Standalone PV system based on Isolated Quasi Z-Source Converter

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Abstract **Standalone PV system based on isolated quasi z-source dc-dc converter is proposed in this paper. Low voltage PV source and battery is integrated on quasi z-source network. Battery is integrated through bidirectional dc-dc converter. Voltage boost is obtained by using shoot-through method as well as isolation transformer. The output of the isolation transformer is rectified, and the dc voltage output is then used as an input of the single phase inverter which supplies to AC load. The PV source and battery power flow control algorithm is proposed. The proposed configuration and control method is verified with simulation.**

***Index Terms*— Quasi z-source, standalone PV, Isolation.**

I. INTRODUCTION

Countries like India that are rapidly growing in economy and population will soon havevery high energy demand. As one of the solution, integration of renewable energies into everyday household reduces energy costs and becoming more sustainable in terms of energy production. The solar photovoltaic (PV) has always been the most preferred renewable energy source.

Stand-alone or off-grid systems include common applications such as solar lanterns, solar home and street-lighting systems, solar water pumping and stand-alone power plants for powering appliances in remote areas away from the grid electricity. Such systems are designed either with or without battery backup options. In literature, many configurations are proposed for standalone PV systems which integrate PV, battery storage and load [1-3,6].From the literature, it can be observed that either number of conversion stages is higher hence number of controlled switches is higher. In some cases, battery charging/discharging is not regulated. Therefore PV system configuration is required which has reduced number of converter stages as well as regulated battery current. This paper proposes use of quasi Z-source converter for standalone PV system. Quasi-Z source converter [4] is a variation of Z source converter. The major advantages are continuous input current, buck-boost capability and common dc rail between source and inverter. Unlike conventional voltage source inverter, where DC link voltage needs a separate control if supplied from variable sources such as PV, quasi-Z source inverter has combined all the stages in a single stage by introducing an impedance network between inverter and source. This arrangement allow 'shoot through state' for inverter switches which gives this inverter a 'buck-boost capability'. Quasi Z-source based standalone PV systems are present in the literature[4,5]. However battery is considered as a buffer for balancing energy but not as a full load energy supplier. References does not discuss about the supply of power to the load when PV power is not available. Further battery current is not controllable in quasi Z-source inverter of [4,5] which is very important aspect in standalone system. This paper explores the use of isolated quasi Z-source dc-dc converter [7] for standalone PV system. It has an advantage of quasi z-source converter along with isolation and it can be operated at higher frequency so that size of the converter can be reduced. Voltage doubler rectifier is used at the secondary side to obtain the dc voltage. To obtain AC voltage, single phase inverter is used to supply the load. Further a control algorithm is developed for this topology which will take care of MPPT as well as power flow from PV source and battery to the load.

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II. PROPOSED STANDALONE PV SYSTEM

A. Description of the System

Figure 1 shows a proposed standalone PV system. The function of the quasi Z-source inverter is same as that described in [7]. The full bridge converter at the primary of the transformer has three states namely Active, Zero and Shoot- Through respectively. The PWM and shoot-through generation scheme is taken same as described in [7]. The AC waveform at the secondary is rectified by a voltage-doubler circuit. This rectified voltage acts as a DC link voltage for the load side inverter. The output of the rectifier serves as a dc link voltage for a single phase inverter. The load is connected to an output of inverter through an LC filter. The load side inverter is controlled to give a constant output at 325 V peak and 50 Hz AC voltage.

For a PV standalone system, it is required to feed the load and also to charge the battery whenever required. To achieve this, the power flow through ac inverter is controlled and the charging/discharging current of the battery is controlled by the bidirectional dc converter connected to the capacitor C1. When the solar PV source is not available for e.g. during nighttime, the changeover switch is provided which will operate battery as a input the quasi Z-source (QZS) converter.

The working of the impedance source converter can be described by mainly two states namely the active state and the shoot through state. Zero state is not considered here. The active state is where inverter is considered as a constant current source and the shoot through state where the inverter is considered as short circuit. The bidirectional battery converter

