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Dual Input Dual Output Converter for Renewable Energy Applications

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ABSTRACT:With the increasing fossil fuel exhaustion, environmental pollution and global energy demand, the use of renewable energy based clean and non-pollutant energy sources are gaining more importance. Since these sources are highly intermittent in nature, power electronic interfaces are necessary for their efficient utilization. For stand-alone applications, energy storage devices are required for backup and fast dynamic response.Existing converters for such applications use a common dc-link, which employ multiple converters. A single stage dual input dual output DC-DC converter with energy storage system for standalone applications is proposed in this paper. The first input of the converter is from photovoltaic (PV) cells and the second input is a rechargeable battery. The work is intended to minimize the complexity of the converter during the integration of rechargeable battery to Solar PV systems. The existing converter is modified to provide a regulated output voltage and to clamp the PV cells' voltage to the maximum power point value to maximize efficiency. When the PV cells harvest more power than the load demand, the surplus energy is used to charge the rechargeable battery. When the PV cells cannot harvest sufficient power, the converter schedules the PV cells and the batterytogetherto power the load . The proposed converter has been modelled and simulated using Simulink in the MATLAB. The simulation results proved that the proposed converter works satisfactorily where the load voltage is regulated in all power flow.

KEYWORDS:Photovoltaic (PV) Systems , Battery Storage System, Dual Input Dual Output(DIDO), P&O MPPT

I.INTRODUCTION

Renewable energy resources are gaining more importance in our day today life because of ever growing demand for energy.Since these sources are highly intermittent in nature, power electronic interfaces are necessary for their efficient utilization. Nowadays, power generation using solar power had increased dramatically because it is pollution free, noise free, requires little maintenance, no wear and tear due to the absence of moving parts and also it is freely available. It is also the most promising candidate for research and development for large scale uses as the fabrication of less photovoltaic devices becomes a reality.

The effectiveness of PV generation does depend on environmental conditions such as solar irradiation and temperature. To use solar energy efficiently, a maximum power point tracking (MPPT) method is usually adopted to extract maximum power from a PV array. By integrating MPPT algorithm, the system's power reconstructing capability and accuracy can be enhanced much.Several MPPT techniques have been proposed till date which includes simple methods like P&O (Perturb and Observe) method[1], Incremental Conductance[2], as well as more complex MPPT algorithms based on fuzzy logic controllers, Sliding Mode controllers etc. P&O algorithm also known as Hill Climbing algorithm compares thevoltage and power before perturbation to the voltage and power after perturbation to reach MPP while InC algorithm compares the incremental conductance with the conductance at MPP. P&O algorithm is implemented in this paper due to its simplicity. Also it requires the sensing of less number of variables compared to other MPPT techniques.

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II.LITERATURE SURVEY

The real-time harvested electrical power may be insufficient to drive the load depending on the environmental energy status and the energy harvesting mechanism. To guarantee the correct operation of the system, hybrid supplies [3], were proposed where the system was powered by several different kinds of energy sources. The sources can be super capacitor, fuel cell, rechargeable battery, or other environmental energy. When the output power from the primary energy source is insufficient for the load, the secondary energy source is used to power the system to achieve a longer lifetime for microsystems.Moreover, a battery storage system is usually added to balance the power difference between PV generation and load. The aforementioned requirements can be achieved by power converters. Plenty of topologies have been proposed to combine the PV array, the battery and the load. This includes multistage converters, single-stage converters and multiport converters.In many prior researches, a dc–dc converter was used as the direct load to match with the MPP [4], by adjusting the switching duty cycle of the converter.

