



A Grid Connected PV System Integrated with Battery Energy Storage Through Three- port Isolated DC-DC Converter

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Abstract-. It contains an inductor–capacitor–inductor (LCL)-resonant circuit to achieve zero-current switching (ZCS) for the main switch. The proposed converter has the advantage of using the least number of switches and soft switching for the main switch, which is realized by using an inductor–capacitor– inductor (LCL)-resonant circuit. The converter is capable of interfacing sources of different voltage–current characteristics with a load and/or a dc micro grid. This is a new isolated three-port bidirectional dc–dc converter, which uses the minimum number of switches. The proposed converter is applied for simultaneous power management of a photovoltaic (PV) system with a battery. The PV system and the battery are connected to the unidirectional port and the bidirectional port of the converter, respectively. A maximum power point tracking (MPPT) algorithm is designed for the PV panel to generate the maximum power when solar radiation is available. A charge and discharge controller is designed to control the battery to either absorb the surplus power generated by the PV panel or supply the deficient power required by the load. The simulation results are presented by using Mat lab/Simulink software.

Index Terms—Battery, bidirectional dc–dc converter, isolated converter, multiport converter, photovoltaic (PV), soft switching, zero-current switching (ZCS).

1. INTRODUCTION

As the world population is increasing rapidly, the power demand and the load demand is also increasing rapidly. Renewable energy sources hold a vital role in generating the power and meeting with the load demands. With surplus advantages like low or almost nil harmful emissions, reliability, durability and low maintenance, renewable energy sources are now playing a major role in satisfying the future energy demand. However, owing to few disadvantages like fluctuation in output due to climatic conditions, irradiance, and temperature and so on, renewable energy sources are still under the research area [1-3]. To cope up with the drawbacks batteries are used as storage mechanism for smoothing output power, improving start up transitions and dynamic characteristics, and enhancing the peak power capacity. For this purpose hybrid power system combining PV, battery, etc are being proposed [4-6]. These hybrid power systems have the potential to provide high quality, more

reliable and efficient power. Many hybrid power systems with various power electronic converters have been proposed in the literature up to now. However, the main shortcomings of these integrating methods are complex system topology, high count of devices, high power losses, expensive cost, and large size [7]. Integrated multi-port converters are used to interface power sources with storage devices. They have the advantages like less components, lower cost, more compact size, and better dynamic performance. In many cases, at least one energy storage device should be incorporated. For example, in the electric vehicle application, the regenerative energy occurs during acceleration or start up. Therefore, it is very important for the port connected to the energy storage to allow bidirectional power flow. Various kinds of topologies have been proposed due to the advantages of multiport converters [8].

A grid connected system is that which works in with the local utility grid so that when the solar produces more electricity than a house is using the surplus power is fed into the grid. If the house requires more power than what the solar panels are producing then the balance of the electricity is supplied by the utility grid [9]. With a standalone solar system the solar panels are not connected to a grid but instead are used to charge a bank of batteries. This set up is used in areas where no public grid is available. But the growth in solar power systems in the last five years has been in the grid connected systems. Because most people live in areas that are connected to a public grid and stand-alone systems are much, much more expensive than the grid connected systems because the batteries are very dear. A grid connected system needs to synchronise input to the grid [10].

Many multiport converter topologies have been presented in the literature and can be roughly divided into two categories. One is non-isolated type [11] the non-isolated converters are usually derived from the typical buck, boost, or buck–boost topologies and are more compact in size. The other is isolated type [12]–[13]: the isolated converters using bridge topologies and multi winding transformers to match wide input voltage ranges. In this

paper, a high step-up three-port dc-dc converter for the hybrid PV/battery system is proposed with the following advantages:

- 1) High voltage conversion ratio is achieved by using coupled inductors;
- 2) Simple converter topology which has reduced number of the switches and associate circuits;
- 3) Simple control strategy which does not need to change the operation mode after a charging/discharging transition occurs unless the charging voltage is too high; and
- 4) Output voltage is always regulated at 380V under all operation modes.

The major contribution of this paper is to propose an integrated three-port converter as a non-isolated alternative other than typical isolated topologies for high step-up three-port applications. The proposed switching strategy allows the converter to be controlled by the same two duty cycles in different operation modes.

II. Topology and Operating Principle of the Proposed Converter:

A. Topology of the Proposed Converter

The circuit diagram of the proposed converter is shown in Fig.1, which consists of a low-voltage-side (LVS) circuit and a high-voltage-side (HVS) circuit connected by a high-frequency transformer. The LVS consists of two ports, an energy storage capacitor C_s , the primary winding of the transformer, and an LCL-resonant circuit consisting of two inductors L_r and L_p and a capacitor C_r , where L_p includes the added inductance L_{p1} and the leakage inductance of the transformer L'_p . The HVS consists of the secondary winding of the transformer and a full-bridge rectifier implemented with the diodes $D_{s1} \sim D_{s4}$. The transformer's turn ratio is defined as: $n = N_p/N_s$, where N_p and N_s represent the numbers of turns of the primary and secondary windings, respectively. Among the switches, S_1 is called the main switch because it not only controls the power generated by the source connected to Port 1 (P1) but also changes the direction of the current flowing through the transformer.

