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A Novel Multi Port Dc/Dc Converter Topology Using Zero Voltage Switching For Renewable Energy Applications

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ABSTRACT: *This paper proposes a novel dc/dc converter topology that interfaces the non-conventional energy sources. It consists of four power ports: two sources (namely solar and wind), one bidirectional storage port, and one isolated load port. The proposed four-port dc/dc converter is derived by simply adding two switches and two diodes to the traditional half-bridge topology. Zero-voltage switching is realized for all four main switches. This paper proposes a new four-port-integrated dc/dc topology, which is suitable for various renewable energy harvesting applications. An application interfacing hybrid photovoltaic (PV) and wind sources, one bidirectional battery port, and an isolated output port is given as a design example. It can achieve maximum power-point tracking (MPPT) for both PV and wind power simultaneously or individually, while maintaining a regulated output voltage.*

Index Terms: *DC–DC converter, half-bridge, multiple-input single-output (MISO), multiport, zero-voltage switching (ZVS).*

I. Introduction

As interest in renewable energy systems with various sources becomes greater than before, there is a supreme need for integrated power converters that are capable of interfacing, and concurrently, controlling several power terminals with low cost and compact structure. This paper proposes a new four-port-integrated dc/dc topology, which is suitable for various renewable energy harvesting applications. Three of the four ports can be tightly regulated by adjusting their independent duty-cycle values, while the fourth port is left unregulated to maintain the power balance for the system. Compared to the effort spent on the traditional two-port converter, less work has been done on the multiport converterCircuit analysis and design considerations are presented. Four-port dc/dc converter has bidirectional capability.

II. Topology and Circuit Analysis

The four-port topology is derived based on the traditional two port half-bridge converter, which consists of two main switches S_1 and S_2 . As shown in Fig. 1, one more input power port can be obtained by adding a diodeD_3 and an active switch S_3 . Another bidirectional power path can be formed by adding a freewheeling branch across the transformer primary side, consisting of a diode D_4 and an active switch S_4 . As a result, the topology ends up with four active switches and two diodes, plus the transformer and the rectification circuit. The proposed converter topology is suitable for a number of power-harvesting applications, and this paper will target the hybrid PV wind application. It should be noted that since the wind turbine normally generates a three phase ac power, an ac/dc rectifier needs to be installed before this four-port dc/dc interface and after the wind turbine output. However, the ac/dc solution is beyond the scope of this paper.

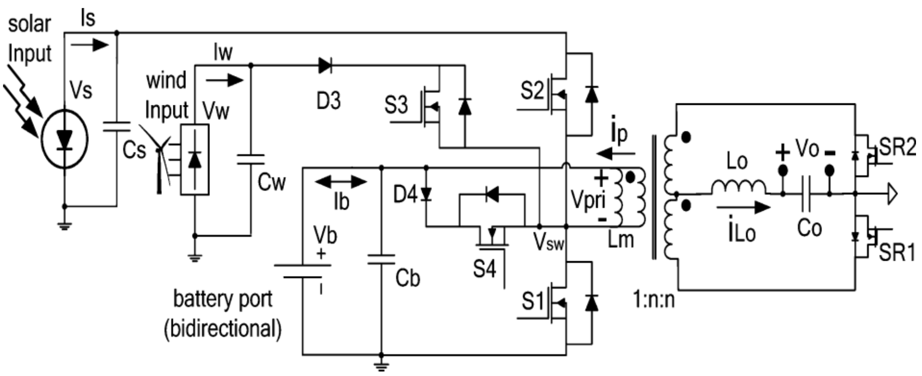


Fig. 1. Four-port half-bridge converter topology, which can achieve ZVS for all four main switches (*S*1 , *S*2 , *S*3, and *S*4)

2.1 Principle of Circuit Operation

The steady-state waveforms of the four-port converter are shown in Fig. 3, and the various operation stages in one switching cycle can be explained by using their respective circuits. To simplify the analysis of operation, components are considered ideal. The main operation stages are described as follows shown in fig. 2:.