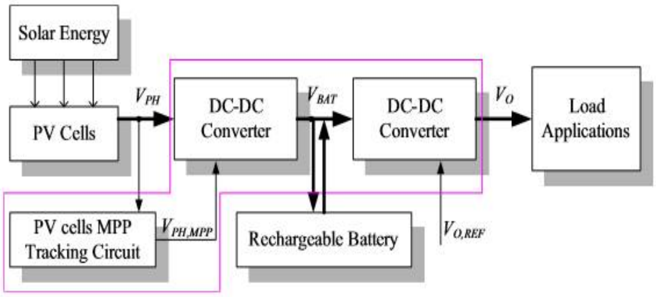

Fig.1 Conventional solar power management system

Fig. 1 shows the conventional solar power management system.The first converter regulates the PV output voltage to the MPP voltage,wherethe converter output voltage varies greatly since it is depending on both the converter’s input voltage and switching duty cycle. The unstable converter output cannot be used to power the application directly, and therefore it is used to charge a rechargeable battery. The battery functions as an energy buffer for the harvested solar energy, as well as a voltage clamper that clamps the converter’s output to the battery voltage. If the application requires a supply voltage different from the battery voltage, a second voltage converter is needed to generate the required supply.The system thus contains two dc–dc converters. The additional electrical components such as power transistors and inductors increase the system volume and cost. The major disadvantage is the low system efficiency due to multiple stage power conversion.

This paper proposes a single-inductor dual-input dual-output (SI-DIDO) dc–dc converter for solar energy harvesting applications that reduces the component count, system cost and increases the overall power transfer efficiency [5]. The converter has two inputs. One of the input sources is the PV cells with an unsteady PV voltage and the second input is the battery. The converter has to generate a required stable voltage at one of its outputs to power the load and also needs to regulate the PV output voltage to the predetected MPP to extract the maximum power from the PV cells. With the change of environmental and loading conditions, the PV output power can either be larger or smaller than that of the load demand. When the source power is more than the load requirement, the excess current is used to charge the battery. Similarly, when the PV output power is insufficient for the load, the converter schedules the PV cells and the rechargeable battery to power the load together. Thus the system meets the load power requirement. At night times power from PV becomes zero. So, total power demand is to supplied by the battery. Here we have to take care of discharging capacity of the battery to improve the life time of battery. PWM based controltechnique is used.The proposed converter is simulated in MATLAB Simulink platform to validate the results.

III.PROPOSED SYSTEM CONFIGURATION

The block diagram of the solar energy harvesting system with the proposed single inductor DIDO dc–dcconverteris as showninFig.2. It consist of a single stage converter with dual inputs-one from the PV panel and the other input from the rechargeable battery.

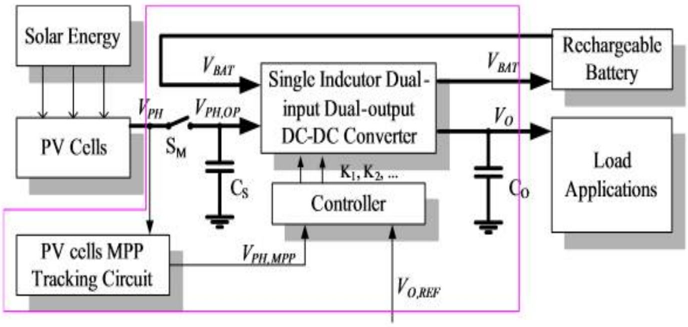

Fig.2 Proposed solar power management system

The proposed converter is derived from the basic topology of the Boost converter, where the power flow from the input source to the load is defined. Boost converter is a single input, single output converter which uses one inductor and one power switch. A storage element like battery is required in a stand-alone renewable power system to supply the load smoothly. When the input power is more than the load requirement, it will charge the battery. The charging is controlled by a power switch connected in series with the battery. And an extra diode is needed to prevent the reverse current from flowing. The battery should discharge to the load when the input source can no longer support the load all alone. The discharging of battery is controlled by another switch connected with the battery in series. Since the input sourcecan't be connected with the battery in parallel, another diode is needed, as shown in Fig 3.

