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Speed vs Efficiency and Storage Type in Portable Energy Systems

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Speed vs Efficiency and Storage Type in Portable Energy Systems

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Abstract. Portable power management systems must optimise power interfacing, storage and routing, to meet application specific functionality requirements. Two key aspects are reliability and efficiency. For reliable operation, it is required that powering on/off the system must occur in a planned manner. For efficient operation, it is desired that the system is powered for an optimal amount of time. maximizing its useful operational outcome per unit of energy consumed. This can be achieved by optimizing energy usage based on the anticipated energy income and power demand of duty-cycled power consumers. Both battery and supercapacitor storage can be employed to meet energy and power density demand, on both sides, and to enable fast transition from cold-starting to active power management. A simplified model is used to calculate the reliability of a simple solar-powered microsystem. The modelling of dynamically configurable interfacing and storage may enable a new generation of power management, providing reliable power from irregular and small energy sources.

1. Introduction

The management of energy delivery, storage and usage in wireless devices is critical for emerging IoT technologies, including mobile phones, wearable electronics, small electric vehicles and wireless sensor networks. Key performance aspects of portable power management include the efficiency of energy conversion and transfer, energy storage density, the ability to store and deliver energy at high rates (power density) but also the efficiency, speed and safety of energy transfer between storage media. Depending on the application, these requirements can be fulfilled by using more than one type of energy storage and a diverse range of power flow interfaces. In parallel, the exploitation of energy sources with challenging features such as low signal level and irregular availability is highly desirable, including indoor lighting, stray motion and stray heat flow. To regulate this increasingly multidimensional energy ecosystem, a holistic design approach is required [1]. In addition, the reliability of energy availability must be quantified.

In this paper, three important aspects of portable power management are discussed: the trade-off between fast versus efficient energy transfer, the use of combined battery and supercapacitor storage and the definition of a figure-of-merit for the quantification of portable power quality. A case study on solar energy availability is analysed against a deterministic energy demand scenario and a control – oriented approach for system level modelling and optimization is proposed.

2. Challenges in Portable Power Management

2.1. Speed vs Efficiency

In the case of energy transfer/transduction from one stored form to another, such as when charging a smaller portable system from a moderately bigger one or when using a fuel, the available energy is finite and it is reduced by usage. There, conversion and transfer efficiency is the main parameter of interest. In contrast, when exploiting a power source such as sunlight, or when using a practically infinite energy source such as the motion or heat of a large industrial machine to deliver energy to sensor systems, any energy that is not converted is practically lost. In such systems maximization of power delivery, instead of efficiency is desirable. This difference is illustrated in Fig.1 (left), using the equivalent output (R_{GEN}) and input (R_{PM}) resistance of the source and the target system respectively. The indices refer to a generator output resistance and the Power Management input resistance, corresponding, as an example, to a generator – power management interface. Maximum energy transfer efficiency is obtained when $R_{PM} >> R_{GEN}$, whereas maximum power transfer is obtained at $R_{PM} = R_{GEN}$.

While this model serves well as a general description of the two different cases, it must be noted that in generators such as solar cells, the output response to different loads may be non-linear and a more detailed circuit model is typically used. Overall, power management systems need to operate either at optimized efficiency or maximum power, depending on their position in the power supply chain, and also on specified usage priorities. As an example, if a portable device is to be charged by an also portable power bank, the choice between efficient and rapid energy transfer may depend on the available connection time window.

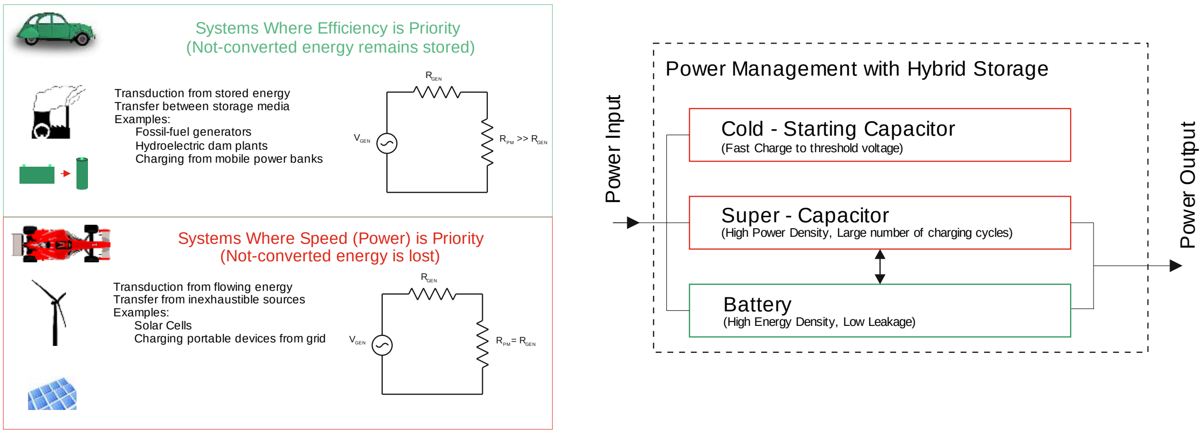

Figure 1. Left: Illustration of the difference between cases where maximization of efficiency or net power transfer is more important. Right: Block diagram of the proposed hybrid energy storage architecture for portable systems.