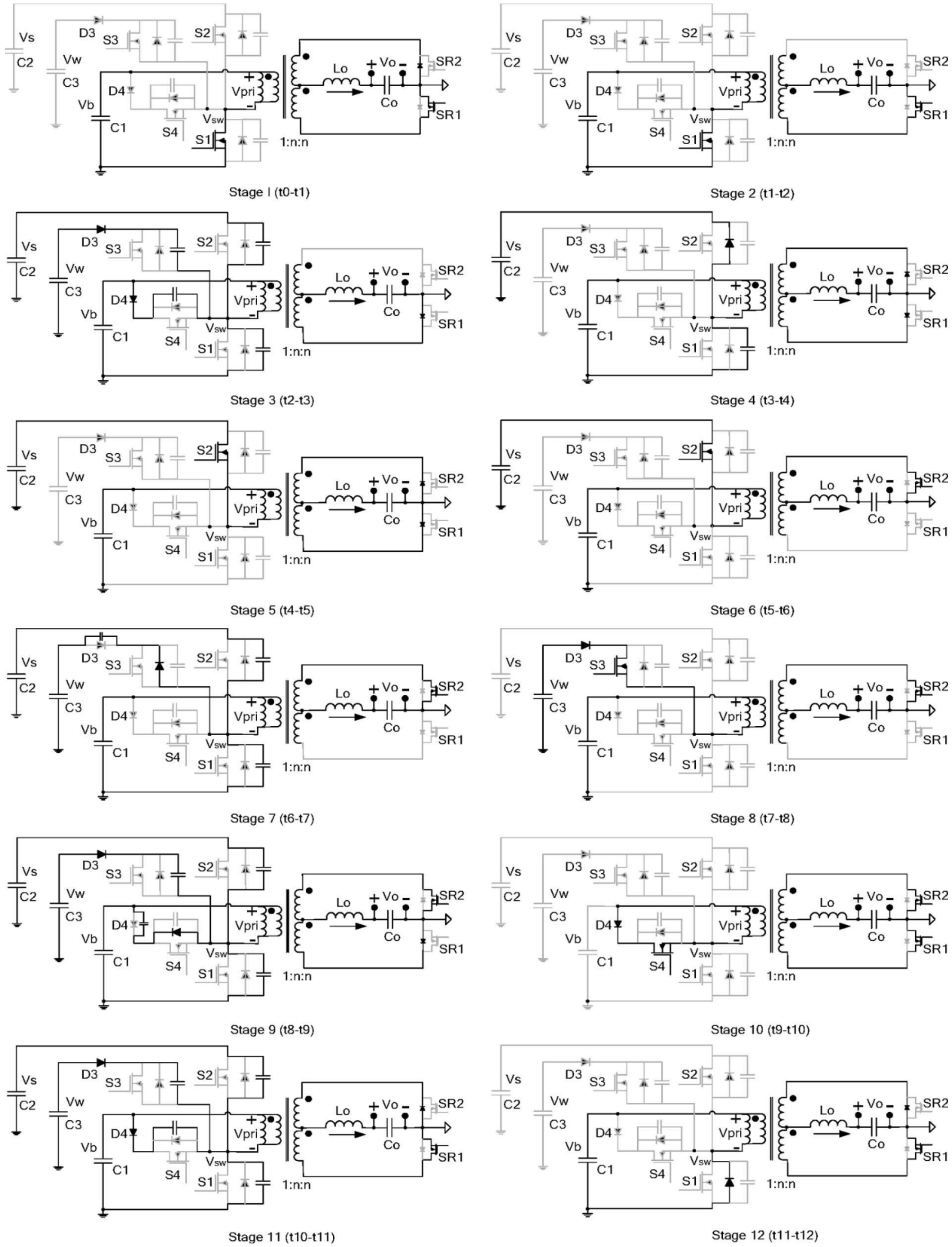


Fig.2: Operation stages of the four-port half-bridge converter.

