Development of a Hybrid Solar Power Management Unit for Mobile Platforms

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ABSTRACT

.A hybrid power management unit was developed to interface photovoltaic energy to loads, and meeting its challenges such as variation of power, unregulated voltage and limited power. the unit implements a Maximum Power Point Tracking (MPPT) to maximize the output power under environmental variations. The power management system proposed applies photovoltaic harvested energy effectively to mobile devices. It mainly consists of an MPPT block and a Power Distribution Control Unit (PDCU). Different cases of operation exist depending on the availability of power, load needs, and battery state of charge. Analysis and simulation results are provided to demonstrate system functionality and sensitivity.

Keywords: Photovoltaic, Energy Harvesting, MPPT, Battery Charging, Power Management Unit, Mobile platforms.

I. INTRODUCTION

Area, performance, cost, reliability, and testability are typical concerns in micro-electronics research. The booming market of mobile computing systems demands longer battery life and higher performance. Freedom from power outlets is a big choice metric of a device. A complex design means higher power consumption, while users demand longer battery life. To increase power outlet independence, two families of methods exist. The first category addresses technology and design issues such as system architecture, voltage scaling, frequency scaling, and usage of efficient technologies, while power harvesting on the go is virtually an unlimited battery life. Photovoltaic are the dominant energy harvesting source as it has a higher energy density compared to other "ambient" harvesting mechanisms.

A Power Distribution Control Unit (PDCU) is developed in this work that allows an efficient management of the generated power of the harvested solar energy. The system allows battery independent operation when enough energy is harvested. The excess power would then charge the battery. In case of insufficient power, the harvesting system would supply as much power as it can and complement it from other sources. The literature is reviewed in section II. The modeling is in section III. In section IV, the results are presented. Conclusion is shown in section V.

II. STATE OF THE ART

Basic mobile devices include a battery and a DC-DC regulator. Half way solutions exist to leverage the conventional infrastructure. A solution is to install a larger battery bank and charge it by the solar cell separately. The output energy from the photovoltaic array is used to charge a battery, and then the stored energy can be used later.Carlos [1] developed a solar charger for portable devices with Li-ion batteries. A simple maximum power point tracking algorithm was used. The battery is charged by the photovoltaic source and the load power is drawn from the battery. Simple and low cost charger, but the efficiency of this system is low. Li et al. [2] presented a simple photovoltaic battery charger with three modes for charging the battery. The modes are current limited charging, MPPT charging and constant voltage charging. The selection between these modes is done automatically using a smart switch. In this work, a good utilization of the photovoltaic power is achieved in addition to a good protection of the battery.

Other research [3] was done to enhance the performance of battery charging process. The battery is disconnected from the load till it is fully charged. The load is then connected to the battery. The battery is disconnected from the PV source when it is fully charged. This mechanism provides a good control of the battery, prevention of overcharging and undercharging and enhances the battery lifetime. The load cannot operate or consume power during the charging periods of the battery and some solar power is lost during the discharging periods. Dual battery storage system is an extension, only one is active at any instant of time. The addition of an extra battery solves the power problem. However, it contradicts the smaller size and weight required by users [4]. Battery charging under PV source was addressed in [5] and [6] where the MPPT was applied to minimize the charging time. Different topologies and power sensing schemes for PV MPPT control with microcontroller design are discussed in [7], [8] and [9]. System power management on multisource renewable energy is getting more attention [10].

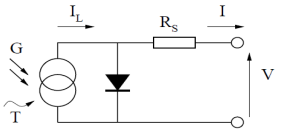

Fig.1 Electrical Model of PV

A diode and a current source that is a function of light as shown in Fig.1 is the simplest model for a PV source. The current (I) supplied by PV can be modeled using the voltage (V) at its terminal using relationship (1). The PV model simulation for the current-voltage relationship and power-voltage graphs for the PV model with the power graph as well are shown in Fig.2 [11].

