ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

IJIREEICE

International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering

nCORETech 2017

LBS College of Engineering, Kasaragod

Vol. 5, Special Issue 1, March 2017

Dual Output Power Management Unit for a PV Battery Hybrid Energy System

Aswathi.S[1], Nimitha Gopinath[2], Dr. Devi.V[3]

M. Tech Student, EEE Dept, NSS College of Engineering, Palakkad, India [1,2]

Professor, EEE Dept, NSS College of Engineering, Palakkad, India[3]

Abstract: As we are aware energy from the environment is theoretically unlimited but the instantaneous harvested power varies with the environmental conditions and also the energy harvesting mechanism have to utilize the environmental energy fully. Power management circuits have to be built which will track the status of environmental energy and can extract the maximum power from the energy transducer. But due to environmental energy status and the energy harvesting mechanism, the real time harvested electrical power may be insufficient to drive the load. In order to guarantee the correct operation of any system, hybrid supplies were proposed where the system was powered by 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. A method with a single inductor dual output DC-DC converter is proposed with proper power management

Keywords: Dual input, DC-DC converter, multiple output, MPPT.

I. INTRODUCTION

Renewable energy resources exist over wide geographical areas, in contrast to other energy sources, which are concentrated in a limited number of countries. Rapid deployment of renewable energy and energy efficiency is resulting in significant energy security, climate change mitigation, and economic benefits. It would reduce environmental pollution such as air pollution caused by burning of fossil fuels and improve public health. It can reduce premature mortalities due to pollution and save associated health costs. Renewable energy sources, that derive their energy from the sun, either directly or indirectly, such as hydro and wind, are expected to be capable of supplying humanity energy for almost another 1 billion years, at which point the predicted increase in heat from the sun is expected to make the surface of the earth too hot for liquid water to exist.

Photovoltaic (PV) energy system is one of the most important sources of renewable energy over the past few years. Due to the unstable output voltage and power the PV cell cannot be directly connected to electrical device. The PV cell's output current and voltage vary with the light intensity and temperature. Furthermore, under certain environmental condition, the PV cells' operating voltage and current are affected by the load impedance. There is an optimum value for the PV cell's operating point that generates maximum power under certain environmental condition. This operating point is called the Maximum Power Point (MPP).

A lot of research was done previously in the area of PV power management. Different architectures were presented to interface both battery and PV cells with the load, using single and multiple DC-DC converters. The battery is used to absorb or supply any surplus or deficit power at the load.

Here a power management unit for PV-battery system, together with an algorithm for implementation of DIMO is proposed. This will provide dual DC power supplies using a single inductor.

II. POWER MANAGEMENT UNIT

Power management unit efficiently direct power to different components of a system. It is especially important for devices that rely on battery power. By reducing and controlling power to the components a good power management system can double or triple the lifetime of a battery.

A. Conventional power management unit

In prior researches, a DC-DC converter was used as the direct load to match with the MPP by adjusting the switching duty cycle of the converter. When the converter regulates the output voltage of the PV cells to the MPP voltage, the output voltage of the converter, which is determined by both the converter's input voltage and the switching duty cycle, varies greatly. The unstable converter output cannot be used to power the application directly, and 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. For the system operation, if the application requires a supply voltage different from the battery voltage, a second voltage converter is needed to generate the required supply as shown in Fig. 1. If a linear regulator is employed in the second power stage, the power overhead is large. Works utilizing another switching mode DC-DC converter in the second stage. contains two DC-DC converters. The additional electrical components such as power transistors and inductors increase the system volume and cost. Power overhead of two DC-DC converters and round trip efficiency of the rechargeable battery increases the overall system power loss.