2.2. The Requirement for Hybrid Energy Storage

The ability of a power management and storage system to optimize efficiency, charging speed and reliability of power availability is largely determined by the storage type that is employed. It is possible to employ both a battery and a super-capacitor, to combine high energy density and low leakage, with high input and output power. Such hybrid systems have been proposed and demonstrated, mainly for electric vehicle applications [2, 3]. In addition, in systems relying on low-voltage power sources such as thermoelectric energy harvesters, a smaller capacitor can be used for fast transition from passive to active power management during cold-starting. A block diagram of a system with a fast-charging, a high power and a high energy storage unit is illustrated in Fig.1 (right).

While the latter technique of using a small capacitor which can charge quickly during cold-starting has been successfully adopted in state-of-the-art power management integrated circuits, the combination of battery and super-capacitor arrays depends on the specific characteristics of power availability and usage applications. The optimum balance between super-capacitor and battery storage can be determined by statistical analysis of anticipated incoming and outgoing energy, based on experimental data. This requirement for storage type customization is a challenge to manufacturing general purpose portable power supplies. The development of printed hybrid energy storage technology may provide a cost-effective solution to this challenge [4].

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2.3. Quantification of Portable Power Quality

One of the major challenges of portable power is its reliability. This is due to the- irregularity of incoming energy and power demand, but also to the uncertainty of storage state. Optimisation requires the definition of a quantitative measure of reliability for such systems. A simple metric would be the percentage of desirable power-on time that is successfully covered by the power supply:

$$R = \frac{Successfully\ covered\ powering\ time}{Total\ desirable\ powering\ time}$$

This reliability metric can be directly calculated by simulating the behaviour of a storage system with a given storage capability, power management efficiency and power routing strategy, under given incoming and outgoing power profiles. In addition, stochastic models and distributions can be used, depending on the application scenario. This approach reveals the requirement for dynamic control of power management within the system, taking into account the history and anticipated future of both power availability and demand. An example architecture will be shown in section 4 of this work.

3. Reliability of a solar-powered power supply

As an example, the behaviour of a solar-powered power supply was simulated, using a simplified model and solar irradiance data in order to provide a quantitative assessment of powering reliability. The data, representing 13.8 years of solar irradiance from the National Renewable Renergy Lab, South Park, Co, USA are illustrated in Figure 2. The Simulink model receives as input, time-series irradiance data and simulates the behaviour of the WSN. The energy storage levels and system voltages are monitored throughout the simulation to determine the fraction of the day in which the WSN is functional.

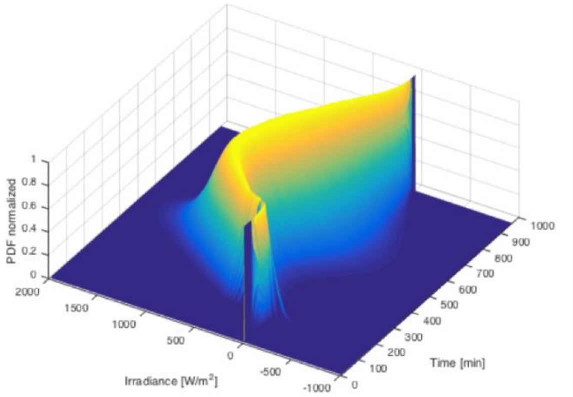

Figure 2. The probability density function of solar input to a Simulink Model. The data represent 13.8 years of solar irradiance from the National Renewable Energy Lab station in South Park, Colorado, USA.

By feeding temporally varying energy availability into the equivalent circuit model of the WSN and applying the voltage triggering algorithm, a model that predicts the behaviour of our energy autonomous WSN over the course of a day is obtained. Because the model applies a voltage triggering algorithm, this model can dynamically adjust its duty cycle to adapt to the input energy availability. Starting the day before sunrise and with a depleted energy reservoir, the WSN is completely off. As the sun rises, the photovoltaic system begins to create a net positive energy flow and the energy reservoirs begin to charge. At the first threshold voltage, the system enters sleep mode and periodically wakes to check the power bus voltage. Once the second threshold voltage is reached, the system has adequate stored energy to undergo a data acquisition and transmission procedure followed by power bus voltage measurement and sleep.

As this model accepts solar availability as its input, it is possible to observe the sensor node responding to periodic cloud cover throughout the day (Figure 3). By considering the ratio of the WSN's actual up time to the length of the day, the fraction of the day in which the WSN operates is obtained. This is a measure of the WSN's reliability, with a perfectly reliably WSN achieving 100% up time. It corresponds to the reliability metric as defined in section 2.3, for a requirement for continuous sensor node functionality. By including larger energy harvesters and more energy reservoirs, it is possible to improve the operation of the simulated WSN toward 100% reliability.