In this paper, the two ports on the LVS are connected to a PV panel and a battery. To simplify the analysis, the proposed converter is analyzed by two separate converters: one is a single-switch LCL-resonant converter, and the other is the battery-related buck and boost converter consisting of L_2 , S_2 , and S_3 .

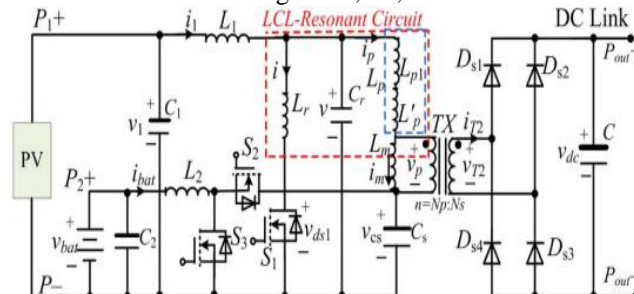


Fig. 1. Proposed isolated three-port bidirectional dc-dc converter for a PV and battery system.

B. Single-Switch LCL-Resonant Converter for PV Panel

In a switching period, the voltages across C_1 and C_s can be taken as constant values. Particularly, in the steady state, $V_{C_s} = V_1$, where V_1 is the output voltage of the PV panel. The converter has seven operating modes depending on the states of the switch S_1 and the resonant circuit. Fig.2 shows the equivalent resonant circuit in different modes. The differential equations of the resonant circuit in Mode k ($k = 1, \dots, 7$) are

$$\begin{cases} v = L_r^{(k)} \cdot \frac{di_r^{(k)}}{dt} \\ i_1 = C_r \cdot \frac{dv}{dt} + i_r^{(k)} \end{cases} \quad (1)$$

Where v represents the voltage of the capacitor C_r ; $L_r^{(k)}$ and $i_r^{(k)}$ represent the equivalent resonant inductance and the current through the equivalent resonant inductor in the k th

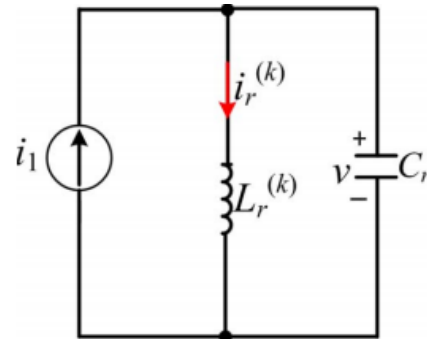


Fig.2. Equivalent resonant circuit.

($k = 1, \dots, 7$) operating mode, respectively. Then, v can be solved from (1) and has the following form:

$$v(t) = A^{(k)} \cos[\omega^{(k)}(t - t_k)] + B^{(k)} \sin[\omega^{(k)}(t - t_k)] + V^{(k)} \quad (2)$$

Where

$$\omega^{(k)} = \frac{1}{\sqrt{L_r^{(k)} \cdot C_r}} \quad (3)$$

is the resonant frequency in Mode k ; $V^{(k)}$ is the particular solution of (1) in Mode k , and $A^{(k)}$ and $B^{(k)}$ are coefficients, which can be expressed as follows:

$$\begin{aligned} A^{(k)} &= v(t_k) - V^{(k)} \\ B^{(k)} &= \frac{I_1 - i_p(t_k) - i(t_k)}{\omega^{(k)} \cdot C_r} \end{aligned} \quad (4)$$

Where $v(t_k)$, I_1 , $i_p(t_k)$, and $i(t_k)$ represent the voltage across C_r and the currents of L_1 (i_1 can be viewed as a constant value I_1 because of a large L_1), L_p , and L_r at time t_k , respectively. Equations (4) and (5) indicate that

only $\omega(k)$ and $V(k)$ are required to determine the parameters of (2).

The steady-state waveforms and equivalent circuits of the seven operating modes of the converter are shown in Figs. 3 and 4, respectively. To facilitate the explanation of the converter operation, define $V_T = n \cdot V_{dc}$ the equivalent output voltage of the converter referred to the primary side of the transformer.

Mode 1— $t \in [t_1, t_2]$ (see Fig.3): Prior to Mode 1, S1 is off; the currents through L_r and L_p are zero and a positive value of I_1 , respectively, i.e., $i(t_1) = 0$, $i_p(t_1) = I_1$. When S1 is on, as shown in Fig. 4(a), L_r and L_p resonate with C_r , the current of the inductor L_r increases, and the voltage of the capacitor C_r decreases. Due to the existence of L_r , the current through the switch S1 increases slowly, so that the switch is turned on under a low-di/dt condition. The resonant frequency and the particular solution in this mode can be expressed as follows:

$$\omega^{(1)} = \frac{1}{\sqrt{(L_r // L_p) \cdot C_r}} \quad (6)$$

$$V^{(1)} = \frac{L_r}{L_r + L_p} \cdot (V_1 + V_T) \quad (7)$$

Where $//$ represents that L_r and L_p are connected in parallel. In this mode, the current i_m through the primary magnetizing inductance L_m increases; the current i_{T2} through the secondary side of the transformer is positive, which indicates the conduction of the Ds1 and Ds3. At the end of Mode 1, $i_p(t_2) = i_m(t_2)$, i achieves its maximum value I_{max} , $i_{T2}(t_2) = 0$, $v(t_2) = 0$, and v_p changes its polarity from positive to negative