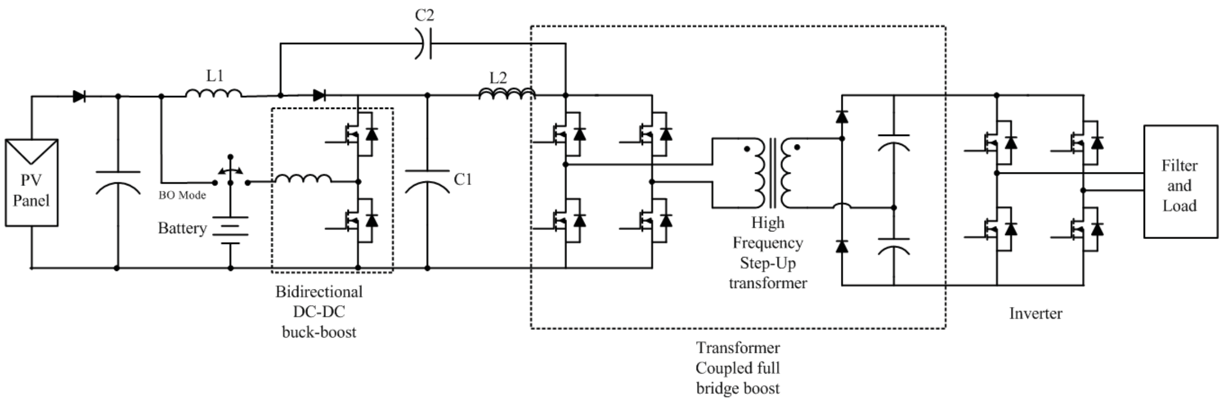

Fig.1. Proposed Standalone PV system.

maintain the battery current as specified by the controller. During battery charging, PV delivers energy to the dc link through capacitor C1 and the battery draws the charging current from it. While during battery discharge, the battery converter transfer energy from battery to C1.

B. Modes of operations

For standalone PV systems it is required to operate in one of the following modes.

1) MPPT mode: In this mode, maximum power is being extracted from the PV array. When power from the PV source is greater than the load requirement, it will supply power to the load as well as charge the battery without being overcharged, The PV power in MPPT mode is given by P_pv + P_bat = P_load(figure 2(a)) where Pbat is the battery power which is treated as positive during charging and negative during discharging. The system operates in MPPT mode, till the battery current I_B is below than the set value specified by SOC of the battery.

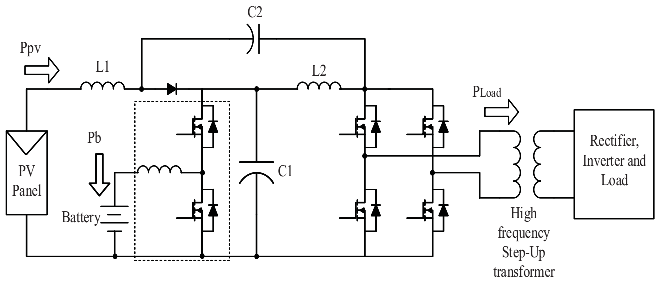

Fig.2. (a): Ppv=Pb+Pload

2) Non-MPPT mode: When demand by the load is lesser than the generated power and the battery charging current is exceeding its limit, converter operates in Non-MPPT mode.This mode also holds the relation P_pv + P_bat = P_load where P_bat is negative (figure 2(b)) and the battery charging current is maintained at its pre fixed value. The operating point will generally be on the decreasing slope of P-V curve.

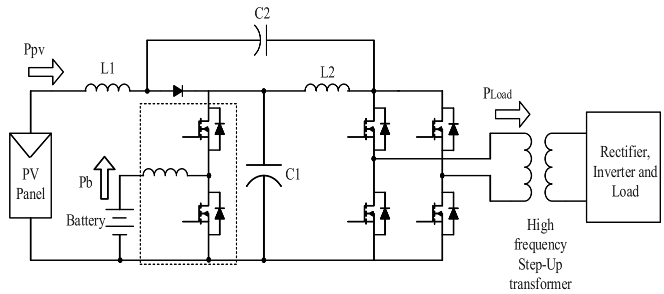

Fig.2. (b): Ppv+Pb=Pload.

3) Battery mode: The standalone system in Battery mode supplies (figure 2(c))the load demand without being over-discharged in the absence of PV power.

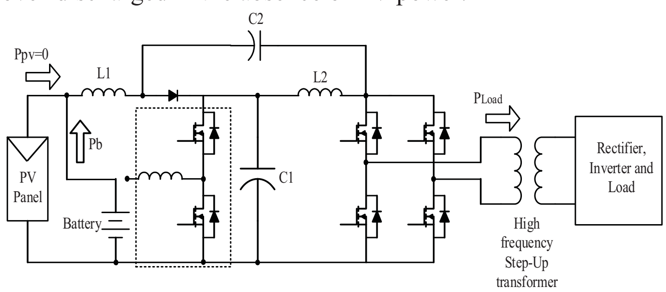

Fig. 2. (c) Pb=Pload

C. Control of Power Flow

Control of power flow plays an important role to achieve an intended operation as described previously. The controller has to take care of multiple aspects in this system.

a) The controller has to decide whether the PV source has to operate in MPPT or non-MPPT mode which depends on availability and demand of power. This also includes control of shoot-through duty ratio which in-turn controls the DC-link voltage of a load inverter.

b) It has to control the maximum battery charging/discharging current which depends on State of Charge (SOC).

c) When the PV source is not available, controller has to take care of supplying battery power to the load.