$$I = I_L - I_o\,(e^{\frac{q(V+IRs)}{nKT}} - 1) \qquad (1)$$

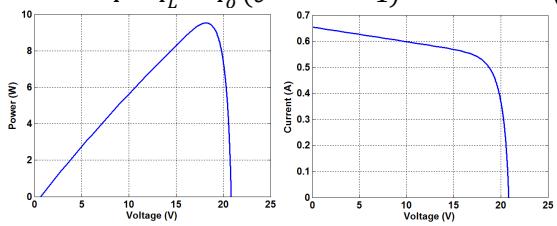

Fig.2 I-V and P-V curves of Simulated PV Model

III. POWER DISTRIBUTION CONTROL UNIT MODELING

The "Source PM Control Unit" (SPMCU, Fig.3) provides battery charging and new features to support the renewable energy to effectively distribute and partition the power. Functional blocks in SPMCU consist of maximum power tracking circuit and algorithm, the battery charger and the power distribution control unit (PDCU). The PDCU job is two-folds: identify the availability and type of power sources and control power distribution.

The battery model can be a simple DC offset voltage, in addition to a large capacitor that can be charged or discharged to mimic the behavior of a battery [12]. The power regulator used here is a simple buck converter responsible of controlling current and voltage supported by PV source.

The MPPT block implements "Perturb & Observe"; the power is measured and saved as old power. A new power value is captured and compared with the old power, and the duty cycle is adjusted until the maximum power point is reached [13], [14], [15].

The easiest way to model a load with a specified power is by use of a voltage regulator with a resistive load. The power consumed at the output node is now fixed and can be obtained by $P_{out} = V_{ref}^2/R_{out}$.

If the solar power is not enough to supply the load power, the remaining power should be supported by the DC external or the battery. So, a mixing mechanism should be introduced in the input side to combine the powers (Fig.5). Source 1 is connected to the load during duty cycle (D) and source 2 during the complement of duty cycle (D') in a single switching period, where: D + D' = 1. A low pass filter is used after the switch to get the average of the signals at the output node. To analyze this architecture, start with basic equation (2) that states the power at the load side must be equal to the summation of power from the two sources.

$$P_{out} = P_1 + P_2 \qquad (2)$$

So,

$$I_{out} \cdot V_{out} = I_1 \cdot V_1 + I_2 \cdot V_2 \qquad (3)$$

And hence I_1 and I_2 are relating to I_{out} with the same relations as buck converter so, $I_1 = D \cdot I_{out}$ and $I_2 = D' \cdot I_{out}$. So, equation (3) can be rewritten as equation (4).

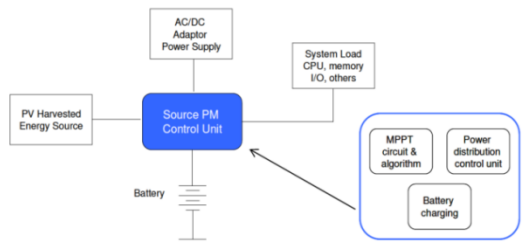

Fig.3 Hybrid System Power Configuration under PV Harvested Energy

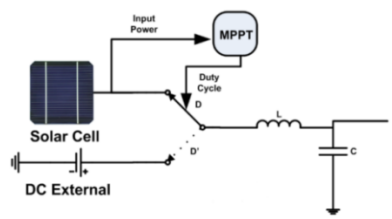

Fig.4 The Proposed Mixing Technique

$$I_{out} \cdot V_{out} = D \cdot I_{out} \cdot V_1 + D' \cdot I_{out} \cdot V_2 \qquad (4)$$

Thus, equation (5) shows that each source is contributing to the output voltage depending on the timeslot assigned to each source.

$$V_{out} = D \cdot V_1 + D' \cdot V_2 \qquad (5)$$

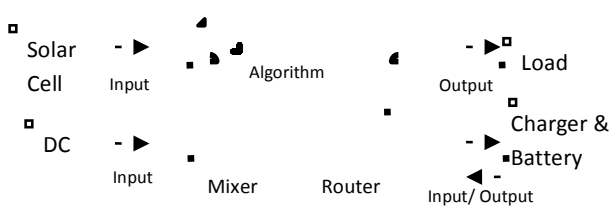

Fig.5 Our PDCU unit has two input power sources solar cell and DC external source. It aliments the Load with the required power.