2.2 Steady-State Analysis

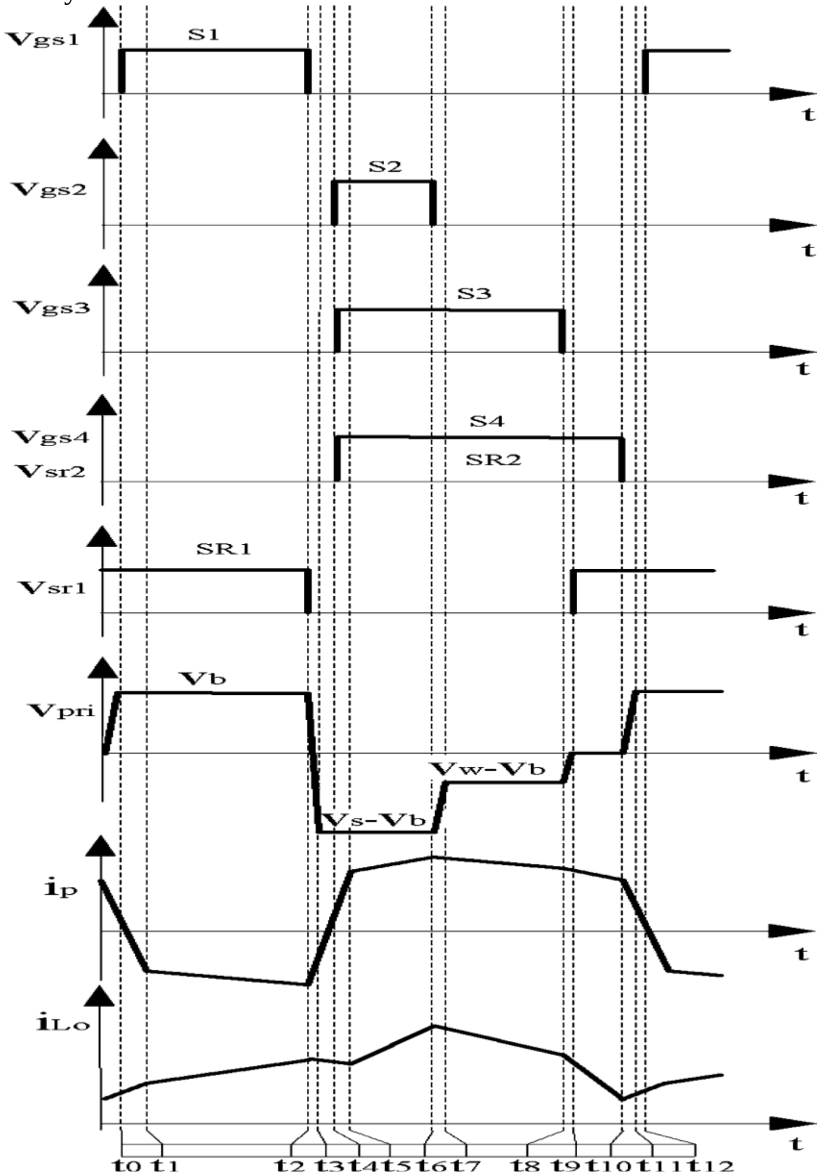


Fig. 3. Steady-state waveforms of the four-port half-bridge converter

The steady-state voltage governing relations between different port voltages can be determined by equating the voltage–second product across the converter's two main inductors to zero. First, using volt–second balance across the primary transformer magnetizing inductance LM in time continuous conduction mode(CCM), we have

$$V_b D_1 = (V_s - V_b)D_2 + (V_w - V_b)D_3 \quad . (1)$$

Assuming CCM operation, the voltage-second balance across the load filter inductor L_o then yields

$$V_b D_1 + (V_s - V_b)D_2 + (V_w - V_b)D_3 = V_{on} \quad . (2)$$

The following equation is based on the power balance principle, by assuming a lossless converter, steady-state port currents can be related as follows:

$$V_s I_s + V_w I_w = V_b I_b + V_o I_o \quad . (3)$$

The battery current I_b is positive during charging and negative during discharging.

2.3 ZVS Analysis

ZVS of the switches S1 and S2 can be realized through the energy stored in the transformer leakage inductor, while ZVS of S3 and S4 is always maintained, because the proposed driving scheme ensures that paralleling diodes of S3 and S4 will be forced on before the two switches turn ON. To sum up, ZVS of all main switches can be achieved to maintain higher efficiency when the converter is operated at higher switching frequency, because of the potential savings in switching losses.

2.4 Circuit Design Considerations

The major difference is that the transformer design of this four-port converter needs to allow for a dc current flow, and therefore, becomes similar to an inductor or a flyback transformer design. The dc biasing current rating is dictated by average transformer magnetizing current I_M, which determines the amount of the air gap to be inserted. Other than the transformer, the circuit design and optimization technique used for the traditional half-bridge topology can be used here for this four-port topology, which provides great convenience for the practicing engineers to implement the power stage design.