Therefore, to develop an appropriate control algorithm for converter power flow control which includes MPPT/non-MPPT operation of solar PV source is one of the major issues.

In MPPT mode the controller ensures maximum power is extracted from the PV array by adjusting the shoot through duty ratio. The MPPT block generates the reference current Ipvmpp which is compared with actual PV current and is given to the input of the PI controller. The output of the PI controller is shoot-through duty ratio Dsh. For controlling the dc-link voltage, the voltage across the capacitor C1 is maintained. The desired value is compared with the measured voltage and the error is passed through a PI controller. The output of the PI controller is the current reference Iref. This reference is compared with the battery current Ib to generate the duty ratio of the bidirectional converter.

In Non-MPPT mode the reference current is taken as Iref through which by subtracting Ibmax, reference PV current Ipvref is generated and the voltage across the capacitor VC1 thereby will be maintained. Any sudden change in load will cause VC1 to fall below certain voltage; the controller will automatically shift from Non-MPPT mode to MPPT mode.

For overall performance, the system has to operate in both the stages i.e. MPPT mode and Non- MPPT mode. These modes needs to be monitored consistently and the system should be capable of shifting the operating modes from one to the other thereby disabling the other mode. This is achieved by generating two control signals M and NM (both complimentary). For M=1, NM=0, the controller operates the PV in MPPT mode and battery is given the responsibility to maintain the dc link. If load reduces or solar radiation increases, IB reaches Ibmax from SOC, and NM is set to 1, M is set to 0. The controller then operates the battery in constant current mode as specified by Ibmax and gives PV the responsibility to maintain VDC. The control strategy is shown in figure 3.

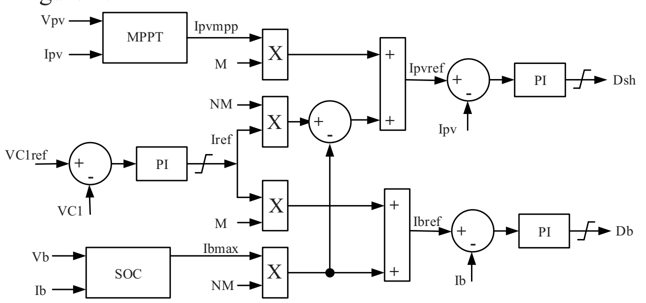

Figure3.Control Logic for operation in MPPT and Non MPPT mode.

III. Simulation Results

Detailed simulations are carried out to study theproposed standalone PV systemdiscussedabove. Both the operating conditions of MPPT and NON-MPPT modes at rated load and variable load are tested. Appropriate gatepulsesare generated for the qZSI switches as discussed in [7]. The Voltage Doubler Rectifier provides the voltage doubling effect of the peak voltage of the secondary winding of the high frequency isolation transformer, thus ensuring ripple free output voltage of 400V DC link for the single phase inverter. The results shows that the system is able to maintain the predefined voltage across the capacitor C1in all cases and thus confirm the validity of the control strategy.

The simulation software PLECS is used to model the system. Switching frequency for the system is taken as 20 kHz. For the configuration shown in Fig1, shoot through duty cycle of 0.25 can provide a gain of 2. PV operating range is 35 to 44 volts. Open circuit voltage is 44 V, MPP Voltage of the selected PV panel is 35.2 V.Battery nominal voltage is taken as 24 V. Hence for MPPT, the primary side DC link voltage is72V. The transformer turns ratio for this case turns out to be 1:2.5 to get a 200 V dc at the secondary side. The VDR doubles the voltage to 400V which in turn is the DC-Link for the single phase inverter.For simulation purpose the maximum allowable battery charging current is taken as 8A.MOSFET and Diode losses are not considered in the simulation.

For MPPT Perturb & Observe Method (P&O) is used to extract the maximum power from the solar panel. Conventional PI control is used for the battery controller to regulate the battery current. For AC control a PR controller is utilised to get the required output.

The following parameters are taken for the system during simulations is given in table 1.

