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.
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].

\[
I = I_L - I_D (e^{\frac{q(V+IR)}{nkT}} - 1) \tag{1}
\]

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, 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).

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.

\[
P_{out} = P_1 + P_2 \tag{2}
\]

So,

\[
I_{out} \cdot V_{out} = I_1 \cdot V_1 + I_2 \cdot V_2 \tag{3}
\]

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).

\[
I_{out} \cdot V_{out} = D \cdot I_{out} \cdot V_1 + D' \cdot I_{out} \cdot V_2 \tag{4}
\]

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

\[
V_{out} = D \cdot V_1 + D' \cdot V_2 \tag{5}
\]

\[
P_1 = V_1 \cdot D \cdot I_{out} = V_1 \cdot D \cdot \frac{V_{out}}{R} = V_1 \cdot D \cdot \frac{V_1 + V_2 \cdot D'}{R} \tag{6}
\]

\[
P_2 = V_2 \cdot D' \cdot I_{out} = V_2 \cdot D' \cdot \frac{V_{out}}{R} = V_2 \cdot D' \cdot \frac{V_1 D + V_2 D'}{R} \tag{7}
\]

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 \( R_{eq} \), 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).

\[
\frac{V_{in}^2}{R_{eq}} = \frac{V_{o1}^2}{R_1} + \frac{V_{o2}^2}{R_2} \tag{9}
\]

And since \( V_{o1} \) & \( V_{o2} \) can be related to \( V_{in} \) through these relations: \( V_{o1} = D \cdot V_{in} \) and \( V_{o2} = D' \cdot V_{in} \)

\[
\frac{V_{in}^2}{R_{eq}} = \frac{D^2 V_{in}^2}{R_1} + \frac{D'^2 V_{in}^2}{R_2} \tag{10}
\]

Fig.6 Routing Power to Many Branches

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

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

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 (\( V_{pm} \)) is large.

\[
V_{Battery} \equiv V_{out} = D \cdot V_{pm} + D' \cdot V_{DC} \tag{12}
\]

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.

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 11 Watts.

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 supply load power, in addition to charging the battery. The load’s consumption is 1 Watts. The remaining power from the photovoltaic source (7 Watts) will be used to charge the battery as shown in Fig.11.
Photovoltaic (PV) energy provides an alternative power source to 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.

REFERENCES