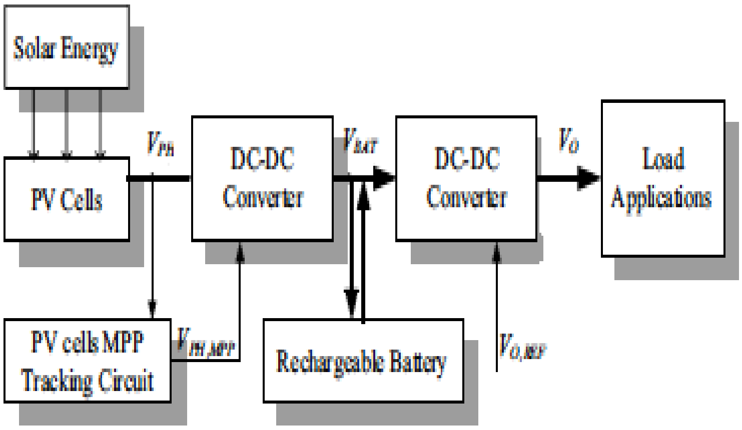

Fig. 1. Conventional Solar Power Management System

B. Proposed Solar Power Management System

Here a DIMO converter is used to interface the PV module and battery with the loads. The converter can operate in different modes such as, Dual Input Dual Output (DIDO) mode, Single Input Triple Output (SITO) mode and Single Input Dual Output (SIDO). The DIDO mode is used to supply power from both PV module and battery. The SITO mode enables the converter to regulate the outputs and charge the battery as well and the converter is able to operate in the Single Input Dual Output (SIDO) mode for a battery independent operation.

Based on the load demand and available PV power the digital controller selects the converter mode of operation. The controller makes the converter to operate at the MPP. There are several methods for Maximum Power Point Tracking(MPPT) such as Perturb and Observe Maximum Power Point method, Incremental conductance method, Current sweep method, Fill factor method, Fractional open circuit voltage method etc.Due to simple control structure and low power consumption the fractional open circuit voltage is implemented in the controller. This MPPT algorithm is based on the linear relationship between the MPP and the open circuit voltage.

$$V_{MPP} = K.VOC$$

The PV module's and converter's output voltage are used as feed back signals to the controller. Analog to Digital Converters (ADCs) senses these signals. A switch is provided to connect the PV module and the system inorder to enable the controller to disconnect the PV module and calculate the open circuit voltage to estimate MPP. A Linear Drop-Out (LDO) voltage regulator is used to step down the PV module's voltage and supply the controller.

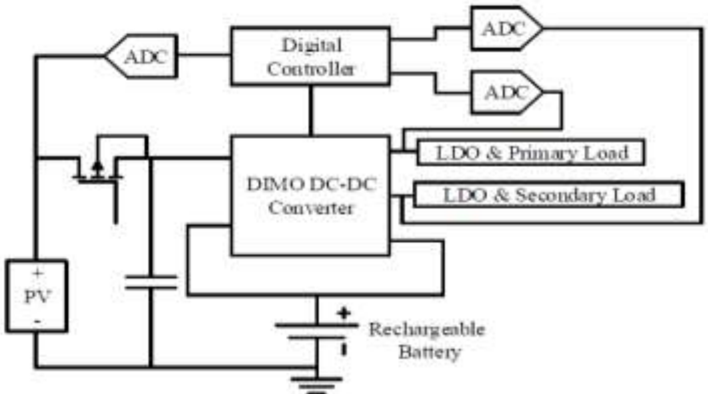

Fig. 2. Proposed Solar Power Management System

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II. DIMO DC-DC CONVERTER

The circuit diagram of the proposed converter is shown in Fig. 3. The converter consists of five MOSFETS (Q_1 to Q_5) and two diodes (D_1 and D_2).the converter is connected to PV panel via Q_1 to estimate MPP. The average conduction current of any switch is directly proportional to its ON time (T_i).