TABLE I

PARAMETERS USED FOR SIMULATION

Parameters	**Values**
PV Panel Rating	Vmp=35.2 V, Voc=44 V Imp=7.38 A, Isc=8 A
Battery Rating	Vb=24 V, 150 Ah
L1,L2	1 mH
C1, C2	4400 uF
Lf and Cf	2mH and 1 uF
Fs	20 kHz
Transformer turns ratio	2.5

Case 1: MPPT mode

The standalone system operates in MPPT mode, supplying a battery current well within the set reference value from battery controller. Solar radiation S=1000 W/m^2, Load = 150 W, Maximum charging current is taken as 8A.

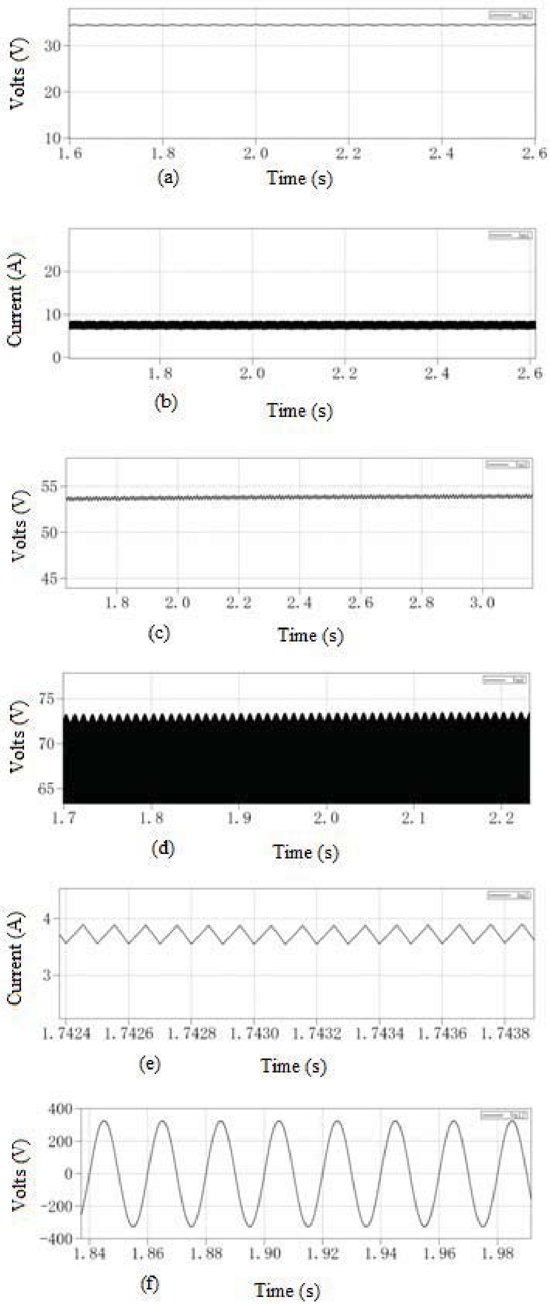

Fig4. (a) PV Voltage. (b) PV current. (c) Capacitor voltage. (d) DC-Link. (e) Battery Current. (f) Output AC Voltage.

In Fig.4(d), the dc link voltage is maintained constant at 72V by the battery which takes a charging current of 3.5 Amps(approx.) as shown in Fig.4 (e). Fig.4 (b), shows the current delivered by PV at MPPT, Fig 4(f)show the output ac voltage of the inverter representing a constant load operation. MPPT is maintained at 35V and ac output at 230V.

Case2: Irradiation change

PV initially operates at MPPT, while a step change in solar radiation takes place at t=2 sec from 1000 W/m2 to 800W/m2.

