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A Multimode DC-DC Converter for Alternative Energy Conversion systems

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Abstract: The growing popularity of renewable energy systems such solar and wind power substantiates the need to have a clean source of power. However these systems are more reliable when used as hybrid systems along with an auxiliary source such as a battery. Such systems utilise a boost converter and a bidirectional converter for efficient power conversion. In this paper,we propose a modified version of single leg multimode converter which itself is a combination of a boost converter and a bidirectional converter. This innovative topology for renewable conversion system conserves all the functionalities of the conventional hybrid layout . In addition to it, it provides fault tolerance at the input and accomplishes each task of multimode operation with fewer number of elements. Thus it is economical and is suitable for wide range of applications. The performance of the proposed system is verified by categorizing its operations into different modes and each mode is simulated in MATLAB.The results show that the proposed conversion is feasible.

Keywords: Renewable Energy Systems, DC-DC converters, multimode conversion.

I. INTRODUCTION

Today, energy crisis is a major hassle faced all over the world for which there is no immediate remedy in the near future. This is because the gap between the power demand and supply is increasing every year. As convention fossil fuel resources diminish and the world's environmental concern about global warming increases, renewable energy sources (solar, wind, tidal, biomass and geothermal etc) are attracting more and more attention as alternative energy sources. These are advantageous because they are pollution free, eco friendly and available free of cost. However, their intermittent nature is a matter of concern. Therefore, hybrid systems combining the renewable energy source and an auxiliary source such a battery or ultra capacitor may be used for constant power.

Off grid renewable energy technologies can satisfy energy demand directly and avoid the need for long distribution infrastructures. A combination of different but complementary energy generation systems based on renewable energies is known as a hybrid power system.

Hybrid systems capture the best features of each energy resource and can provide "grid-quality" electricity, with a power range between 1 kilowatt (kW) to several hundred kilowatts. They can be developed as new integrated designs within small electricity distribution systems (mini-grids) and can also be retrofitted in diesel based power systems.

Furthermore, due to their high levels of efficiency, reliability and long term performance, these systems can also be used as an effective backup solution to the public grid in case of blackouts or weak grids, and for professional energy solutions, such as telecommunication stations or emergency rooms at hospitals. The block diagram of a hybrid system is shown in Fig.1.

Since various types of renewable energies are inherently intermittent in nature, they cannot supply the load demand continuously. To provide a more regular flow of electricity, clean sources are integrated with auxiliary energy storage systems such as a battery or ultra capacitor. Batteries have higher capabilities and are less expensive per unit energy. Hence in this paper, battery has been used as an auxiliary source.

In conventional hybrid architecture, power is transferred to the load via a unidirectional and a bidirectional converter. As the number of power conversion stages increases losses add up resulting in lesser efficiency. The unidirectional converter is a boost converter with a switch, an inductor and a diode. It boosts the input voltage to the voltage level at dc bus. The bidirectional converter utilizes two switches and an inductor which charges or discharges the battery, from the bus voltage. In [1] this was combined to act as a single leg multimode converter while providing the same functionality.

In this paper, we propose an amendment to the existing architecture by introducing a switch and two diodes, which will provide fault tolerance at the input. Thus even in case of overvoltages at the input, the dc bus will be maintained at constant voltage for supply to various loads.

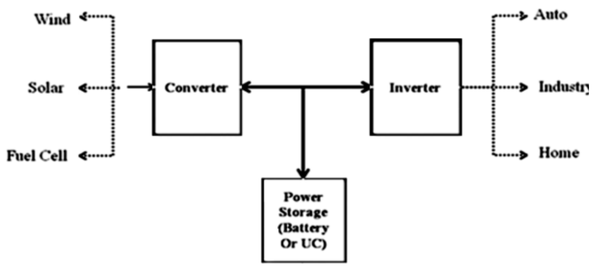

Fig. 1. Hybrid Energy System

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II. CONVENTIONAL TOPOLOGY OF THE MULTI-MODE SINGLE LEG CONVERTER

In paper [1], a novel energy conversion topology was proposed which comprised of two switches on the same leg, one diode, and two inductors to implement different converter modes in the operation of DC-DC converters. This was an improvement over the conventional boost and bi-directional structure by removing a switching element from the converter, while offering the same modes and functionalities. The battery is charged in one mode of operation. A DC voltage is being supplied to the output of the circuit at the same time while the battery is being charged or discharged.