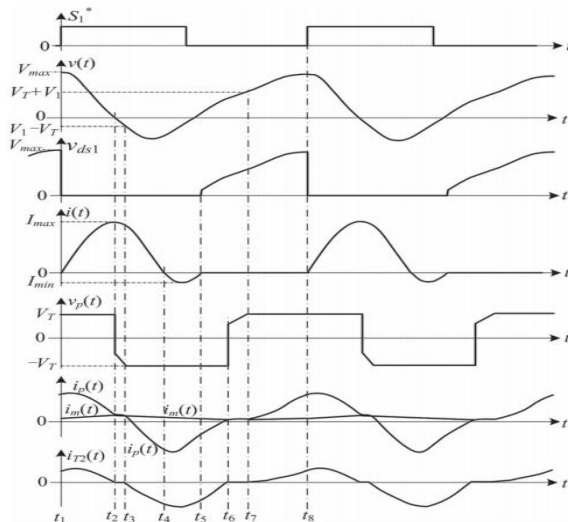


Fig.3.Steady-state waveforms of the proposed converter.

Mode 2— $t \in [t_2, t_3]$: During which S1 is on, $i(t) > 0$, $i_p(t) = i_m(t)$, and Ds1–Ds4 are reverse biased, such that $i_T = 0$. As shown in Fig. 4(b), L_m , L_p , and L_r resonate with C_r . Since $L_m // L_p // L_r$, then

$$\omega^{(2)} = 1/\sqrt{[(L_p + L_m) // L_r] \cdot C_r} \approx 1/\sqrt{L_r \cdot C_r} \quad (8)$$

$$V^{(2)} = \frac{L_r}{L_r + L_p + L_m} \cdot V \approx \frac{L_r}{L_m} \cdot V_1 \quad (9)$$

At the end of Mode 2, $v_p(t_3) = -V_T$, $v(t_3) = V_1 - V_T$, and the diodes Ds2 and Ds4 begin to conduct.

Mode 3— $t \in [t_3, t_4]$: During which S1 is on, $i(t) > 0$, $v_p(t) = -V_T$, and $i_{T2} < 0$. As shown in Fig. 4(c), L_r and L_p resonate with C_r ; the energy stored in L_r is released to charge the capacitor C_r ; v_p is clamped to $-V_T$; and i_{T2} is negative, which indicates the conduction of Ds2 and Ds4. Compared to Mode 1, the only difference in the equivalent circuit in this mode is the sign of v_p . Thus, $\omega(3) = \omega(1)$, and

$$V^{(3)} = \frac{L_r}{L_r + L_p} \cdot (V_1 - V_T) \quad (10)$$

This mode terminates at time t_4 when the current of L_r decreases to zero, i.e., $i(t_4) = 0$.

Mode 4— $t \in [t_4, t_5]$: During which S1 is on, $i(t) < 0$, $v_p(t) = -V_T$, $i_{T2} < 0$, and Ds2 and Ds4 conduct. As shown in Fig.4(d), a negative current flows through the internal diode of the switch S1; the gate signal can be removed to turn off the switch, e.g., at time t_5 , under the ZCS condition. The circuit equations are the same as those in Mode 3. Thus, $\omega(4) = \omega(1)$, $V(4) = V(3)$. At the end of Mode 4, $i(t_5) = 0$, and the voltage across the switch S1 is the same as that across the capacitor C_r , i.e., $v_{ds1}(t_5) = v$.

Mode 5— $t \in [t_5, t_6]$: During which S1 is off, $i(t) = 0$, $v_p = -V_T$, and $i_{T2} < 0$. As shown in Fig.4(e), L_r and the switch S1 can be neglected in the circuit. The inductor L_p resonates with C_r , and the direction of i_p changes from negative to positive. The following can be obtained:

$$\omega^{(5)} = 1/\sqrt{L_p \cdot C_r} \quad (11)$$

$$V^{(5)} = V_1 - V_T \quad (12)$$

At the end of Mode 5, $i_p(t_6) = i_m(t_6)$, $i_{T2}(t_6) = 0$, and v_p changes its polarity from negative to positive.

Mode 6— $t \in [t_6, t_7]$: During which S1 is off, $i(t) = 0$, $i_p(t) = i_m(t)$, and Ds1 – Ds4 are reverse biased, such that $i_{T2} = 0$. As shown in Fig. 4(f), L_m and L_p resonate with C_r , and C_r is charged. The following can be obtained:

$$\omega_6 = 1/\sqrt{(L_p + L_m) \cdot C_r} \approx 1/\sqrt{L_m \cdot C_r} \quad (13)$$

$$V^{(6)} = V_1. \quad (14)$$

At time t_7 , $v(t_7) = V_1 + V_T$ and $v_p(t_7) = V_T$.

