY ON THE TWO PORT DC-DC CONVERTERS AND IT'S BASIC TOPOLOGIES

Basic Functions of DC-DC Converters

The DC-DC converter has some functions. These are: i) Convert a DC input voltage Vs into a DC output voltage V_o. ii) Regulate the DC output voltage against load and line variations. iii) Reduce the AC voltage ripple on the DC output voltage below the required level. iv) Provide isolation between the input source and the load (if required) v) Protect the supplied system and the input source from electromagnetic interference [2]. For a traditional two-port DC-DC power electronic converter, the main function is to implement the energy conversion between the two ports. In fact, all of the multi-port DC-DC converters can be viewed as the combination of several two-port DC-DC converters and the function of these new converters is to implement a simplified topology for the energy conversion between any two of all the ports available in the converter.

Two-port DC-DC Converter

PV and battery voltages are combined together to act as a two-port of the converter as shown in Figure 1. There are six operating modes per switching cycle in battery charging mode. For battery charging mode, the waveforms in steady state are as depicted in Figure.2 with voltage doubler (voltage gain). The voltage doubler increases the output capacity of the Two-port DC-DC Converters.

A voltage doubler at the converter output yields a DC voltage equivalent to twice the peak value of the input voltage. The battery operates in charging or discharging mode, based on its voltage level [3].

Different Types basic Topologies of the DC to DC Converter

The various topologies of the DC to DC converter can generate voltages higher, lower, higher and lower or negative of the input voltage; their names are:

- Buck
- Boost
- Buck boost
- Cuk
- Sepic

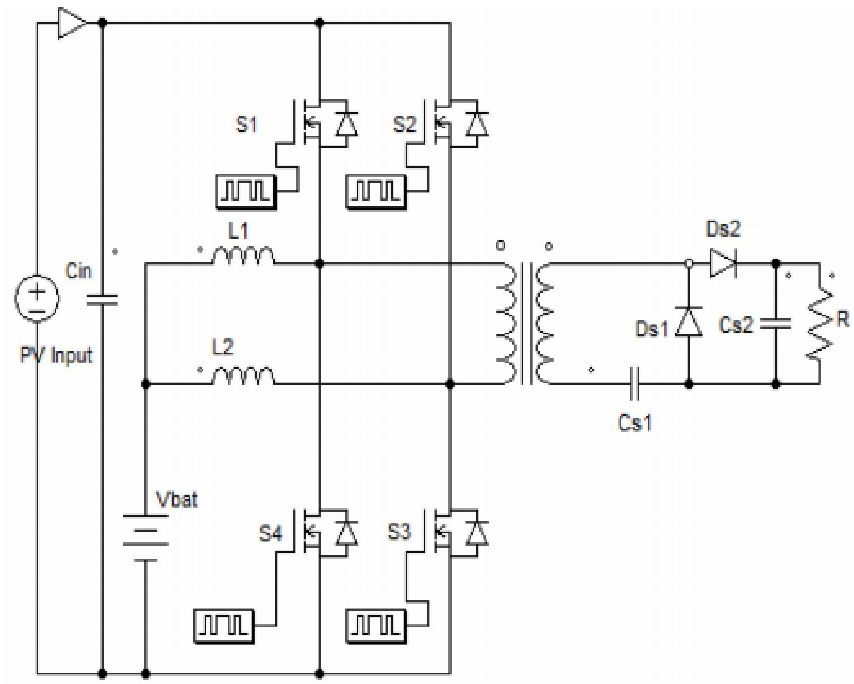

Figure 1: Two-port Converter with Output Voltage Doubler

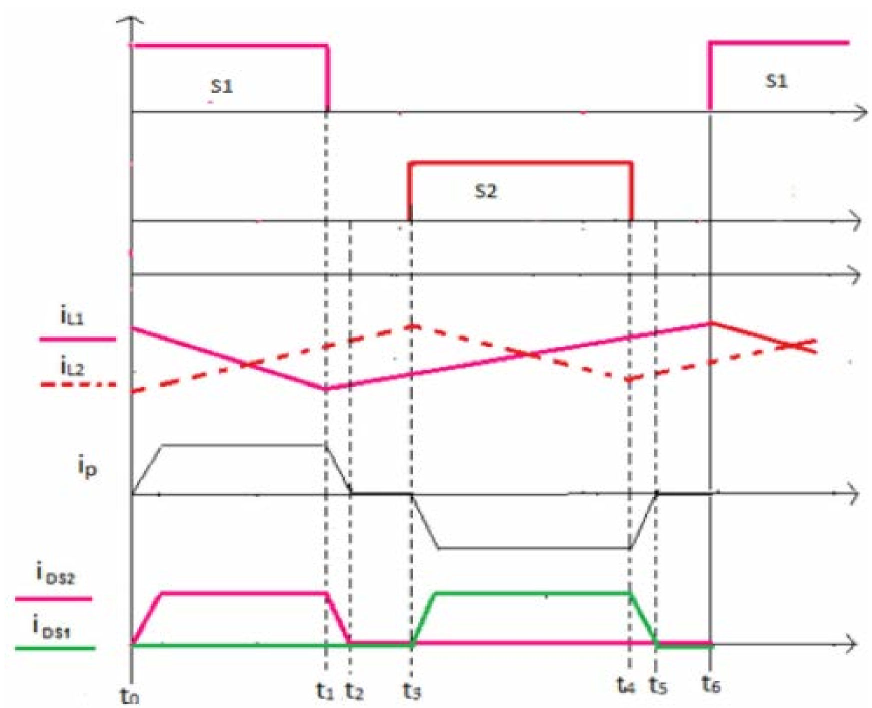

Figure 2: Timing Illustration of Two -port Converter with Output Voltage Doubler

Buck Converter

A buck converter or step-down switch mode power supply can also be called as a switch mode regulator. Buck converter produces a lower average output voltage than the DC input voltage, Vi. When the switch S is on, the diode D in Figure 3 becomes reverse biased and the input provides energy to the load as well as to the inductor. While, when the switch is off, the inductor current flows through the diode D, transferring some of its stored energy to the load R.

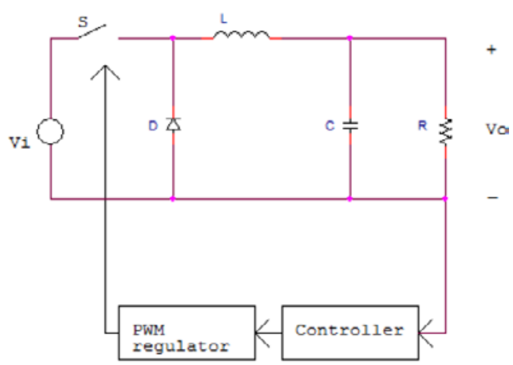

Figure 3: Buck Converter

Boost Converter

A boost converter or step-up converter is a power converter with an output DC voltage greater than its input DC voltage. The circuit of boost converter is shown in Figure 4. When the switch S is on, the diode D is an reversed bias, thus isolating the output stage. The input supplies energy to the inductor. When the switch is off, the output stage receives energy from the inductor as well as from the input. The boosts main application is in the regulated dc power supplies and the regenerative braking of dc motors.

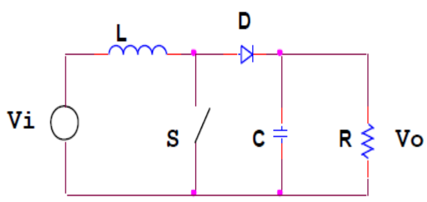

Figure 4: Boost Converter

Buck Boost Converter

The buck–boost converter is a converter shown in Figure 5, that has an output voltage that is either greater than or less than the input voltage. Buck-boost converter can be obtained by the cascade connection of the two basic converters which are the step down converter and step up converter. These two converters can be combined into the single buck- input that provides energy to the inductor and the diode is reverse biased. When the switch S is open, the energy stored in the inductor is transferred to the output. No energy is supplied by the input during this interval. The main application of buck-boost converter is in the regulated dc power supplies.

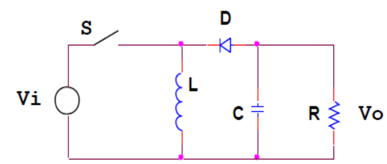

Figure 5: Buck-boost Converter

The basic buck is combined with boost DC converter topology to introduce the buck boost converter. Different applications are implemented based on buck boost converter implementation such as motor drives, stand alone and grid connected photo voltaic system [4]. The solar PV based applications using buck boost converter is still under research to increase the efficiency [5]. Based on buck boost converter topology, different non-isolated DC to DC converters are developed by worldwide researchers such as cuk, SEPIC and Luo converters to increase the voltage gain. A group of researchers analyzed the effect of discontinuity in buck boost non inverting converter that happened by the effective duty cycle [6]. A novel compensation technique is used for rectifying to smooth the transition during mode changes. Based on DC link inductors, a novel multiport converter is proposed by Hongfei et.al (2008) [7].