However, the methods on [1] allowed the input range from the renewable source to be from zero to the output voltage level only, above which the converter may malfunction. In this paper, a switch is re-introduced at the input and the configuration was changed for the benefit of an additional mode. In this additional mode, known as the input buck mode, the converter is made capable of withstanding overvoltages at the input, the occurance of which will be stabilized by the converter to provide the required output voltage. Despite the re-configuration of the converter, the former three modes of operation worked without fail.

The placement of the switch at the input to the proposed converter does not introduce any new switching losses during the original three modes, as it acts only in case of an increased voltage at the input. In these four modes, MOSFET is fully on and acts like a short.

The paper is structured as follows. In the next section, the three modes in [1] are re-tested with new configuration and the operating conditions of various modes are elaborated. Also, it introduces the new mode. The second section will cover the principle of operation and the corresponding equations. In the final section, simulation results will be presented from MATLAB's Simulink followed by a conclusion, which presents future scope.

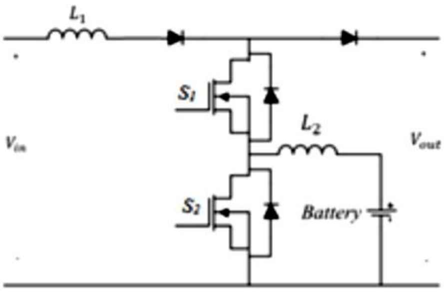

Fig. 2. Multi mode single leg Converter

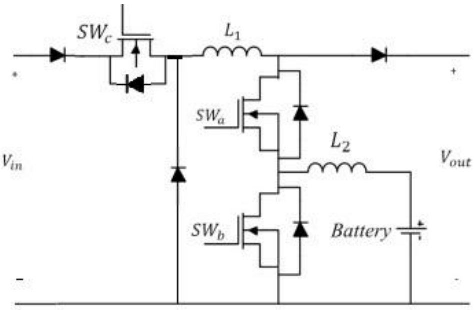

Fig. 3. Modified converter with input switch

III. SYSTEM CONFIGURATION

The schematic for proposed configuration is shown on fig.3 As in figure, an input switch is placed in series with the inductor along with two diodes which acts as fault protection at the input. The input diodes along with the switch and the inductor acts like a buck converter to eliminate excess voltage at input from affecting the output.The diodes essentially to block the reverse current flow.

The three original modes are the Main Boost Mode, the Boost-Buck Mode and the Battery Boost Mode. The new mode is the Input buck mode. In the Main Boost mode, the converter boosts the input voltage to the required DC level. In the Boost-Buck mode, energy is stored in the battery while the boosted voltage is available at the DC bus. And during cloud cover or when the generation is absent due some fault or inclement weather, energy can be supplied from the battery in Battery-Boost mode.

In cases where a high voltage appears at the input which is greater than the output level of the converter, it works in the input buck mode where the excess voltage is bucked to the normal output voltage.This is an improvement over the previous topology as it adds an additional functionality.

IV. PRINCIPLE OF OPERATION

A. Main Boost Mode

In this mode, switches *SWa* and *SWb* change state with the same duty ratio. Boost converter operation is performed to boost the main voltage source. During this mode, *SWc* is fully on. The output voltage of the main boost mode operation can be written by using the traditional boost converter equation as:

$$Vout = \frac{Vin}{1-D} \quad (1)$$

Where,

$$D = \frac{Ton}{Ts} \quad (2)$$

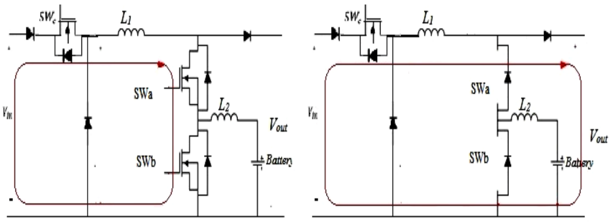

Fig. 4. Main boost mode

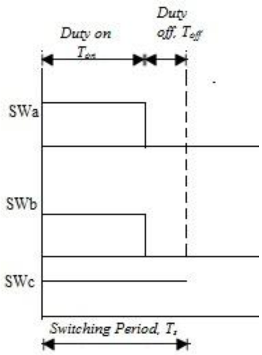

Fig 5. Switch Pattern for Main Boost Mode Operation

B. Boost Buck Mode

In this mode, the duty ratio of *SWa* is longer than *SWb* . Thus the input voltage is boosted during the time when both switches are "ON". When *SWa* remains "ON" while *SWb* is turned "OFF," input voltage supply energy to the load and charges the battery. *SWc* is fully "ON". Fig. 3 shows the operation in this mode. To determine the output of the boost converter for this mode, the equations are:

$$Vout = \frac{Vin}{1 - Dboost} \quad (3)$$

Where,

$$Dboost = \frac{Ton\_boost}{Ts\_boost} \quad (4)$$

For battery charging, the equations become:

$$Vbat = Dbuck2\ Vin \quad (5)$$

Where,

$$Dbuck2 = \frac{Ton\_buck}{Ts\_boost} \quad (6)$$

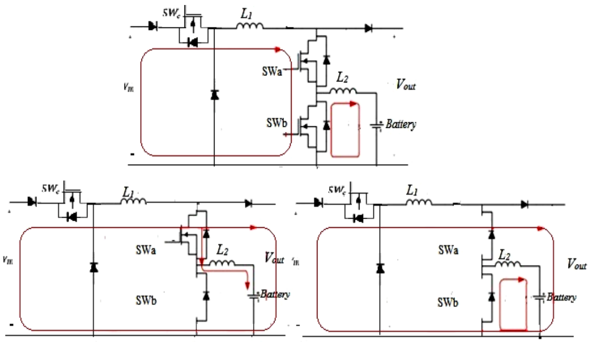

Fig. 6.Boost-Buck mode

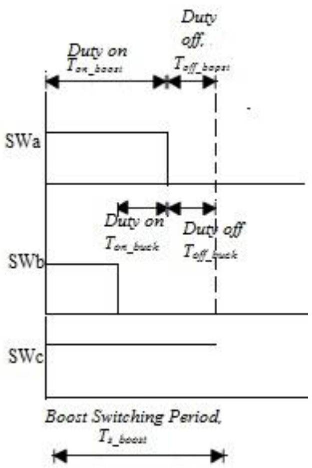

Fig 7. Switch Pattern for Boost-Buck Mode Operation

C. Battery Boost Mode

The battery boost mode is employed in the case of input fault such as cloud cover, or damaged modules ie when the generation is nearly zero.The state of *SWa* is no longer relevant while acts as a diode. *SWb* controls the battery discharge. *SWc* is fully on. In this mode, the battery supplies all power to the load.The mathematical equations are:

$$Vout = \frac{Vbat}{1 - D} \quad (7)$$

Where the duty ratio of *SWb* is,

$$D = \frac{Ton}{Ts} \quad (8)$$

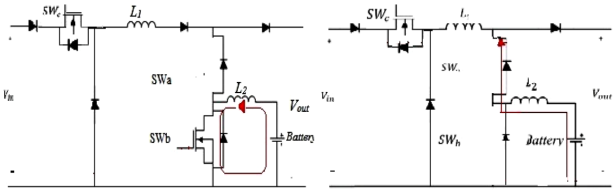

Fig. 8.Battery-Boost mode

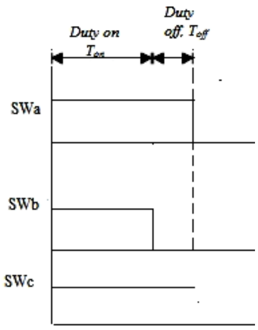

Fig 9. Switch Pattern for Battery-Boost Mode Operation

D. Input Buck Mode

The Input Buck Mode (IBM) benefits from the additional switch *SWc* provided. Whenever the input voltage is higher than that of output ie when it exceeds the permissible range, the normally "ON" switch *SWc* will be turned off by a switch pattern as shown in the figure. The gate pulses to switches *SWa* and *SWb* will be withdrawn at this moment. The input voltage is bucked to the dc bus level. The mathematical equations for this mode are:

$$V = L\,\frac{\Delta I}{\Delta T} \quad (9)$$

Where,

$$Vin - Vout = L\,\frac{(\Delta I)}{(D/Fsw)} \quad (10)$$

Therefore,

$$Dbuck1 = \frac{L\,\Delta I\,Fsw}{(Vin - Vout)} \quad (11)$$

Where

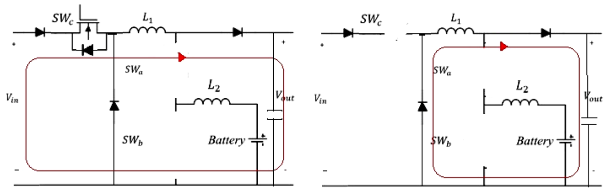

Fig.10.Input Buck Mode

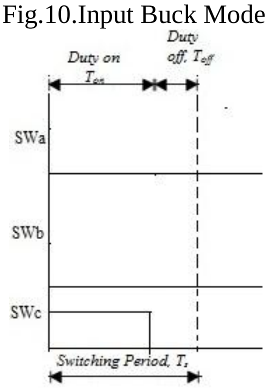

Fig. 11. Switch Pattern for Input-Buck Mode Operation

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V. SIMULATION RESULTS

The proposed multimode power converter was simulated in MATLAB/ Simulink environment. The Simulink model is shown in fig.11 and the simulation parameters used are given in table.1. The results for different modes of operation are also included.

Table I: Simulation Parameters

Nominal input voltage	90 V	Inductor L1	9.6 mH
Battery Voltage	50 V	Inductor L2	7.14mH
Switching Frequency	50kHz	Filter Capacitor	4 µF

1)Simulation results for the Main Boost Mode

Fig.12 shows the simulation results of the main boost mode. The output voltage is maintained at 150V which is the reference voltage. The state of charge of battery is 100 %. Here the battery is fully charged. Hence V_{bat} is maintained at full voltage. Inductor L_1 current is positive. Inductor L_2 current is zero. Fig.13 shows the PWM patterns, for switches *SWa*, *SWb* and *SWc.*

2)Simulation results for the Buck Boost Mode

Fig.14 shows the simulation results of the buck boost mode. The output voltage is maintained at 150V. The state of charge of battery is 50 %. Here the battery is not fully charged. Inductor L1 current is positive. Inductor L2 current is negative, which implies that the battery is being charged. Fig.15 shows the PWM patterns, for switches *SWa*, *SWb* and *SWc* used in the buck boost mode.

3)Simulation results for the Battery Boost Mode

Fig.16 shows the simulation results for the battery boost mode. The output voltage is maintained at 150V. The state of charge of battery is 100 %. Here the battery alone supplies the load. Inductor L_1 current is zero. The input is absent. Inductor L_2 current is positive, which implies it supplies to the load demand. Fig.17 shows the PWM patterns, for switches *SWa*, *SWb* and *SWc* for this mode.

4)Simulation results for the Input Buck Mode

Fig.18 shows the simulation results for the input buck mode. The output voltage is maintained at 150V. The switch *SWc* alone operates in this mode. *SWa* and *SWb* are off. Inductor L_1 current is positive. Inductor L_2 current is zero. Fig.19 shows the PWM patterns, for switches *SWa*, *SWb* and *SWc* for this mode.