Mode 7: $t \in [t_7, t_8]$, during which S1 is off, $i(t) = 0$, $v_p(t) = V_T$, and Ds1 and Ds3 conduct. As shown in Fig.4(g), L_p resonates with C_r , the circuit equations are the same as

those in Mode 5 except the sign of v_p , then $\omega(7) = \omega(5)$, and

$$V^{(7)} = V_1 + V_T \quad (15)$$

Once S1 is turned on at time t_8 , Mode 7 switches to Mode 1. There are five inductances L_1 , L_2 , L_r , L_{p1} , and L_m in the proposed converter that need to be properly designed. L_m is designed based on the following critical inductance L_{mc}

$$L_{mc} = \frac{V_T \cdot T}{4 \cdot I_{m,pk}} \quad (16)$$

Where T is the switching period of the switch S1; $I_{m,pk}$ is the peak current through the magnetizing inductor. In this paper, the root-mean-square (RMS) value of the magnetizing current is designed to be 2% of the RMS value of i_p . Then, L_m is designed to be larger than L_{mc} . Once the transformer is designed, the leakage inductance L'_p of the transformer can be measured. Given the load resistance R_L and the transformer's turn ratio n , the quality factor Q of this LCL-resonant converter can be calculated as follows

$$Q = \frac{8 \cdot n^2 \cdot R_L}{\pi^2 \cdot Z} \quad (17)$$

Where Z is the characteristic impedance of the resonant circuit defined as follows:

$$Z = \sqrt{\frac{L_r // (L_{p1} + L'_p)}{C_r}} \quad (18)$$

Given the desired value of Q and the value of R_L , the value of Z can be calculated from (16). In this paper, Q is selected in the optimal range of [1.5, 5]. Specifically, the value of Q is

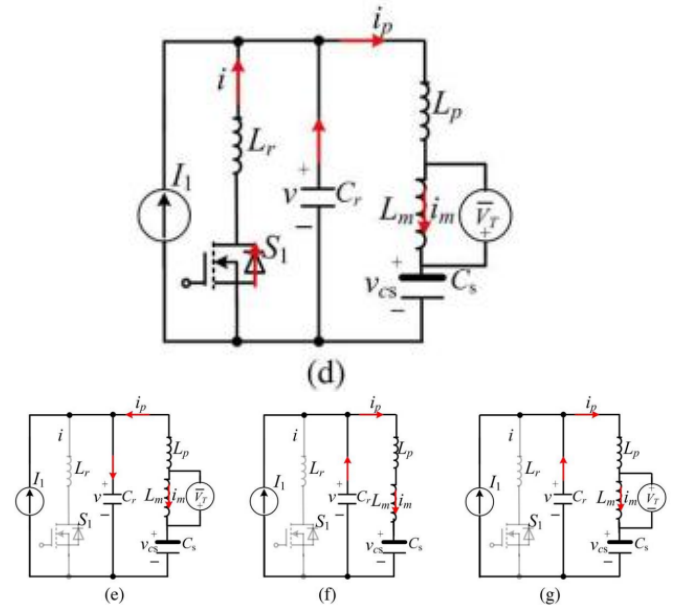
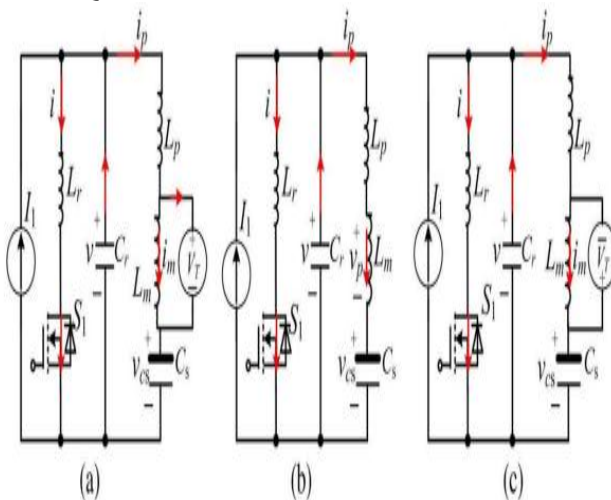


Fig. 4. Equivalent circuits for different operating modes. (a) Mode 1: S1 is on, $i > 0$, and $v_p = V_T$. (b) Mode 2: S1 is on, $i > 0$, and $i_p = i_m$. (c) Mode 3: S1 is on, $i > 0$, and $v_p = -V_T$. (d) Mode 4: S1 is being turned off, $i < 0$, and $v_p = -V_T$. (e) Mode 5: S1 is off, $i = 0$, $v_p = -V_T$. (f) Mode 6: S1 is off, $i = 0$, and $i_p = i_m$. (g) Mode 7: S1 is off, $i = 0$, and $v_p = V_T$.

3.7, when the nominal load is applied. Then, given the resonant frequency, C_r can be calculated from (6) and (18). Considering the necessary condition $L_p > L_r$ to achieve ZCS, $L_r = L_{p1}$ is selected, such that the currents through the switch S1 and the transformer are close during the resonant stage. Then, L_r and L_{p1} can be calculated from (18) with the measured value of L'_p .

The values of L_1 and L_2 are designed, according to their desired current ripples [10]. In this paper, it is expected that the current ripples are within 5% of their nominal currents.

C. Buck and Boost Converter for Battery

The buck and boost converter consists of the inductor L_2 , switches S2 and S3, and capacitor C_s . When the generated solar power is larger than the power required by the load, S3 is inactive and S2 is switched on to form the buck converter. Then, the surplus energy generated from the PV panel is stored in the battery. In contrast, when the generated solar power is less than the power required by the load, S2 is switched off and S3 is switched on to form the boost converter. The battery is discharged to C_s to provide the deficient energy required by the load.