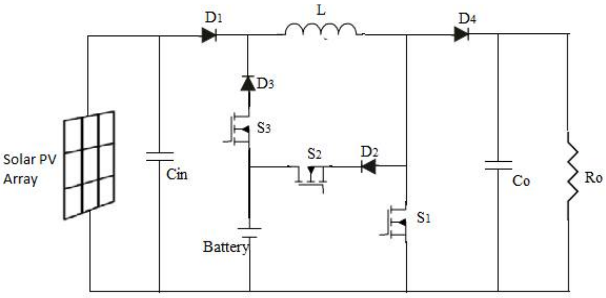

Fig.3 Circuit of the proposed SI-DIDO dc–dc converter

Based on the above analysis, a Boost three port converter is derived by introducing two additional power flow paths into the Boost converter. The additional circuit incorporates a rechargeable battery as shown in Fig. 3. In the Boost converter, the inductor L and the power switch S1 is connected to the input source in series. A power switch S2 can be introduced into the converter and a power flow path is configured to bridge the input source and battery. When input power is greater than the load demand, battery will charge through S2, and a diode D2 is provided to prevent the reverse current flow. The power flow path is PV array to the load and battery. Another power switch S3 is introduced into the converter and a power flow path is configured to bridge the battery and the load. Here also a diode (D3) is provided to prevent reverse current flow.The equivalent circuit is also a Boost converter.

IV.MODELLING AND DESIGN

A. PV Array Model

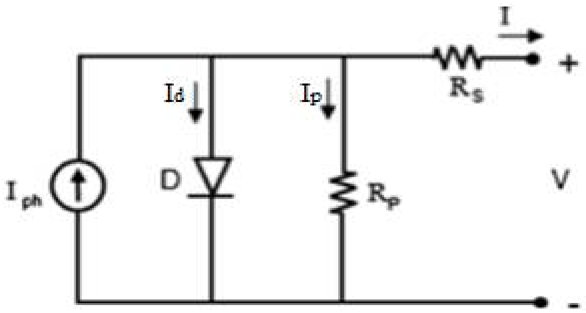

Fig.4 Practical equivalent circuit of the solar cell

Fig.4 shows the equivalent circuit of a PV panel with a load.The PV module is modeling is done by considering it as a current source in parallel with an antiparallel diode. Takinginto account the internal losses series and shunt resistances are also added as in Figure 4 The modeling is done as per the equations in [6]. The relevant equations are given below.

By applying Kirchhoff's law,

$$I = I_{ph} - I_d - I_p \tag{1}$$

Where $I_{ph}$is the photocurrent

$I_d$is the diode current and

$I_p$is the current leak in the parallel resistor

But $$I_d = I_0 \left[\exp \left(\frac{V + IR_s}{a} \right) \right] \tag{2}$$

Where I_0 is the reverse saturation current

$R_s$is the series resistance

a is the modified ideality factor given by

$$a = \frac{AkT_c N_s}{q} \tag{3}$$

Where A is the diode ideality factor (0.3 for Si)

k is the Boltzmann constant (1.381×10^{-23}J/K)

N_s is the number of series connected cells

T_c is is the cell temperature

q is the electron charge (1.602×10^{-19}C)

R_p is the parallel resistance

$$I_p = \frac{V + IR_s}{R_p} \tag{4}$$

B. Modelling of battery

Two important parameters to represent state of a battery areterminal voltage V_b and state of charge (SOC).

$$V_b = V_0 + R_b . i_b - \text{K} \frac{Q}{(Q + \int i_b dt)} + \text{A. exp}(\text{B} \int i_b \, dt) \tag{5}$$

$$SOC = 100+\left(1+\frac{\int i_b dt}{Q}\right) \qquad (6)$$

where $R_b$is the internal resistance of the battery, V_0 is the opencircuit voltage of the battery, i_b is the battery charging current, K is the polarization voltage, Q is the battery capacity, A is the exponential voltage and B is the exponential capacity.

V. CONTROL STRATEGY

The main objective of the converter in this paper is to feed the maximum power extracted from the PV array to the load. Rechargeable battery is employed in the power management system to support continuous and robust operation. It serves as the system's secondary energy source when the output power of the PV cells is insufficient for the load, as well as an energy buffer when the PV cells output power is higher than the load requirement.