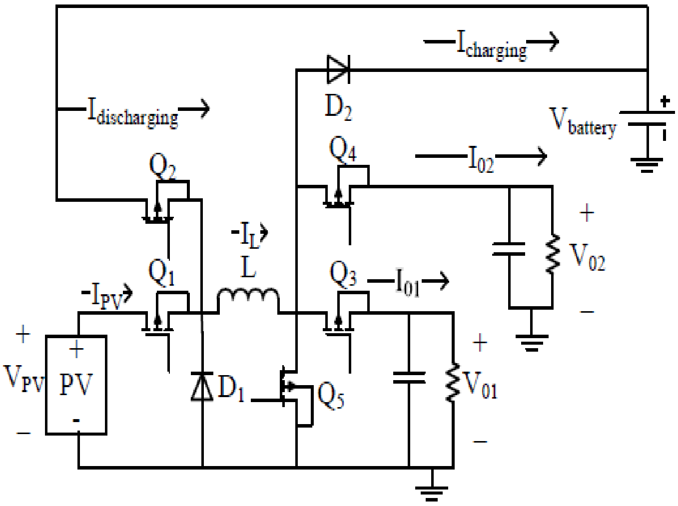

Fig. 3. The single inductor DIMO DC-DC converter

The average power supplied by the battery is directly proportional to the ON time of 'Q_2'. Similarly, the power supplied to the loads and the battery is directly proportional to the ON time of 'Q_3', 'Q_4', and 'D_2'. On the other hand, the PV module supplies its maximum power only at the MPP. Thus, increasing the PV's output current beyond the MPP will decrease the PV power. Accordingly, there is an optimum value for the ON time of 'Q_1' that tracks the MPP The switching period of the converter is divided into two phases. In the first phase, the input energy will be stored in the inductor. Whereas in the second phase, the inductor will supply all the stored energy to the outputs and no current will be drawn from the inputs. The proposed time multiplexing scheme provides the appropriate path for the inductor's current to flow during each phase.

Phase 1: In this phase through the inductor a closed path between the inductor and ground is established. Hence, the input current is allowed to flow and store energy in the inductor. Inorder to oppose the input current a voltage drop is induced across the inductor. Thus the inductor current increases linearly. The first phase is achieved by allowing 'Q_1', 'Q_2', and 'Q_5' to conduct current. Inorder to avoid any interactions between the input sources 'Q_1' and 'Q_2' are not allowed to conduct current simultaneously.

Phase 2: The inductor is disconnected from the input source during this phase and 'Q_5' is turned OFF. Hence, the inductor starts to resist the decrease in current by reversing its polarity, increasing the induced voltage to turn on 'D_1', and supplying the stored energy to the outputs. Thus in this phase the current flowing in the inductor decreases linearly. Inorder to independently control the load voltages 'Q_3' and 'Q_4' are not allowed to conduct current simultaneously. If the battery's voltage is higher than the steady state load voltages then 'D_2' conducts current only if 'Q_3' and 'Q_4' are turned OFF.
The energy stored in the inductor during the first phase must be equal to the energy released from the inductor during the second phase for steady state operation,i.e the inductor's current at the start and the end of the switching period must be equal. As all inductor based converters; the inductor's current can be continuous or discontinuous. In the Discontinuous Conduction Mode, 'D_1' prevents the inductor's current from decreasing below zero.

III.POWER MANAGEMENT CONTROLLER

The controller consists of 3 phases as shown in Fig. 4.
1. MPP estimation phase
2. Primary output regulation phase
3. Secondary output regulation phase

The system starts up with only the primary load connected to the converter.

MPP Estimation phase: During this phase the external transistor connecting the PV panel and the system is turned OFF. To estimate the MPP voltage the PV's open circuit voltage is measured. This phase is performed until the PV's operating voltage is not equal to the estimated MPP. In order to avoid oscillation around the MPP, a range for the estimated MPP [V_{MPP}-Δ to V_{MPP}+Δ] is introduced. This phase is shown in Fig. 4. The PV voltage is increased by decreasing the PV current (T_1--) and vice versa. 'T_2', 'T_3', or 'T_4' must be recalibrated after varying 'T_1' to fit the converter's switching period. A delay is introduced to enable the system to sample the steady state voltages after varying the ON time of any switch.