Cuk Converter

The Cuk converter is a step-down/step-up converter based on a switching boost-buck topology. Essentially, the converter is composed of two sections, an input stage and an output stage. The input voltage vg is fed into the circuit via inductor L1. When transistor Q1 is on, current i1 builds the magnetic field of the inductor in the input stage. The diode CR1 is reverse biased, and energy dissipates from the storage elements in the output stage. When Q1 turns off, inductor L1 tries to maintain the current flowing through it by reversing polarity and sourcing current as its magnetic field collapses. It thus provides energy to the output stage of the circuit via capacitor C1, R1 and R2 are parasitic or stray resistances of inductor.

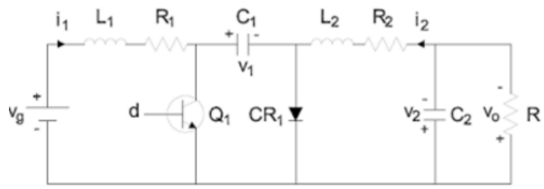

Figure 6: Cuk Converter

Cuk converter is a negative output capacitive DC to DC fly back energy converter. It is developed based on the simple buck boost converter. The only difference is that cuk converter is using capacitor for power transfer and energy storage rather than inductor [8]. The cuk converter output voltage polarity is reversed of the input voltage. This converter produces free ripple output if it is connected in suitable way and it can be sued in many applications [9]. Depending on cuk converters there are different topologies introduced [10]. The modified cuk converter efficiency is significantly improved. To control the current and voltage, this converter is recommended for optimal bidirectional operation [11]. Several control techniques like sliding mode control and conventional proportional integral (PI) are used within closed loop systems and fuzzy logic controller to regulate the output voltage [12].

SEPIC Converter

Single Ended Primary inductor converter (SEPIC) Figure.7 [13, 14], is a type of dc to dc buck boost converter. The output can be greater than or lesser than the input voltage. Duty cycle of the control switch is controlled to control the output of the SEPIC converter. SEPIC consists of input filter inductance L1 and controllable switch S. It also consists of diode D and filter capacitor Cf in the output side. The main feature of the SEPIC is the presence of series capacitor C and inductor L2. It is essentially a boost converter followed by buck boost converter. The input DC voltage is chopped to get desired output voltage. The output is similar to buck boost converter but has the output polarity same as the input voltage.

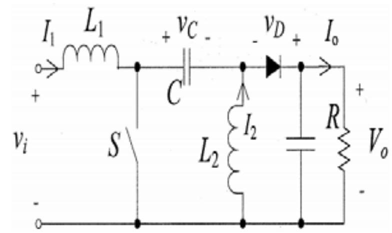

Figure 7: SEPIC Converter

To obtain the DC power from available AC line, AC to DC converter is required. To correct the power factor in AC line, the SEPIC converter is proposed. SEPIC converter is widely used in solar power generation field to regulate flickering DC voltage. There are different control methodologies that are recommended to obtain the maximum power like PI control, sliding mode control, dP/dV feedback control and fuzzy logic control that can be used to increase the robustness [15]. Solar fed DC motor sensor less is performed through the SEPIC converter [16]. This proposed system can be the solar based transportation solution. The major criteria's of SEPIC converter design is the switching losses and conduction. This issue can be reduced by using soft switching technique and it will minimize the current ripple output [17]

III. LITERATURE WORKS BASED ON DC-DC CONVERTERS

Peng et al .[18] presents a new zero-voltage-switching (ZVS) bidirectional dc-dc converter. Compared to the traditional full and half bridge bidirectional dc-dc converters for the similar applications, the new topology has the advantages of simple circuit topology with no total device rating (TDR) penalty, soft-switching implementation without additional devices, high efficiency and simple control. These advantages make the new converter promising for medium and high power applications especially for auxiliary power supply in fuel cell vehicles and power generation where the high power density, low cost, lightweight and high reliability power converters are required. The operating principle, theoretical analysis, and design guidelines are provided in this paper. The simulation and the experimental verifications are also presented.

Jaber, [19] designed a fuzzy controller of DC-DC Buck-boost converter which is presented in this work. In order to control the output voltage of the buck-boost converter, the controller is designed to change the duty cycle of the converter. The mathematical model of buck-boost converter and fuzzy logic controller are derived into design simulation model. The simulation is developed on Matlab simulation program. To verify the effectiveness of the simulation model, an experimental set up is developed. The buck-boost circuit with mosfet as a switching component is developed. The fuzzy logic controller to generate duty cycle of PWM signal is programmed. The simulation and experimental results show that the output voltage of the buck-boost converter can be controlled according to the value of duty cycle.