A) MPPT Control

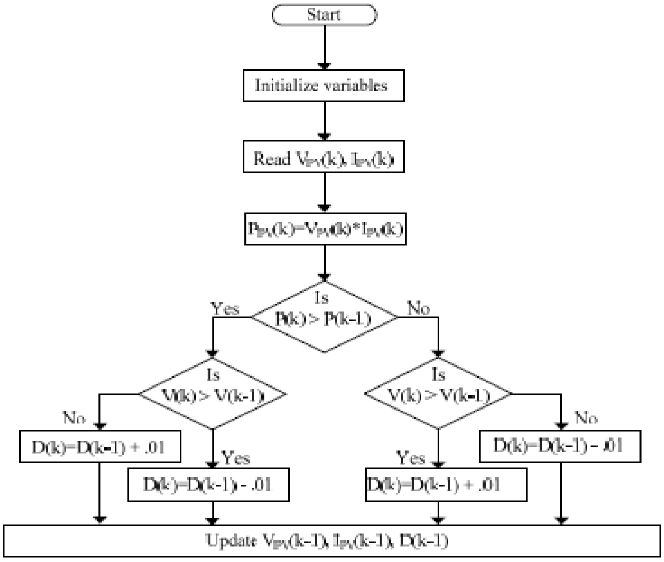

Fig.5 P&O MPPT

The MPPT controls the dc-dc stage which is composed of a boost converter whose duty ratio is modulated to achieve boost operation and extraction of maximum power. P&O Algorithm also called Hill Climbing algorithmis implemented in this paper owing to its simplicity and robustness.The P&O MPPT algorithm is shown in the Fig.5.

The MPPT algorithm was implemented using MATLAB Simulink Platform. It involves the deliberate perturbation of PV array output voltage and Power.The controller compares the value before perturbation to that after perturbation to arrive at MPP.The relevant equations governing the controller are as given below,

$$D(k) = D(k-1) - \Delta D \text{ if } dP_{PV}>0 \,\&\, dV_{PV}>0 \text{ if } dP_{PV}<0 \,\&\, dV_{PV}<0 \qquad (7a)$$

$$D(k) = D(k-1) + \Delta D \text{ if } dP_{PV}>0 \,\&\, dV_{PV}<0 \quad \text{ if } dP_{PV}<0 \,\&\, dV_{PV}>0 \qquad (7b)$$

where ΔD is the perturbation duty ratio. The different operating points of the MPPT as described in the equation are as shown in the Fig.6.

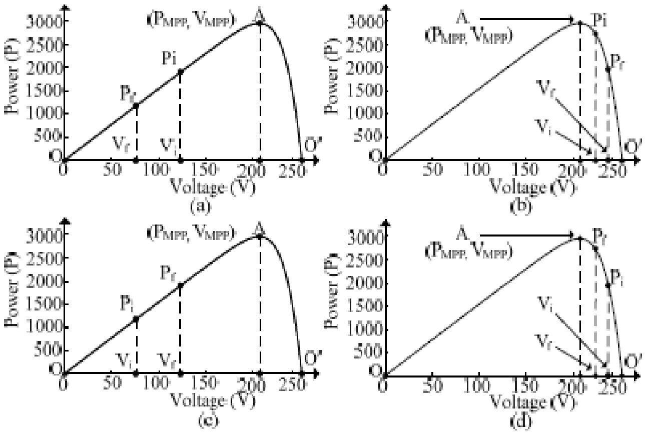

Figure 6: Possible operating points of P&O

B)PWM Control for the proposed system

The multiobjective control architecture that aims to regulate different operating modes arenamed as follows: input voltage regulation (IVR), output voltage regulation (OVR), battery voltage regulation (BVR), and battery current regulation (BCR).The output-port loop is simply a voltage-mode control loop, closed around the load voltage, and duty cycle d_1 is used as its control input. PI regulators are used to ensure MPPT at input source, maximum voltage/current charging at the battery side and the voltage control for the load, respectively.Battery control loop has two controllers: BVR and BCR. BCR is usedtopreventbatteryovercurrent,andtherefore,itcanbeconsidered as a protection function. Under normal operation, only one of two loops (IVR or BVR) will be active depending on the batterystateofcharge.The control strategy proposed is illustrated in Fig. 7.