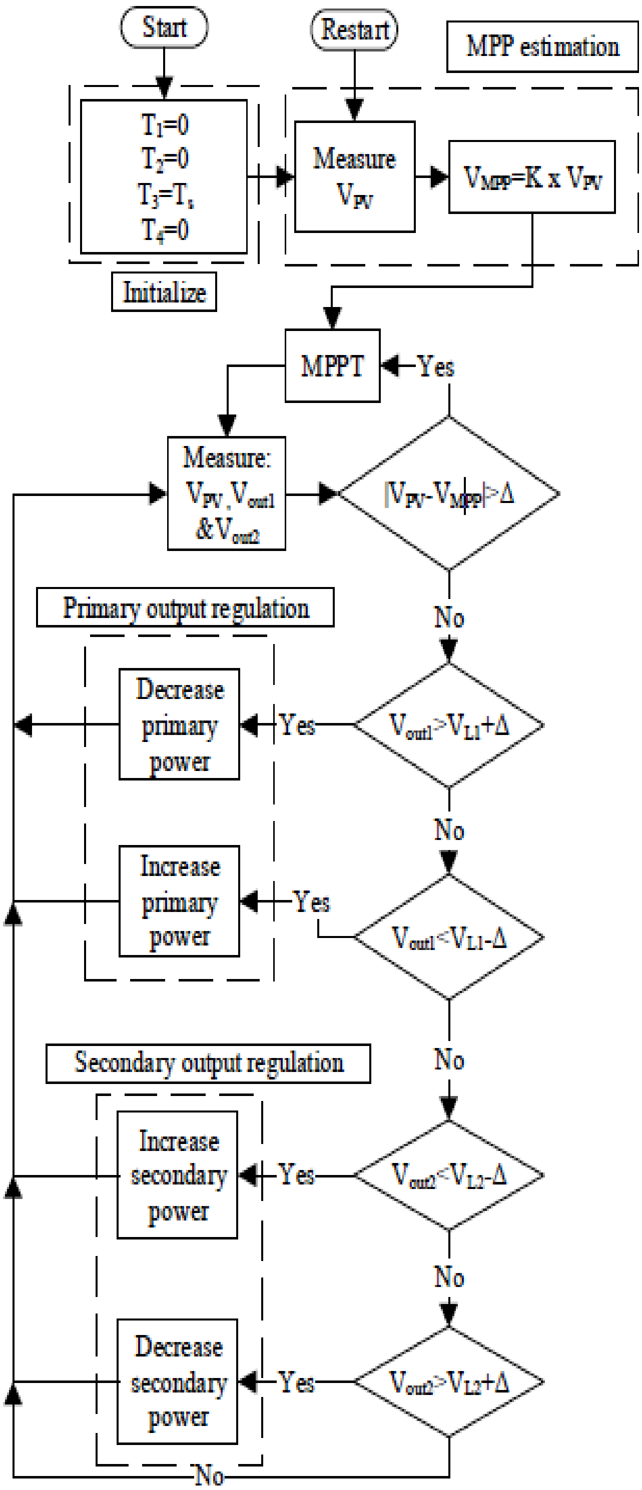

Fig. 4. Flow chart of the power management controller algorithm

After reaching the MPP, the algorithm attempts to regulate the output voltages starting by the primary then secondary output. Furthermore, the algorithm is allowed to restart the "MPPT" in order to readjust the PV's operating point. In the CCM, the PV's output current depends on the ON time of 'Q_1', and the inductor's average current. The average current flowing in the inductor will change due to any variation in the load or the amount of current supplied by the battery. Accordingly, the PV's output may change during regulating the outputs even if the environmental condition is constant.