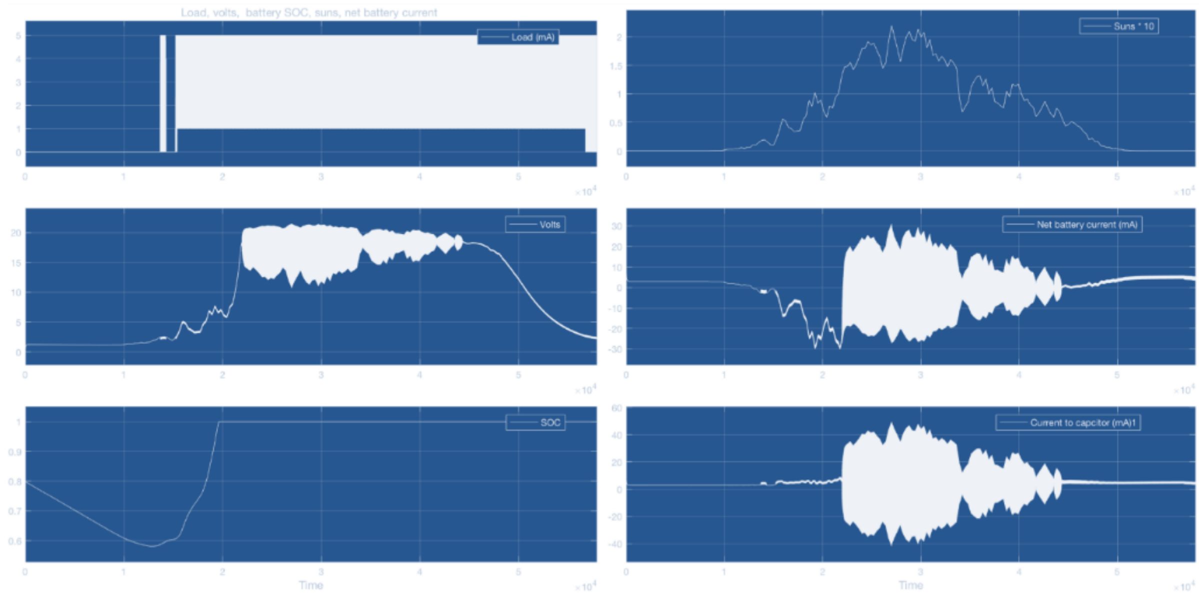

Figure 3. Simulated performance of an example power management system. Storage levels and system voltages are monitored to determine the fraction of the day in which the node is functional.

4. Conclusion

In conclusion, portable power supply systems can improve their performance by selecting the balance between power transfer speed and efficiency either at the design stage or dynamically, according to conditions and power demand specifications. In addition, hybrid energy storage systems, i.e. balancing use of both a supercapacitor and a battery unit, can expand their incoming and outgoing power and energy capabilities. Active power routing and dynamic interfacing may be required to provide flexibility and optimal exploitation of small amounts of energy, especially for energy harvesting systems. A block diagram of such a system is illustrated in Figure 4. The expansion of hybrid storage models to account for stochastic input and duty cycled power demand, and to allow dynamic interfacing, could allow the design of advanced power management systems for a range of contemporary electronic devices.

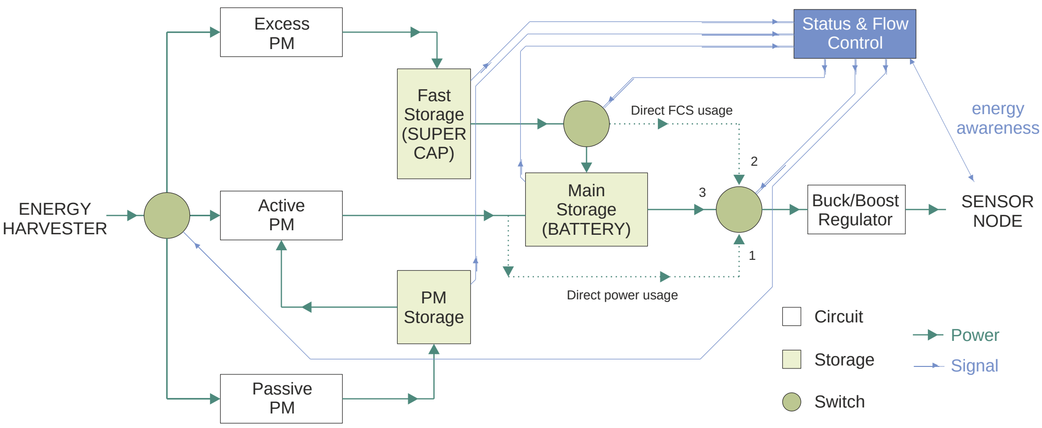

Figure 4. Block diagram of an example hybrid storage architecture with dynamic power routing control for portable power supplies. energy harvesting systems. This system includes a battery main storage, a super-capacitor high-power storage (FCS) and a separate storage unit for passive power management.

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