Dave & Bhavesh [20] presented a single-phase single stage transformerless photovoltaic (PV) inverter for residential application. The inverter is derived from a buck-boost converter along with a line frequency unfolding circuit which will be used to supply the generated photovoltaic energy to load (Grid/Stand Alone). Interfacing a solar inverter module with the load involves three major tasks. One is efficiency, the second is to inject a sinusoidal quantity into load and the third is the power quality. Since the inverter is connected to the grid, the norms given by the utility companies must be obeyed. Due to its novel operating modes, high quality (without filter) and efficiency can be achieved, because there is only one switch in buck-boost converter operating at high frequency and rest of the switches of unfolding circuit is operated at fundamental frequency only. This work contains theoretical analysis and simulation result of this buck-boost converter based inverter for off grid. This shows the comparison of the norms with the simulation result of the product in terms of power quality and efficiency.

Inoue, & Akagi [21] described a bi-directional isolated dc/dc converter considered as a core circuit of 3.3-kV/6.6-kV high-power-density power conversion systems in the next generation. The dc/dc converter is intended to use power switching devices based on SiC and/or GaN, which will be available on the market in the near future. A 350-V, 10-kW and 20-kHz dc/dc converter is designed, constructed and tested. It consists of two single-phase full-bridge converters with the latest trench-gate Si-IGBTs and a 20-kHz transformer with a nano-crystalline soft-magnetic material core and litz wires. The transformer plays an essential role in achieving galvanic isolation between the two full-bridge converters. The overall efficiency from the dc-input to dc-output terminals is accurately measured to be as high as 97%, excluding gate drive circuit and control circuit losses from the whole loss. Moreover, loss analysis is carried out to estimate effectiveness in using SiC-based power switching devices. The loss analysis clarifies that the use of SiC-based power devices may bring a significant reduction in conducting and switching losses to the dc/dc converter. As a result, the overall efficiency may reach 99% or higher.

Li et al.[22] introduced a new bi-directional, isolated DC-to-DC converter. A typical application for this converter can be found in the auxiliary power supply of hybrid electric vehicles. A dual half-bridge topology has been developed to implement the required power rating using the minimum number of devices. Unified zero-voltage-switching was achieved in either direction of power flow with neither a voltage-clamping circuit nor extra switching devices and resonant components. All these new features allow high power density, efficient power conversion and compact packaging. Complete descriptions of operating principle and design guidelines are provided in this work. An extended state-space averaged model is developed to predict large and small signal characteristics of the converter in both directions of power flow. A 1.6 kW prototype has been built and successfully tested under full power. The experimental results of the converter's steady-state operation confirm the soft-switching operation, simulation analysis, and the developed averaged model. The proposed converter is a good alternative to full-bridge isolated bi-directional DC-DC converter in high power applications.

Ma et al. [23] proposed a new soft-switching bidirectional DC/DC converter. The proposed converter achieves zero-voltage switching (ZVS) for the entire main switches and zero-current switching for the rectifier diodes in the large-load range. These features reduce switching loss, voltage and current stresses, and diode reverse-recovery effect. The simple electrical isolated topology with the soft-switching characteristic provides an attractive solution for a battery charge/discharge system in an electric vehicle, distributed power system, or uninterruptible power system. This work describes the operation principle and the ZVS condition in detail. The mathematical model based on the state-space averaging method is also deduced to depict the performance characteristic. Then, design guidelines are presented to ensure the ZVS condition for all the switches. Finally, simulation and experimental results obtained from a 1-kW prototype verify the discussed theoretical analysis.

IV. Inference from Work

From the study of the two port DC-DC converter and various topologies of the DC to DC converter, this study revealed that an important feature required in a PV solar application is lower current ripple and higher conversion efficiency as high ripple decreases the energy obtained from the PV array. The ripple can be reduced by adding a filter between the power source and the converter. It results in increased losses, volume and cost of the system. An efficient method to reduce input ripple is to use interleaved converter structure. Buck- Boost converter is preferred for PV system to fetch peak output from solar panel consistently, irrespective of the load. Hence it is proposed a two port hybrid high gain buck boost converter (TPHGC) integrated PV-DVR system to achieve the high energy conservation in PV solar system. TPHGC is well suited for low power photovoltaic application.

V. Conclusion

In this paper basics of converters and its types are explained briefly. Detailed analysis of different topologies of Boost converter with advantages and disadvantages are done. The upcoming work may be extended for the design of two port boost converter topologies for efficient, reliable, self-sufficient and fault tolerant nanogrid and will be compared for their operation and performance for the wide varying input.

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