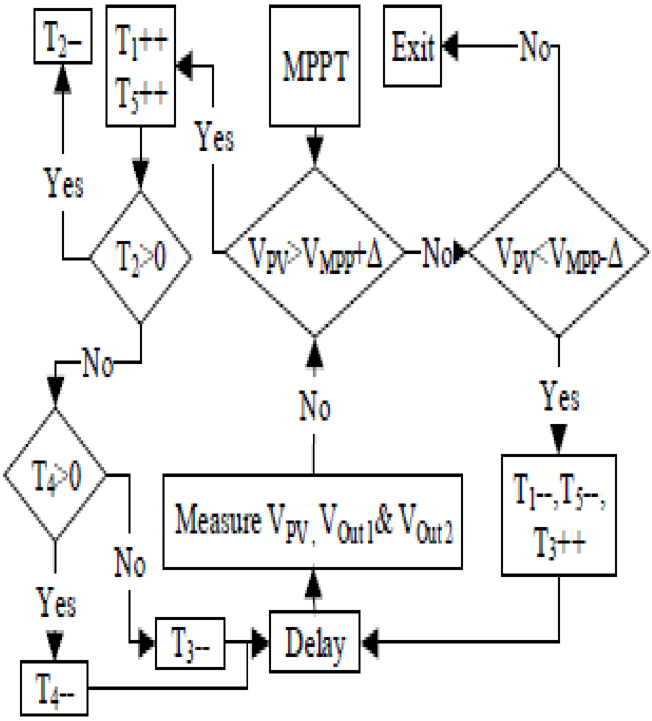

Fig. 5. MPP estimation phase

Primary output regulation phase: In "Primary output regulation" phase, in case the primary power is higher than the load demand then the system will route the surplus power to the secondary output as shown in Fig. 6.Inorder to decrease the primary power the turn on time of T_3 is decreased and turn on time of T_4 is increased thus delivering more power to the secondary load. On the other hand, the shortage of power at the primary output is compensated as shown in Fig. 7.in this phase if $V_{out\,1} < V_{L1}$ and $V_{out\,2} > V_{L2}$ then turn on time of T_4 is decreased and T_3 is increased thus delivering required power to primary load.

