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A sustainable power architecture for mobile computing systems

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Abstract

Extension of battery life and dissipation of heat from components with high power density are significant challenges in mobile computing platforms. A power architecture suitable for the integration of low voltage, low power renewables into the bus is described in this paper as an innovative, green approach to help both of these issues. The architecture is both scaleable and flexible in order to accommodate the intermittent nature of the renewable energy sources. A new charge pump based boost scheme with fully asynchronous control is utilized as the enabling building block to meet the stringent power dissipation and efficiency requirements of this application. The resulting power electronics do not contain magnetic components and can be integrated into an LSI chip.

Keywords: Asynchronous control; Charge pumps; Mobile computing; Renewable sources; Sustainable power management

1. Introduction

Extension of battery life to a full workday while preserving high mobility is a fundamental concern for Thin and Light computing platforms [1]. Critical development areas have been identified in the industry such as energy efficient cooling (the need to dissipate over 50 W in a size constrained box) [2], higher density energy sources, fast renewable sources, and enhanced power and thermal management features [3]. Much work has been done on silicon power efficiency techniques, power management features, and new costly cooling technologies. An approach that has not been thoroughly investigated is to model each platform as an isolated island where access to the resources of the "mainland" entails high cost. This dictates the effective use of energy sources in the vicinity of the computer. In a separate paper, the authors have examined fundamental issues related to the integration of thermoelectric (TE), photovoltaic (PV) and piezoelectric power modules for battery life extension in mobile computing platforms [4].

Power conversion efficiency has been identified as a significant barrier in the feasibility of the integration of these low power renewables from low, intermittent voltage levels to the system dc bus voltage required to charge a battery. This paper will present the implementation of an innovative charge pump boost converter for integration with low power renewables, resulting in enhancements to mobile power architectures for green notebook designs. At the heart of the proposed power conversion system is an asynchronous charge pump designed to achieve net battery life benefits.

2. Integrated sustainable power management

The motivation for integrating renewable sources in a mobile computing platform is a direct consequence of the current design trends in thin and light notebook systems. These can be summarized as

(i) *Longer battery life*. New technologies [1] drive energy efficient operation and longer lasting batteries.
(ii) *Performance on demand*. The performance is expected to scale up to desktop computing capabilities over time.
(iii) *Compact design*. Systems become thinner, smaller, and lighter in order to enable mobility which makes it challenging to cool high power density components.

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Table 1
Current, voltage, and power range for TE and PV integration

Design range	*I* (mA)	*V* (V)	*P* (mW)
TE	0–50	0–0.5	0–25
PV	1–100	0.5–5	0.5–500

(iv) *Cost*. Mainstream mobile computing platforms need to be cost aware in order to enable large volumes. This requirement prevents expensive solutions from being deployed to address issues associated with (i)–(iii).

In response to (i) above, dynamic system management is necessary and common in high-performance platforms to reduce power demands, and dynamically trade off performance against power. Among the response mechanisms are voltage and frequency scaling, decode throttling, speculation control, and *I*-cache toggling. For example, the frequency and voltage scaling scheme reported in [5] yields a 50% power reduction but limits the performance impact to 20% for the duration of the event. It is expected in the future that systems will be designed to respond dynamically to the requirements of a particular application for maximum efficiency and reliability, as exemplified by fan speed control [6], and Enhanced Intel Speedstep® [7] technologies.

2.1. Use of renewables for power management

Scavenging energy from renewable sources in the vicinity of the computing system is an elegant method for saving power and thus extending battery life. The problem with small-scale renewable sources is the low efficiency associated with significantly stepping up the low-voltage output to allow integration with the system battery. In addition, there may not be any net benefit after accounting for the power dissipation in the required converter. The problem is compounded if scalability to multiple sources with different characteristics and intermittent properties are considered.

Two renewable energy sources in particular are considered viable for enhanced power management due to favorable characteristics in extracting mWatts to thousands of mWatts depending on the conditions: thermoelectric (TE) and photovoltaic (PV). Prior work has shown these to be the power sources with the highest potential benefits as determined from commercially available bulk modules [4]. As reported, the use of a readily available low cost, low efficiency PV module could extend the battery life by approximately 5%, and the use of a state-of-the-art, high efficiency, multi-junction PV module could extend the lifetime by up to 25%.

Notebook integrated TE and PV output power specifications are summarized in Table 1 per module. It can be recognized from the table that achieving the goal of net battery life benefit will require setting system ON/OFF thresholds for the low end of the power range, so that power scavenging is inactivated when power electronics consume higher power than generated power. Voltage, current, and power always scale together for TE and PV, allowing only one of these parameters (e.g. voltage) to be utilized in ON/OFF thresholds.

The two types of energy sources have different integration issues, but share the fact that depending on the operating conditions under which the mobile computing platform is used (e.g., variable CPU performance demand, variable light intensity) variable voltage levels are produced by the integrated power generation module. Specifically, low light levels will generate low power levels from PV modules, and low CPU performance demand can decrease the heat produced by the system which will, in turn, lead to low TE module voltages. A proposed system would therefore need to detect different voltage levels and dynamically scale the power electronics in order to achieve the best efficiency.

A new approach is taken in this work with the goal of making energy from renewable sources available to the mobile computing system as a means for extending battery life. This approach also advances recent industry initiatives, like Energy Star [8], to design computer platforms with environmentally friendly characteristics. Some characteristics, which ensure that mobile platforms with sustainable power management are superior to the existing systems, are identified below:

(i) *Battery life assumptions*. Longevity should be improved by providing net charge directly to the system battery instead of powering up specific sub-systems (as opposed to the implementation in [9]). The generated power should be higher than the power dissipated in the power electronics interfacing with the renewable sources for net battery life benefit. Renewable sources like PV components should be enabled to scavenge energy even when the system is off. When the system is on, the renewable power should supplement both the externally supplied ac power (e.g. from the cord connected power supply) or the dc power from the battery. This is a highly desirable attribute for a truly green implementation.

(ii) *Performance assumptions*. It is not acceptable to degrade system performance as a result of integrating renewable sources. In fact any TE component used to scavenge thermal energy should operate in hybrid mode, as discussed in [10,11], in order to offset negative performance impact from reduced cooling capacity, and even improve performance when required by the system tasks.

(iii) *Size*, *cost*, *and scalability assumptions*. The added renewable components and associated power electronics should represent common technology for lowest cost. They should be scalable with system size. Power electronics should be compact, and easy to integrate into an LSI chip. Magnetic components should therefore be minimized or avoided.

3. New sustainable power architecture

In a conventional mobile power architecture, wall ac voltage is rectified to ∼19.5 V dc, which is further stepped down by dc/dc converters for system loads, as depicted in Fig. 1. The battery charger bucks down the voltage to ∼10.8–16.8 V depending on the charge state. When unplugged, the input to the dc/dc converters switches to the battery.