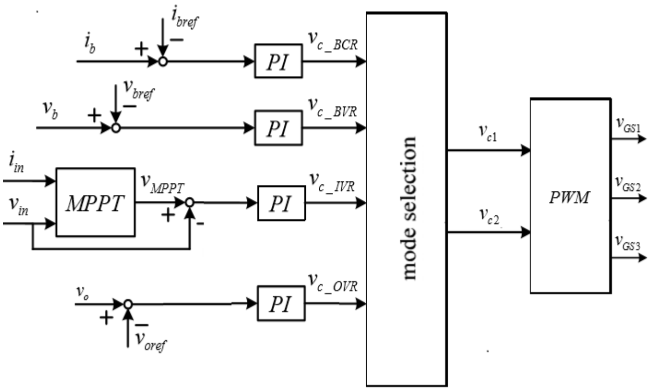

Figure 7: Control strategy for the proposed converter

1)*DO mode*: When both the charging current and voltage doesn't reach the limitations, the IVR loop is used to regulate the solar panel voltage to achieve MPPT. The output voltage regulator (OVR) is used to realize the voltage control of the load. On the other hand, when i_b (or v_b) reaches the limitation, V_{c1} will be regulated by the battery current regulator (BCR) or the battery voltage regulator (BVR), to achieve maximum currentcharging control or maximum voltage charging control, instead of MPPT. And V_{c2} is still regulated by OVR to control the output voltage.

2)*DI mode*: The battery is discharged in this mode. The BCR and BVR outputs are saturated at the lower limit. Thus V_{c1} is controlled by IVR to achieve MPPT. V_{c2} is controlled by OVR to control the load voltage.

3)*SISO mode*: When the input source voltage is lower than the minimum voltage, the input source should be cut off. The IVR is used to control the load port. V_{c1} is controlled by IVR to control the load voltage. It can be concluded that there are at most two regulators working at any time. V_{c1} is controlled by one of IVR, BCR and BVR. V_{c2} is controlled by OVR in DO mode and DI mode.
The system is validated through simulations and the results are presented in the subsequent section.

VI. SIMULATION RESULTS

The operations of the proposed converter are simulated to verify the proposed control algorithms.The Simulation diagram of single inductor dual input-output DC-DC converter with a PV port and a Battery port feeding a resistive load is shown in the Fig. 8.

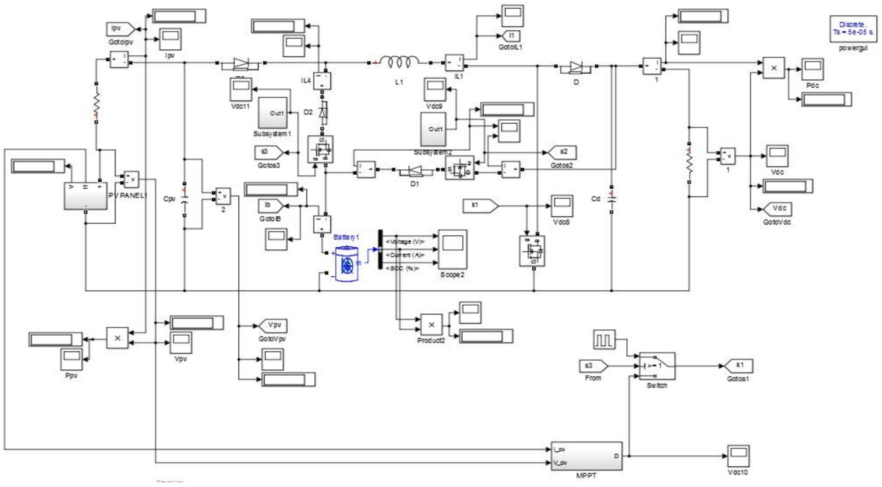

Fig.8 Simulink block diagram of the proposed converter

The entire system was simulated in MATLAB Simulink Platform. The key parameters used for simulation are: Vin~200-250V, Vb~200V, L=3mH, C0=2.2mF, Output voltage V_o~ 400 V, Output power P_o~ 2.25 kW, Switching frequency = 10kHz.