III. POWER MANAGEMENT OF THE PROPOSED CONTROLLER

Two controllers are needed to manage the power in the LVS. Their objectives are to regulate the output dc-link voltage to a constant value and manage the power for the two sources, respectively. According to the availability of the solar power, there are three working scenarios of the converter, as illustrated in Fig.5.

A. Three Working Scenarios

Scenario 1 ($p_1 \geq p_{out}$): the available solar power is more than the load demand. As shown in Fig.5(a), the PV converter works in the MPPT mode; the battery is charged so that the dc-link voltage is controlled at a constant value.

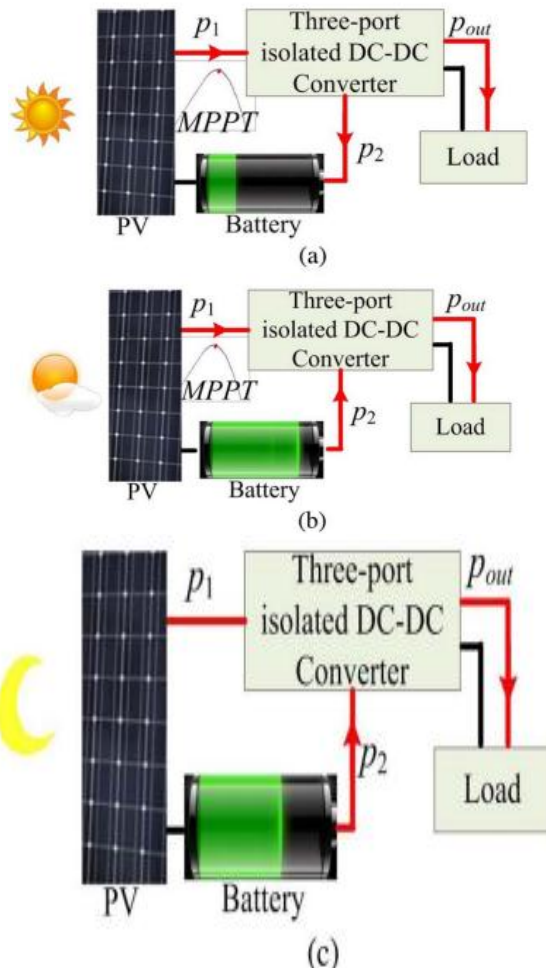


Fig.5. Three working scenarios of the converter (the arrows show the directions of energy flow). (a) Scenario 1 ($p_1 > p_{out}$): PV works in MPPT mode and the battery works in charge mode to absorb the surplus solar energy. (b) Scenario 2 ($p_1 < p_{out}$): PV works in MPPT mode and battery works in discharge mode to provide the deficient energy. (c) Scenario 3 ($p_1 = 0$): there is no solar power available and battery is discharged to supply load.

Scenario 2 ($0 < p_1 < p_{out}$): there is solar radiation, but the solar power is not sufficient to supply the load. As shown in Fig.5 (b), the PV panel is controlled in the MPPT mode by the MPPT algorithm described later. On the other hand, the deficient power is supplied by the battery, which is discharged by the boost converter, so that the dc-link voltage can be main tained at a constant value. Scenario 3 ($p_1 = 0$): there is no solar power available and, thus, the battery is discharged to supply the load, as shown in Fig.5(c). The active switches are S1 and S3.

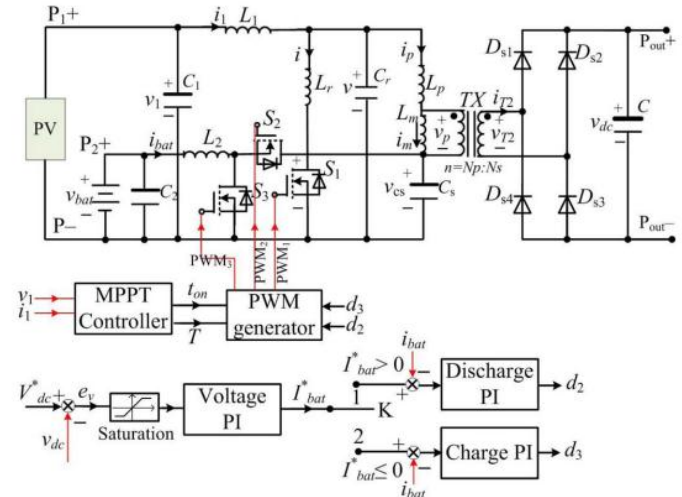


Fig. 6. Overall block diagram of the system with controllers.

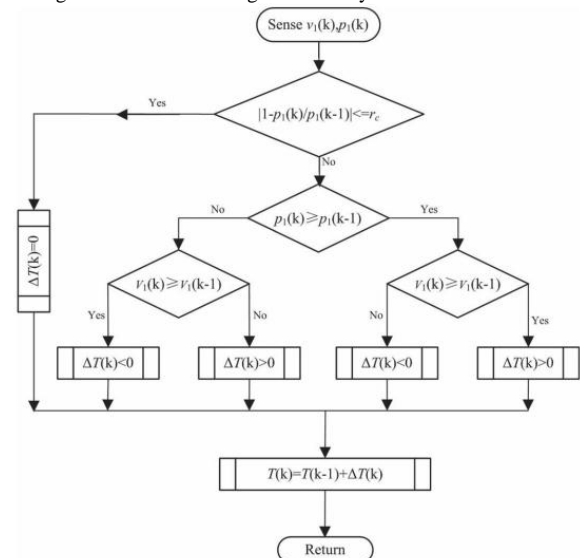


Fig.7. Flowchart of the MPPT algorithm.