TABLE I Values of Circuit Parameters

Output inductor	L_0	45μH	Solar port filter capacitor	C_s	100 μF
Magnetizing inductor	L_m	45μH	Battery port filter capacitor	C_b	330 μF
Output filter capacitor	C_0	330 μF	Wind port filter capacitor	C_w	100 μF

III. Control Structure and Dynamic Modelling

The proposed converter has three freedoms to control the power flow of three power ports, while the fourth port is to maintain the power balance. That means the operating point of up to three ports can be tightly regulated, while the fourth port should be left "flexible" and would operate at any point that satisfies the power balance constraints. The choice of the flexible power port dictates the feedback control layout, which is based on different control objectives. For instance, if the battery is chosen to be left "flexible," the maximal power from the solar and wind sources can be tracked by their port voltages or currents independently, and the load voltage can be regulated by a voltage feedback as well.

3.1 Control Structure

Fig. 3 shows the control structure for the hybrid PV wind system. Three feedback controllers are as follows: a solar voltage regulator (SVR), a wind voltage regulator (WVR), and an output voltage regulator (OVR). In this system, the battery storage plays the significant role of balancing the system energy by injecting power at heavy loads and absorbing excess power when available PV and wind power exceeds the load demand.

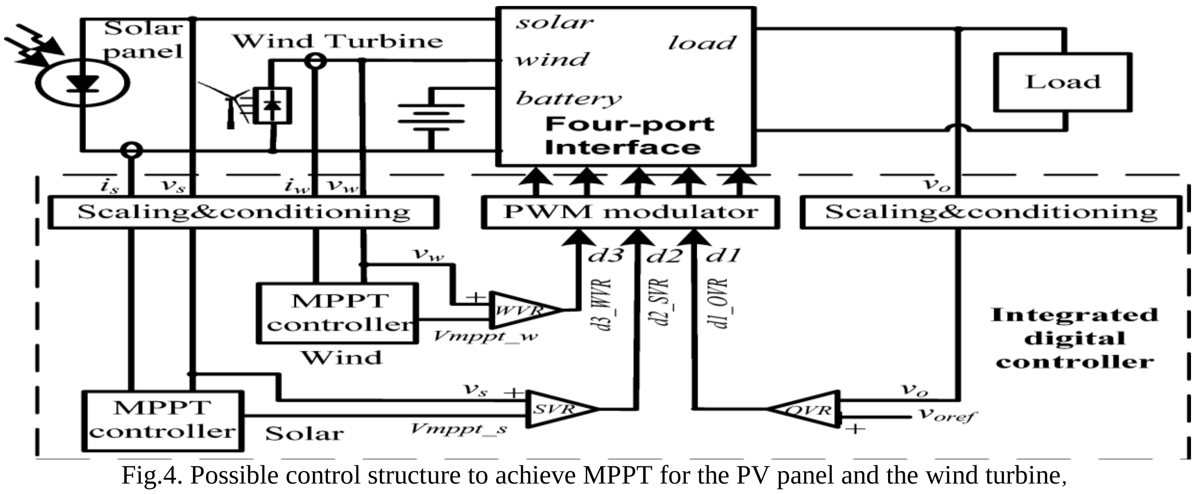


Fig.4. Possible control structure to achieve MPPT for the PV panel and the wind turbine,

3.2 Dynamic Modelling

In order to design the SVR, WVR, and OVR controllers, a small signal model of the four-port converter is desired. First, state-space equations for five energy storage elements during the four main circuit stages are developed. For the aforementioned mode of operation, these include the solar side capacitor *Cs* , the wind-side capacitor *Cw* , the transformer magnetizing inductor *LM* , the output inductor *Lo* , and the output capacitor *Co* . In the next step, state-space equations in the four main circuit stages (corresponding to the turn ON of four main switches) will be averaged, and then applied with the small signal perturbation. Finally, the first-order small-signal perturbation components will be collected to form the matrices A and B, which actually represent the converter power stage model. Alternatively, the dynamics of the plant can be calculated by computer software like MATLAB. The resultant state-space averaging model takes the following form:

$$d\hat{x}(t)/dt = A\hat{x}(t) + B\hat{u}(t),\ \hat{y}(t) = I\,\hat{x}(t) \qquad (8)$$

$\hat{i}_{Lo}(t)$, and $\hat{v}_o(t)$, $\hat{u}(t)$ is a matrix containing the control inputs $\hat{d}1(t)$, $\hat{d}2(t)$, and $\hat{d}3(t)$, $\hat{y}(t)$ is a matrix containing the system outputs, and I is the identity matrix.