The input PV voltage is fed to the boost converter. When the output power changes, the battery balances the power between the input source and the load. Thus the load voltage is always tightly controlled. Fig.9(a) shows the output voltage,Fig.9(b) shows the output current and 9(c) shows the power waveforms, where an output voltage of 400V and a power of around 2kW was obtained. Battery State of Charge(SOC) is also shown in Fig.9(d).When the PV output is less than the load requirement, battery SOC is decreasing implying that the battery is discharging. After sometime, the battery SOC is increasing implying that the battery gets chargedwhen the PV output is more than the load requirement.

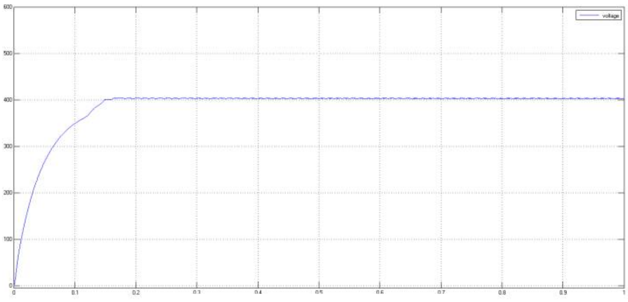

Fig.9(a) Load voltage

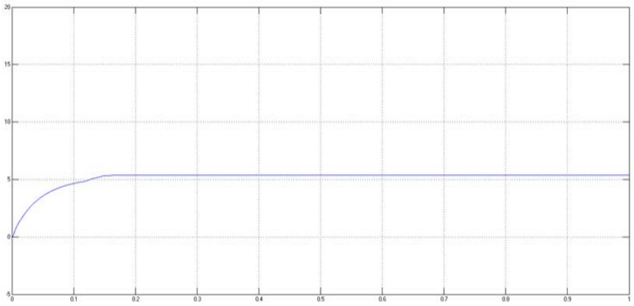

Fig.9(b) Output current waveform

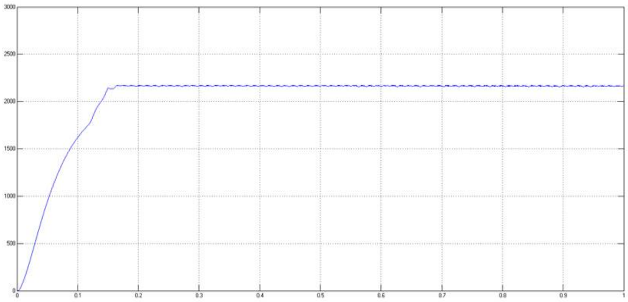

Fig.9(c) Output power

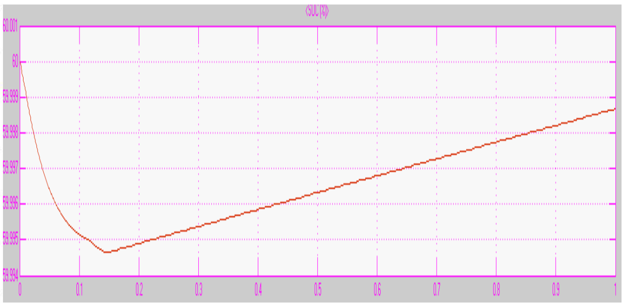

Fig9(d) Battery SOC

VII. CONCLUSION

A Single stage single inductor dual input-output dc–dc converter with PWM control is proposed for solar power management systems. It regulates one of the input voltages that is connected to the PV cells to track with the MPP voltage. At the same time, it generates a regulated output voltage to power the loading circuits. When the PV cells output power is insufficient for the load, the converter schedules the PV cells and the battery to power the load together. When the PV cells output power is larger than the load requirement, the converter diverts the surplus PV cells energy to charge the rechargeablebattery.When higher levels of solar irradiation are provided, the excess energy is stored in the battery. With the flexibility it offers, with an input source, an energy storage system, the proposed converter is a preferred candidate for industrial applications particularly when an energy storage system is to be integrated with the solar PV or the wind generation system.

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