Proper controllers are designed to manage the power of the system in different scenarios. Fig.6 shows the overall system with controllers, which include a MPPT controller for the PV panel and charge and discharge controllers for the battery.

B. MPPT Controller for PV Panel

The proposed converter is applied for MPPT control of a PV panel using the perturbation and observation (P&O) MPPT algorithm to maximize the PV panel's output efficiency. Fig.7 shows the flowchart of the MPPT algorithm. A ratio r_c is defined to specify the relative power change (RPC) of the PV panel between two consecutive sampling steps. Thus,

$$r_c = \frac{|P_1(k) - P_1(k-1)|}{P_1(k-1)} \quad (19)$$

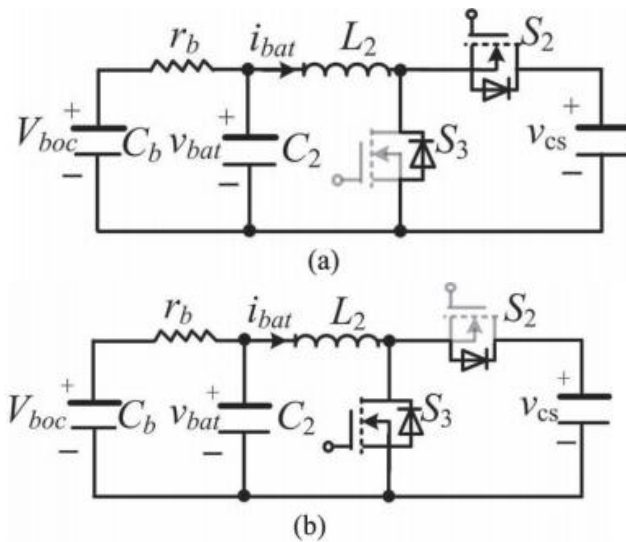


Fig.8. Equivalent circuit of the battery with (a) the buck converter in charge mode and (b) the boost converter in discharge mode.

Where $P1(k)$ and $P1(k-1)$ represent the measured output power of the PV panel in the k th and $(k-1)$ th steps, respectively.

It can be seen that, for the same power variation value, r_c is proportional to $1/P1(k-1)$. In this paper, the switching period (T) will not be changed if the RPC is lower than a predefined value (e.g., 10–4). As shown in Fig. 7, the P&O MPPT algorithm is realized by the frequency modulation method, where the conduction time of $S1$, i.e., t_{on} , is fixed so that $S1$ can achieve soft switching.

C. Charge and Discharge Controllers for Battery

Fig. 8(a) and (b) shows the equivalent circuit of the battery and the converter when the battery works in the charge and discharge modes, respectively. To simplify the analysis, the battery is modeled as a capacitor C_b connected in series with its internal resistance r_b . Since C_b is sufficiently large, the terminal voltage of the battery, i.e., v_{bat} , can be calculated as $V_{boc} - i_{bat} \cdot r_b$, where V_{boc} is the open-circuit voltage of the battery. Then, the transfer function between the battery current i_{bat} and the duty cycle d_2 of the switch S_2 in the charge mode can be derived as follows:

$$G_c(s) = \frac{i_{bat}(s)}{d_2(s)} = \frac{(V_1 - V_{bat}) \cdot \left(s + \frac{1}{r_b \cdot C_2}\right)}{s^2 + \left(\frac{r_2}{L_2} + \frac{1}{r_b \cdot C_2}\right)s + \frac{r_2/r_b + D_2}{L_2 \cdot C_2}} \quad (20)$$

Where V_1 and V_{bat} represent the average voltages of the PV panel and the battery, respectively; r_2 and r_b represent the parasitic resistance of the inductor L_2 and the internal resistance of the battery, respectively; D_2 is the steady-state value of the duty cycle of the switch S_2 .

Similarly, the transfer function between i_{bat} and the duty cycle d_3 of the switch S_3 in the discharge mode is

$$G_d(s) = \frac{i_{bat}(s)}{d_3(s)} = \frac{V_1 \cdot \left(s + \frac{1}{r_b \cdot C_2}\right)}{s^2 + \left(\frac{r_2}{L_2} + \frac{1}{r_b \cdot C_2}\right)s + \frac{r_2/r_b + 1}{L_2 \cdot C_2}} \quad (21)$$

To control the current of the battery, a proportional–integral (PI) controller $K_p + K_i/s$ is used in the charge/discharge mode separately, as shown in Fig.6. Each battery current PI controller takes the current error as the input to generate the duty cycle for S_2 or S_3 in the charge or discharge mode, respectively. When the reference current I^*_{bat} is zero or negative, the charge PI controller is selected, such that $d_2 \geq 0$ and $d_3 = 0$. Otherwise, when the reference current I^*_{bat} is positive, the discharge PI controller is selected, such that $d_3 > 0$ and $d_2 = 0$.