If for example, a resistive load was used then the power supplied by the two sources be as shown in equation (6) & (7).

$$P_1 = V_1 \cdot D \cdot I_{out} = V_1 \cdot D\,\frac{V_{out}}{R} = V_1 . D\,\frac{V_1 \cdot D + V_2 \cdot D'}{R} \qquad (6)$$

$$P_2 = V_2 \cdot D' \cdot I_{out} = V_2 \cdot D'\,\frac{V_{out}}{R} = V_2 \cdot D'\,\frac{V_1 \cdot D + V_2 \cdot D'}{R} \qquad (7)$$

The mixing operation is implemented in the photovoltaic buck converter. The buck converter is

responsible for tracking the maximum power of the photovoltaic source with a duty cycle (D) and the complement of this signal (D'is used to connect the secondary source.

In the router block, each load is allocated a certain portion of the incoming power based on the duty cycle (D) granted to the load. To increase the amount of power fed to a load, its duty cycle D is increased. Due to the switching between loads, a low pass filter is used as described in Fig.6. To calculate the input resistance (*Req*), start with this equation (8).

$$P_{in} = P_1 + P_2 \tag{8}$$

Then substitute with power as function of voltages to get relation (10).

$$\frac{Vin^2}{R_{eq}} = \frac{{Vo_1}^2}{R_1} + \frac{{Vo_2}^2}{R_2} \tag{9}$$

And since V_{o1} & V_{o2} can be related to *Vin* through these relations: $Vo_1 = D \cdot Vin \text{ and } Vo_2 = D' \cdot Vin$

$$\frac{Vin^2}{R_{eq}} = \frac{D^2 \cdot Vin^2}{R_1} + \frac{{D'}^2 \cdot Vin^2}{R_2} \tag{10}$$

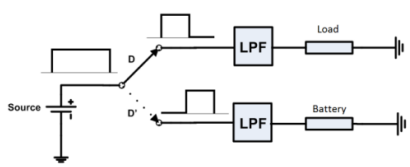

Fig.6 Routing Power to Many Branches

Then, the Input resistance can be found by relation (11).

$$\frac{1}{R_{eq}} = \frac{D^2}{R_1} + \frac{{D'}^2}{R_2} \text{ and } \frac{1}{R_{eq}} = \frac{1}{R_1/D^2} + \frac{1}{R_2/{D'}^2} \tag{11}$$

The battery and the load are setup in a parallel construction. There are two contradicting equations for the value of output voltage node (V_{out}). From equation (12), the value of duty cycle (D) should be small as voltage of solar panel (V_{pvm}) is large.

$$V_{Battery} \cong V_{out} = D \cdot V_{PVm} + D' \cdot V_{DC} \tag{12}$$

Consequently, the MPPT will be hampered in its search for the duty cycle and the maximum power of solar cell won't be tracked. If the system is working using a solar source only without using the mixer, then the battery can be connected directly, and the maximum power obtained by the solar source is supplied to the load and the battery. On other hand, if the solar source is supplying the power with the help of the DC source, then a voltage regulator before the battery is needed. In this case, the battery is isolated from the mixer output voltage node. The final solution is proposed in Fig.7.

IV. RESULTS

Case 1: PV and DC source supply load and battery

The load power is greater than the photovoltaic power and the battery is not charged. The DC source complements the required power for load and battery. The load is running at nearly 11 Watts.

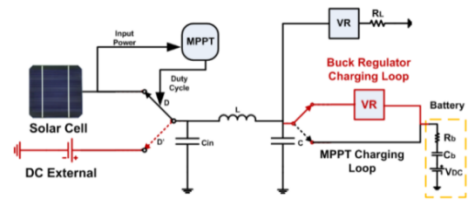

Fig.7 The Final Proposed System

The voltage regulator of the battery charges it by maintaining the voltage at 4.8V. The maximum photovoltaic power of 9.5Watts is tracked at duty cycle of 0.08. In Fig.8, all the values of the power supplied and consumed are shown. After tracking, the photovoltaic source supplies 9.5Watts and the DC source supplies the rest while the battery is charged by power up to 28 Watts.