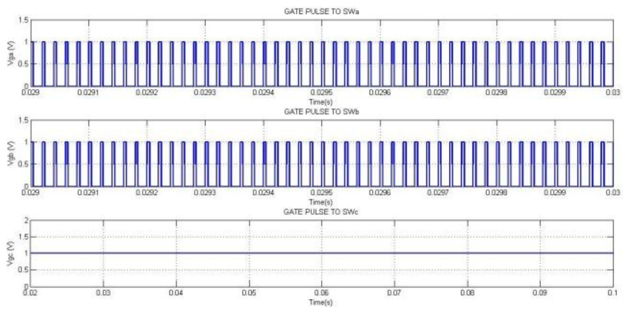

Fig. 12. Switch pattern of main boost mode

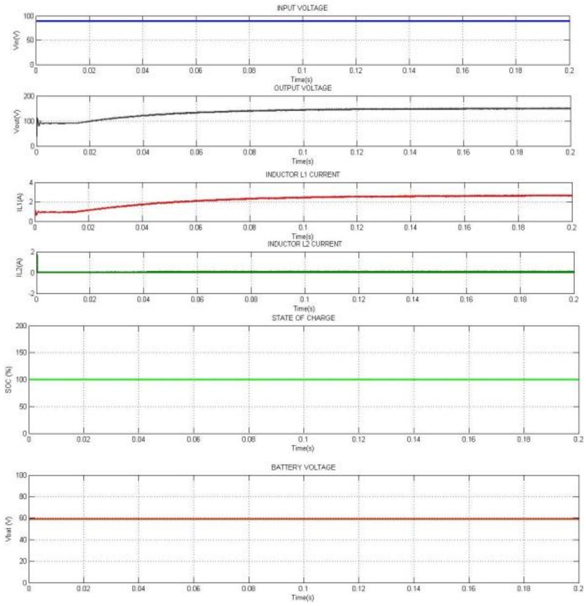

Fig. 13. Results of Main Boost mode

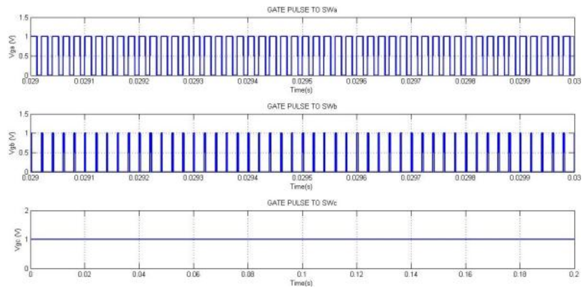

Fig. 14. . Switch pattern of buck boost mode

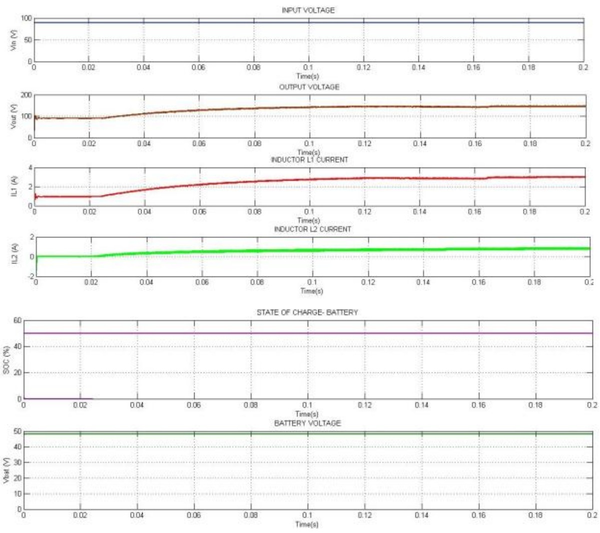

Fig. 15. Results of Buck Boost mode

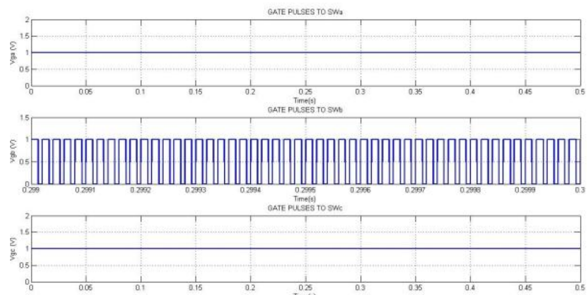

Fig. 16. . Switch pattern of battery boost mode

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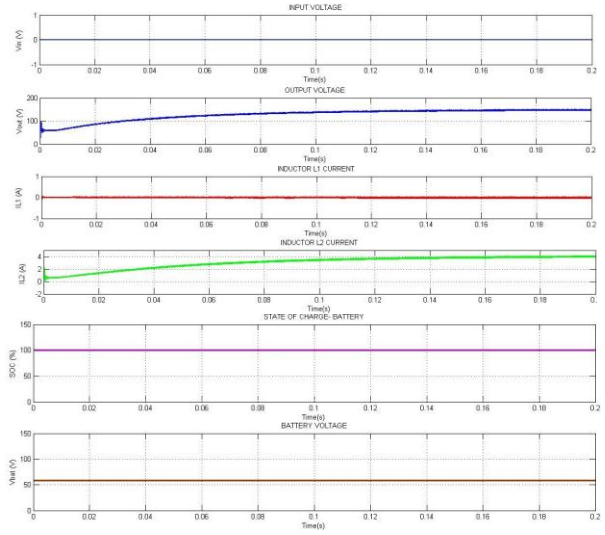

Fig. 17. Results of Battery Boost mode

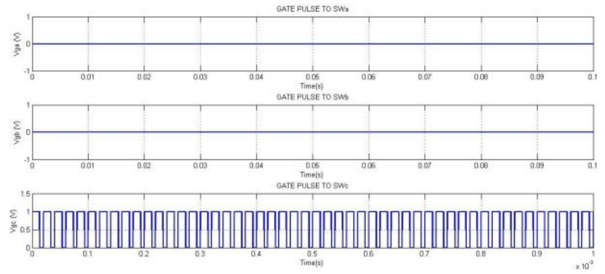

Fig. 18. Switch pattern of Input buck mode

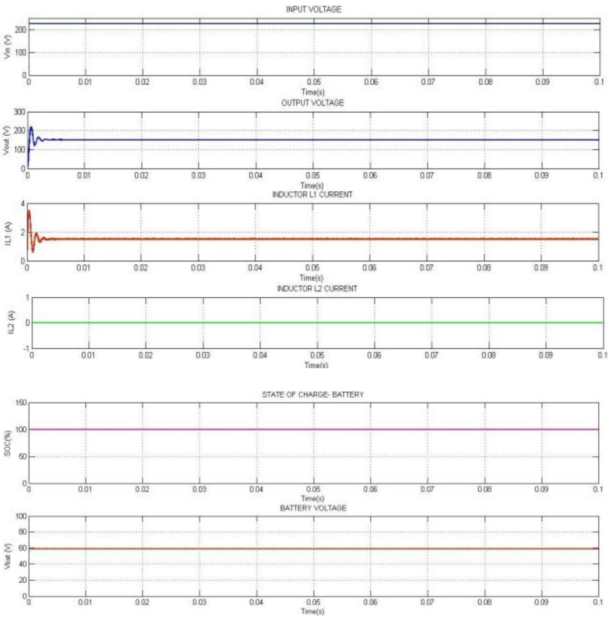

Fig. 19. Results of Input Buck mode

VI. CONCLUSION

In this paper, a novel topology of the multimode converter with an additional buck mode has been proposed . An additional switching element was introduced to an existing method at the expense of adding a valuable capability . The model is cost effective and can find suitable applications in microgrids. The proposed converter has four different operational modes enabling the replacement of two independent converters (boost converter and bidirectional dc/dc converter).

To verify the operation and performance characteristics of the proposed converter, computer simulations were performed. The proposed converter find use in a variety of energy conversion applications.

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