The bode plots of $i_{bat}(s)/d_2(s)$ and $i_{bat}(s)/d_3(s)$ without the PI compensations (i.e., the open-loop transfer functions). The plots imply that the two open loop systems have low gains and 0-dB/dec slopes in the low frequency region. Therefore, the design objective of the PI compensation is to increase the low-frequency gains and make them cross the 0-dB line with a -20 -dB/dec slope, while maintaining a sufficiently large phase margin ($> 45^\circ$) and a high crossover frequency. By setting the crossover frequency in the range of one to several hundred hertz with a phase margin of 70° , the charge and discharge PI controllers can be derived. The bode plots of $i_{bat}(s)/d_2(s)$ and $i_{bat}(s)/d_3(s)$ with the PI compensations (i.e., the closed-loop transfer functions). After the compensations, the low frequency gains have been increased, and the low-frequency slopes are changed to be -20 dB/dec. The crossover frequencies corresponding to the charge and the discharge controllers are 300 Hz and 400 Hz, respectively.

IV GRID CONNECTION

This paper presents a single-phase five-level photovoltaic (PV) inverter topology for grid-connected PV systems with a novel pulse width-modulated (PWM) control scheme. Two reference signals identical to each other with an offset equivalent to the amplitude of the triangular carrier signal were used to generate PWM signals for the switches. A digital proportional-integral current control algorithm is implemented in DSP TMS320F2812 to keep the current injected into the grid sinusoidal and to have high dynamic performance with rapidly changing atmospheric conditions. The inverter offers much less total harmonic distortion and can operate at near-unity power factor. The proposed system is verified through simulation and is implemented in a prototype, and the experimental results are compared with that with the conventional single-phase three-level grid-connected PWM inverter.

A grid-connected photovoltaic power system, or grid-connected PV system is an electricity generating system that is connected to the utility grid. A grid-connected PV system consists of solar panels, one or several inverters, a power conditioning unit and grid connection equipment. They range from small residential and commercial rooftop systems to large utility-scale solar power stations. Unlike stand-alone power systems, a grid-

connected system rarely includes an integrated battery solution, as they are still very expensive. When conditions are right, the grid-connected PV system supplies the excess power, beyond consumption by the connected load, Residential, grid-connected rooftop systems which have a capacity more than 10 kilowatts can meet the load of most consumers.^[2] They can feed excess power to the grid where it is consumed by other users. The feedback is done through a meter to monitor power transferred. Photovoltaic wattage may be less than average consumption, in which case the consumer will continue to purchase grid energy, but a lesser amount than previously. If photovoltaic wattage substantially exceeds average consumption, the energy produced by the panels will be much in excess of the demand. In this case, the excess power can yield revenue by selling it to the grid. Depending on their agreement with their local grid energy company, the consumer only needs to pay the cost of electricity consumed less the value of electricity generated. This will be a negative number if more electricity is generated than consumed.^[3] Additionally, in some cases, cash incentives are paid from the grid operator to the consumer.

V.MATLAB/SIMULATION RESULTS

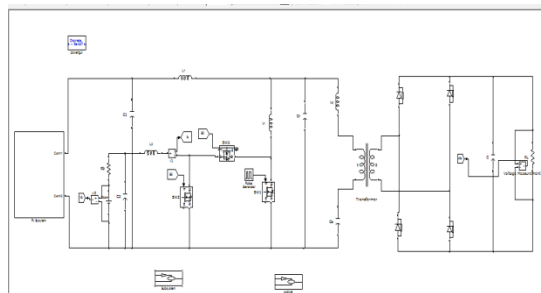
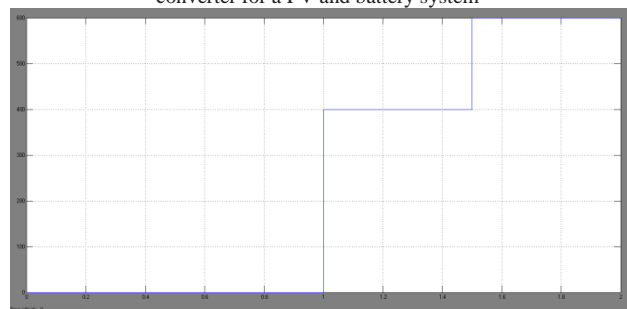
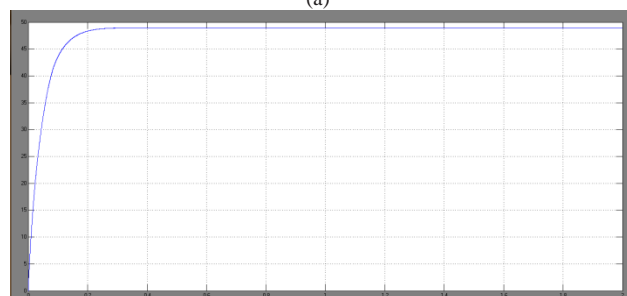


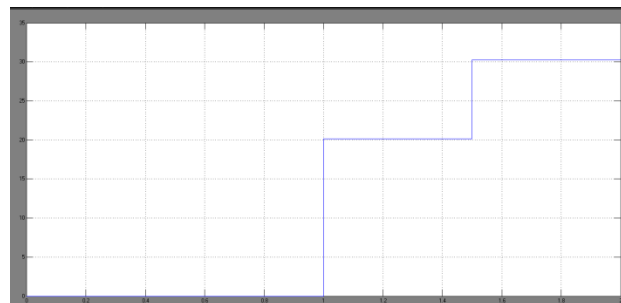
Fig 9 Matlab/simulation circuit of isolated three-port bidirectional dc-dc converter for a PV and battery system