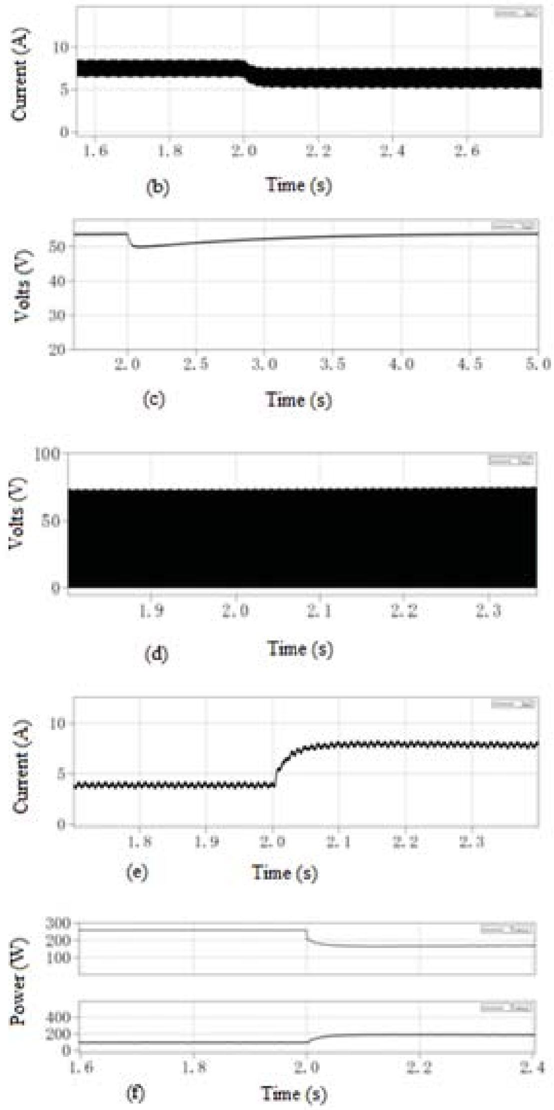

Fig5. (a) PV current. (b) Capacitor voltage. (c) DC-Link. (d) Battery Current. (e) Power Profile.

Fig.5shows at t=2sec, radiation decreases by a step. DC link falls. The battery comes out of constant charging mode, Fig 5(e)delivering power required to restore VC1 Fig.5(c) thereby maintaining the DC link Fig.5(d).

Case 3: MPPT to NON-MPPT Transition

A sudden change in load from 150W to 100W is applied at t-2 secs.

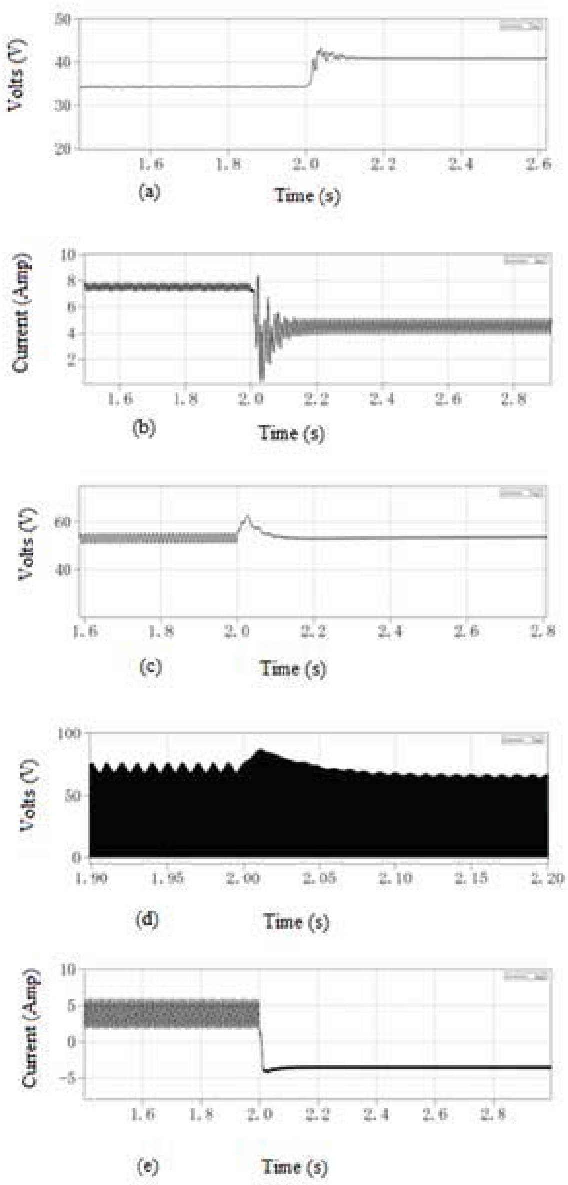

Fig6. (a) PV Voltage. (b)PV current. (c) Capacitor voltage. (d) DC-Link. (e) Battery Current.

Figs. 6(a),(b), (c), (d) and (e) show that the operation shifts from MPPT to NON-MPPT mode when there is a sudden change in the load.

IV. Conclusion

Solar PV-based stand-alone system based on isolated quasi Z source converter is proposed in this paper. The proposed system requires less number of conversion stages, provides isolation between the load and source along with stepping up of voltage. The inclusion of the bi-directional dc-dc converter regulates the battery charging and discharging. This scheme permits use of low voltage levels for the PV array and the battery. The control structure of the overall stand-alone scheme is presented and is validated through detailed simulations.

V. ACKNOWLEDGEMENT

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