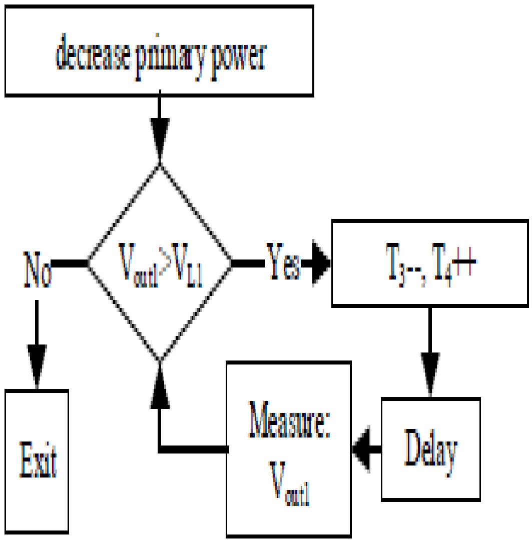

Fig. 6. Decrease primary power phase

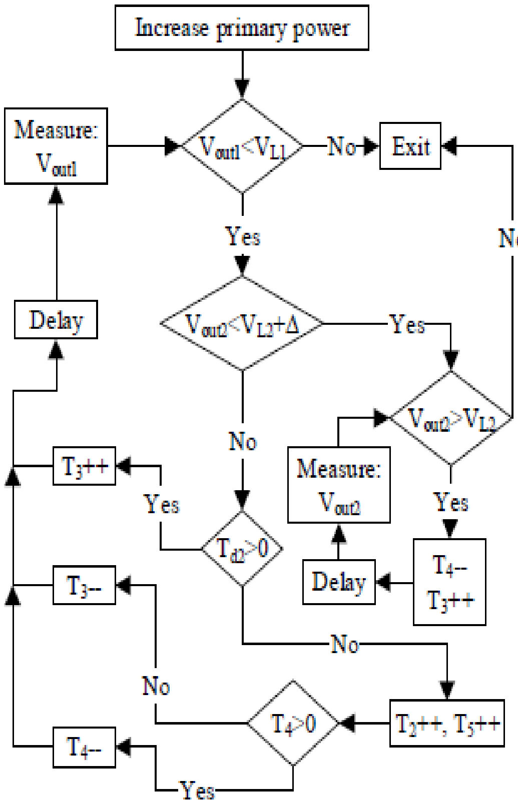

Fig. 7. Increase primary power phase

Secondary output regulation phase: In the "secondary output regulation" phase, the shortage of power at the secondary output is compensated as in Fig. 8. If T_2 is turned on and $V_{out\,2} > V_{L2}$ then the turn on time of T_2 and T_5 are decreased and T_3 is increased thus delivering more power to secondary load.

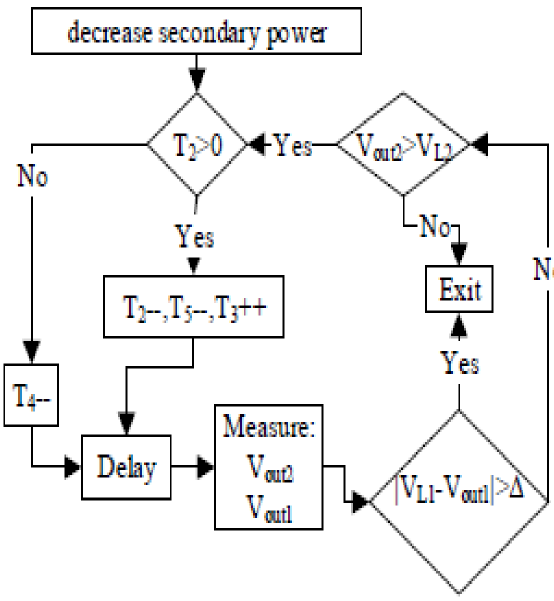

Fig. 8. Decrease secondary power phase

The excess power at the secondary output is managed as shown in Fig. 9. To achieve this the turn ON time of T_2,T_5,T_3 and T_4 are varied depending on the values of $V_{out\,1}$,$V_{out\,2}$,V_{L1} and V_{L2}.

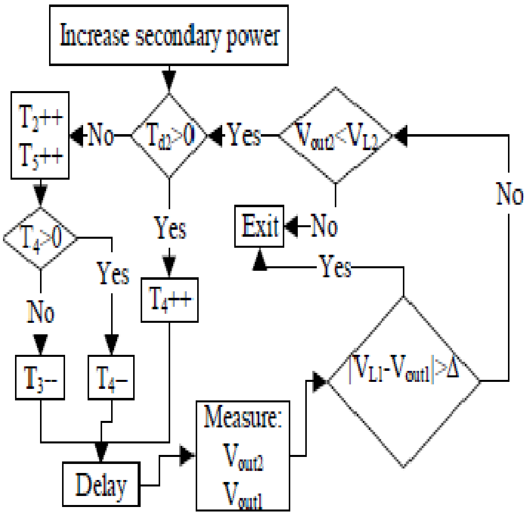

Fig. 9. Increase secondary power phase

A delay is introduced to enable the system to sample the steady state voltages after perturbing the ON time of the switches.

IV. CONCLUSION

Photovoltaic (PV) cells have showed a significant contribution in the generation of electricity over the past few years. However, the PV cells cannot be connected directly to an electrical device; due to the unstable output voltage and power. The PV cell's output current and voltage vary with the light intensity and temperature. A lot of research was done previously in the area of PV power management. Different architectures were presented to interface both battery and PV cells with the load, using single and multiple DC-DC converters .The battery is used to absorb or supply any surplus or deficit power at the load. A dual output power management unit has been proposed for PV-battery hybrid system. A single inductor DIMO DC-DC converter was employed in the system and a power management controller is proposed.

ACKNOWLEDGMENT

Authors are thankful to NSS College Of Engineering Palakkad for all the support provided for the completion of this paper.

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