(a)

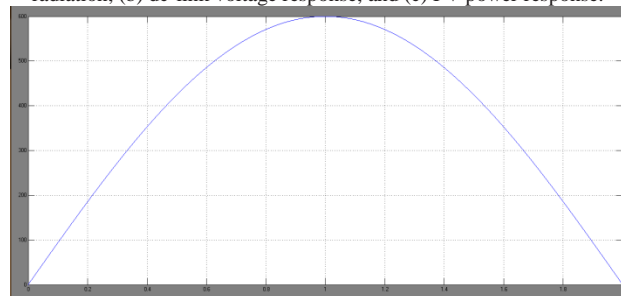


(b)

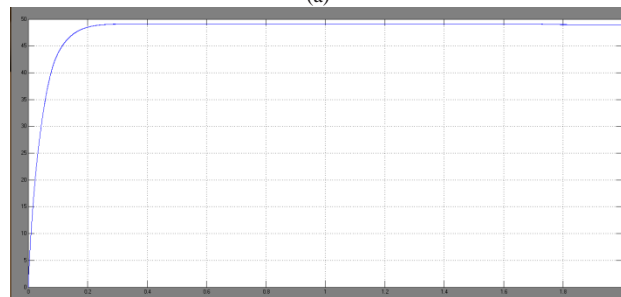


(c)

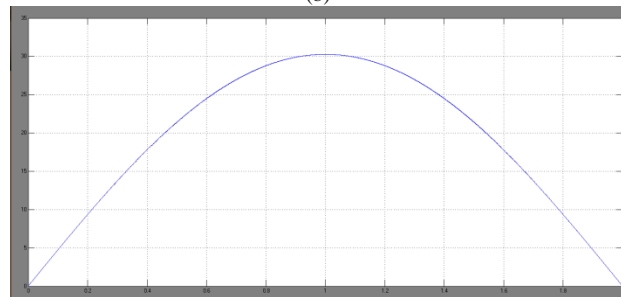
Fig 10 simulation wave form of step responses: (a) profile of solar radiation, (b) dc-link voltage response, and (c) PV power response.



(a)



(b)



(c)

Fig 11 Simulation results using the NREL data: (a) generated PV power and (b) the dc-link voltage. (c) PV power response

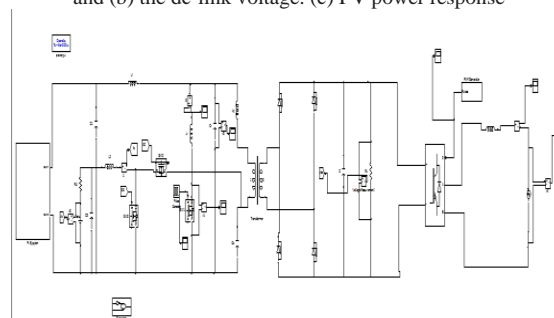


Fig 12 Matlab/simulation circuit of isolated three-port bidirectional dc-dc converter for a PV and battery system with grid connected system

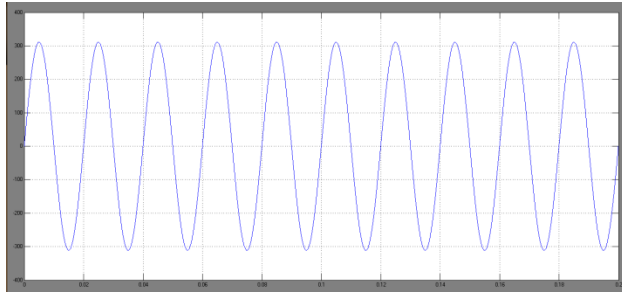


Fig 13 simulation wave form of output grid voltage

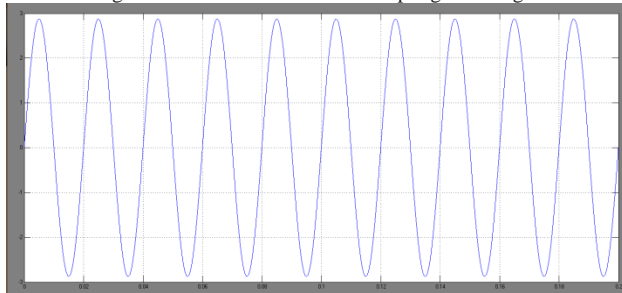


Fig 14 simulation wave form of output grid current

VI.CONCLUSION

A high step-up three-port DC-DC converter for grid connected power systems is proposed to integrate solar and battery power. The model is developed and evaluated for different load conditions, mode change conditions etc.,. The simulation results validate the functionality of the proposed converter under different solar irradiation level and load demand. Simulation results have shown that the converter is not only capable of MPPT for the PV panel when there is solar radiation but also can control the charge/discharge of the battery to maintain the dc-link voltage at a constant value. Moreover, the voltage stress and the value of di/dt of the main switch have been reduced compared with the corresponding hard-switched converter. The charging/discharging transitions of the battery could be achieved without changing the operation mode; therefore, the MPPT operation will not be interrupted. In light load condition, once the charging voltage is higher than the present level, the operation mode will be changed rapidly to protect the battery from overcharging.

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