IV. MATLAB Design and Experimental Results

A four-port dc/dc converter prototype is built to verify the circuit operation. The switching frequency is 100 kHz, and it is implemented by the digital control to achieve the close-loop regulation. The conclusion is that all four main switches can achieve ZVS, because they all turn ON after their *V*ds go to zero.

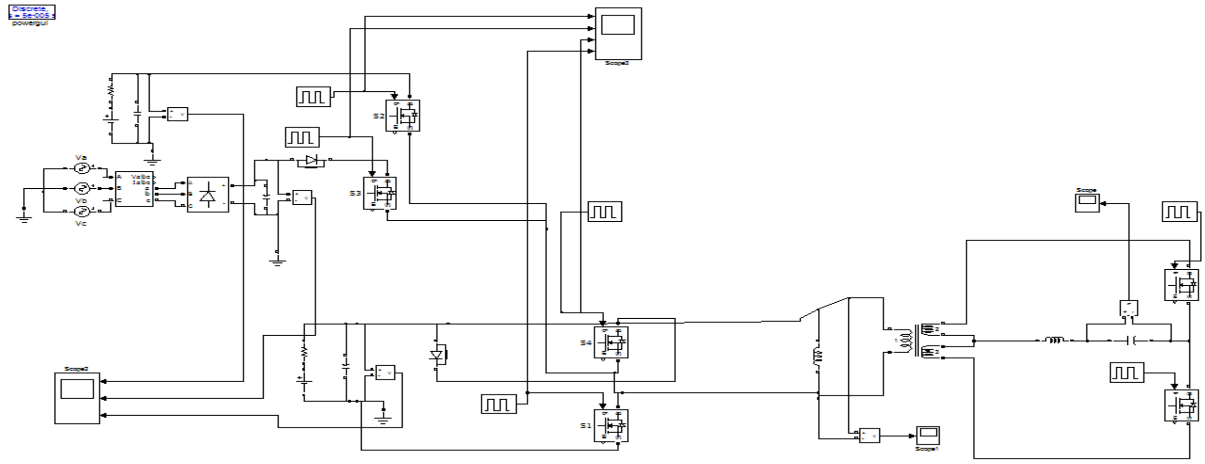


Fig. 4. MATLAB Design of the proposed four port dc/dc converter

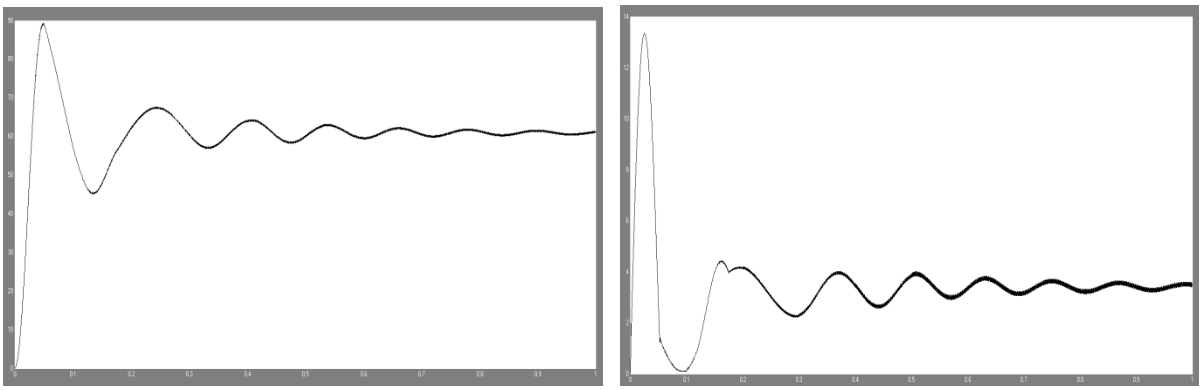


Fig. 5. Transient responses of the MPPT controller

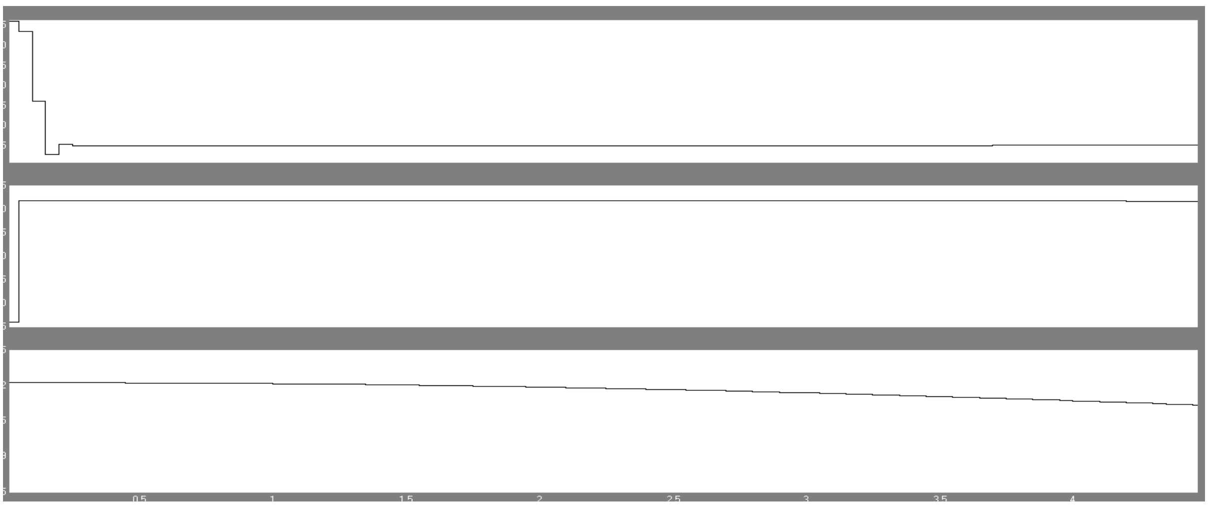
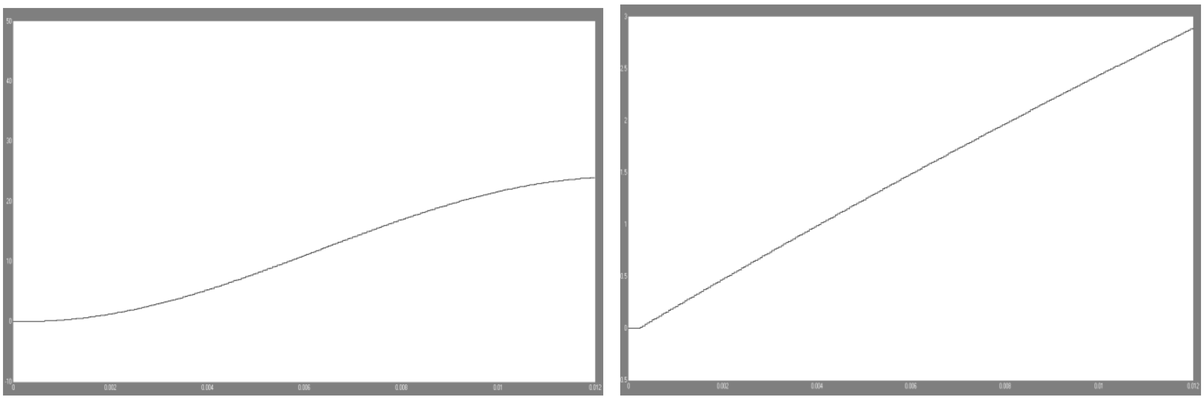


Fig. 6: Steady state waveforms: Solar, Wind, and battery output voltage responses under different load and source conditions



(a) Vo (b) Io

Fig. 7. (a) Output voltage and (b) Output current waveforms

V. Extension Of The Topology

In the proposed four-port dc/dc converter, there are two input switch branches, which enable two sources. However, the number of the unidirectional switch branches is not limited. Addition of a half-bridge upper switch plus a diode will provide one more input port to interface another renewable energy source which is one of the extension of the proposed. In order to use the same for high power applications, a full bridge multiport converter can be designed which is also considered as the extension for the proposed.

VI. Conclusion

This paper has presented a novel dc/dc converter topology in which, the converter features low component count and ZVS operation for all primary switches. Modification based on the traditional half-bridge topology makes it convenient for the practicing engineers to follow the power stage design. Three degrees of freedom necessary to control power flow in the system are provided by a four-stage constant-frequency switching sequence. This four-port converter is suitable for renewable energy systems, where the energy storage is required while allowing tight load regulation. It is suitable for low-power applications since based on the half-bridge topology, while the multiport converter based on the full-bridge topology maybe suitable for high-power applications. For the hybrid PV wind system, the proposed control structure is able to achieve maximum power harvesting for PV and/or wind power sources, meanwhile maintaining a regulated output voltage. The circuit operation of this converter and its control system is experimentally verified.

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