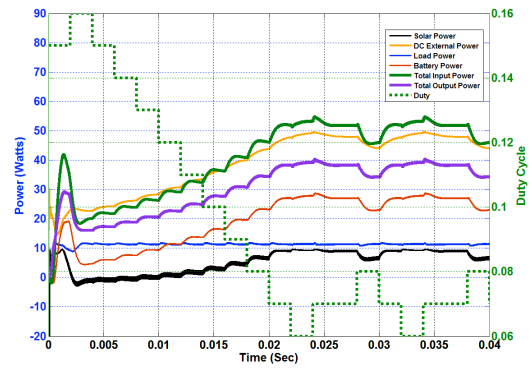

Fig.8 Power curves for case I

Case 2: PV and DC source supplies load

In this case, only the load is supplied by the solar power and the remaining power is coming from the DC source. The maximum power of the solar source is tracked at Duty cycle of 0.37. Fig.9 shows the variation of solar power with changing the duty cycle to reach the maximum power. It is shown that the power supplied by the DC source decreases with increasing the solar power to maintain the power supplied to the load fixed at nearly 11Watts.

Case 3: PV and Battery supplies load

In this situation, the solar power is not enough to supply load power and the DC source is not plugged in. Therefore, the battery along with the solar source is used to supply the required power. This case is similar to case 2; the battery power will decrease as the solar power is increasing to track the maximum power as shown in Fig.10.

Case 4: PV supplies power for load and Battery

In this case, the load is consuming low power so the solar power will be enough to support the load power, in addition to charging the battery. The load's consumption is 1Watts. The remaining power from the photovoltaic source (7Watts) will be used to charge the battery as shown in Fig.11.

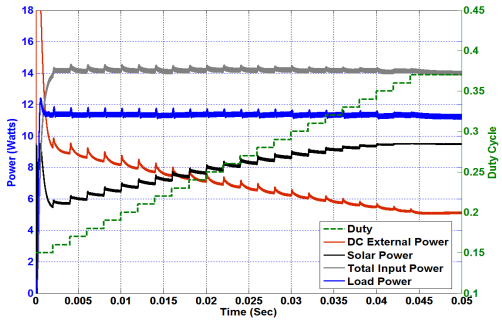

Fig.9 Power curves for case 2.

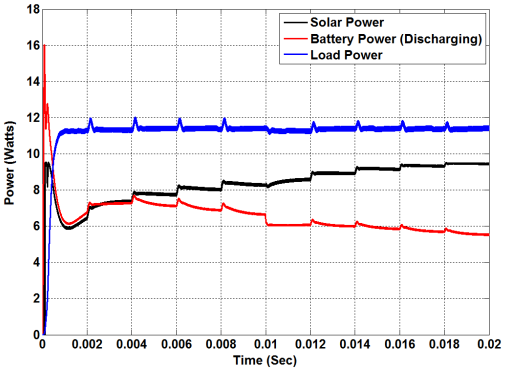

Fig.10 Power curves case 3.

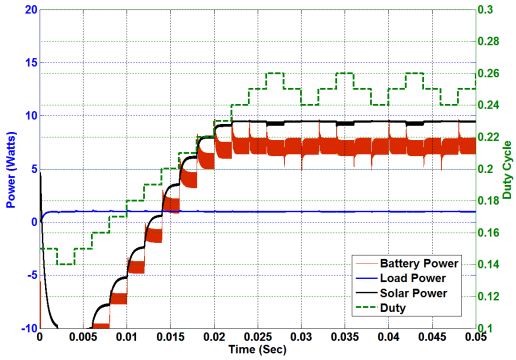

Fig.11 Power curves for case 4

V. CONCLUSIONS

Photovoltaic (PV) energy provides an alternative power source to a conventional power sources due to its availability. Applying PV harvested energy into mobile and handheld platforms will enhance the performance and increase battery life time. A new power management scheme was developed for mobile and handheld platforms. The proposed system was simulated at all different cases of operation. Simulations showed that the power management system utilizes the photovoltaic power to support the load power and to charge the battery in case of enough photovoltaic power. In addition, the power management system uses a mixing technique between the photovoltaic source and a secondary source in case of insufficient photovoltaic power to provide the required load power. The secondary source can be the battery, if it is charged, or a DC source that can be plugged into the whole system. Implementing a full PDCU unit and integrating it with the whole system will enhance the overall performance of the PV based system and provide a simple “plug-and-play” model to apply the photovoltaic power for mobile applications.

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