Not on Demand: Internet of Things Enabled Energy Temporality

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Abstract
Over a century ago alternating current (AC) triumphed over direct current (DC) in the 'war of the currents' and ever since AC has been ubiquitous. Increasingly devices operating internally use DC power, hence inefficient conversions from AC to DC are necessarily common. Conversely, domestic photovoltaic (PV) panels produce DC current which must be inverted to AC to integrate with existing wiring, appliances, and/or be exported the power grid. By using batteries, specifically designed DC devices, and the Internet of Things, our infrastructure may be redesigned to improve efficiency. In this provocation, we use design fiction to describe how such a system could be implemented and to open a discussion about the broader implications of such a technological shift on user experience design and interaction design.

Author Keywords
Energy distribution; energy storage; internet of things; design fiction; world building.

ACM Classification Keywords
K.4.m. Computers and Society: Miscellaneous.

Background
Against the background of energy dependence and climate change, we draw attention to energy loss

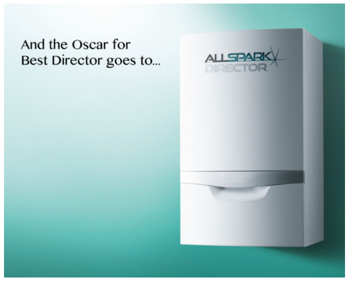


Figure 1. The communications hub and 'buffer' battery in this system – *Director* – is similar in appearance to a conventional Heating, Ventilation or Air Conditioning unit, as depicted in the fictional advert above.

Figure 2. Individual 'Runner' batteries would power any compatible appliance using a universal connection. Usage and charge data would be shared wirelessly with the associated 'Director', which in turn would share this data with a central hub using the LORA protocol. Hence grid operators would have a completely up to date picture of historic and predicted usage and accurate knowledge about the amount of energy stored in Runners and Directors.

stemming from AC/DC conversions. Whilst the loss due to this inefficiency is already significant, DC consumption is projected to increase as a proportion of total usage, hence the energy lost in this way will increase proportionally too [9]. Photovoltaic (PV) cells at residences suffer from the mirror image of this problem; their DC output must be converted to AC so that it can integrate with existing infrastructure.

The maturation of battery technology in recent years presents opportunities for optimization [4]. Innovations such as Tesla's *Powerwall* provide a means to mitigate the losses attributable to the immediate conversion of domestic solar to AC. If a residence is fitted out with PV cells as well as a battery storage system, the energy generated by the PV cells will be stored by the battery for later consumption with no associated conversion loss. In this scenario, despite being stored *before* conversion, the energy stored by the battery will *ultimately* be inverted to AC to integrate with users' existing AC appliances. Hence, when using PV panels to charge a storage battery, there is an argument for introducing DC appliances that can utilize this power without necessitating a conversion to AC.

Batteries can play role in reducing reliance on unsustainable energy production at grid level, too. A recently opened facility at Mira Loma in California uses 396 batteries to provide 80 MWh of energy storage which are charged during the day when locally generated solar power is abundant. During the late afternoon, demand surges while solar generation tails off. At these times the batteries at the Mira Loma facility supplement the grid's supply, and thus reduce the dependency on gas-powered 'Peaker' power stations. It is useful to be aware of such grid-level innovations, however, *our* focus is on the potential to realize a similar effect by utilizing domestic battery technologies and the Internet of Things.

Exploring Provocations with Design Fiction

To explore the 'Implications for Adoption' of emerging technologies, design fiction has become increasingly common in HCI research [5,7,8]. Among the angst of many interpretations of design fiction [6] we apply a 'world building' approach to design fiction [2,3], an approach which involves creating several artifacts which when viewed together, describe and define different elements within, and ways of viewing, a fictional world. There is a reciprocal prototyping relationship between the world and the artifacts which create it; whilst the world prototypes the artifacts, the artifacts also prototype the world. These mutually critical speculations should *not* be interpreted as attempts to predict a preferable future. Rather, they are provocations which extrapolate along plausible trajectories to explore the technical practicalities of implementing such a system, while also creating a space for discussion around the broader consequences of the technology's potential adoption [5,8] (e.g. social, ethical, and design implications). The remainder of this provocation is dedicated to communicating the design fiction world using a series of images and textual accompaniments. Each artifact in a 'design fiction-as-world building' assemblage (in this case product and app focused images) may be considered as an 'entry point' into that world and each entry point describes the fictional world at a different detail level or scale [3]. For example, entry points to the world may be 'zoomed out' (e.g. product advertisements in figures 1 & 2) or could be 'zoomed in' (e.g. app wireframes in figures 3 & 4).

Figure 3. *Current* charge levels of the batteries in a home using the Allspark system.

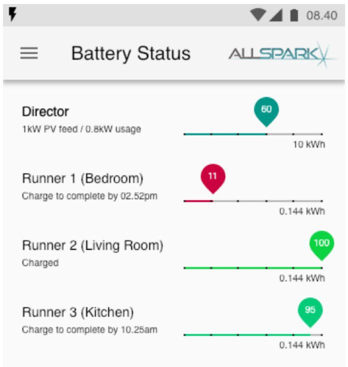
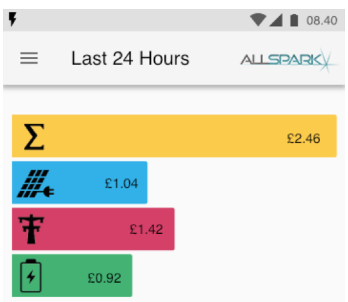


Figure 4. A *retrospective* view of the last 4 hours' energy usage in monetary terms: total value of energy consumed, value of local PV production, value of energy 'imported' from the grid, value of energy stored in the Director and Runner batteries.



Allspark, Director, Runner

The world this design fiction builds is, for the most part, identical to the one we live in. The notable differences from the world we live in are communicated by various artifacts related to a fictional corporation, which is called *Allspark*. These artifacts include two battery products which Allspark sells named *Director* (figure 1) and *Runner* (figure 7), various household appliances which are powered by the Runner battery (figure 2 & 6), and a software app which supports the entire system (figure 3, 4 & 8). As per the earlier discussion, Allspark's products are intended to facilitate more efficient use of electrical energy in domestic settings (with an associated reduction of peak load on the power grid) and the design fiction is intended to open a discursive space around the practicalities of implementation, social and ethical dimensions, and the implications of this technology's adoption on design and HCI.

Director is a large domestic battery (10 kWh) which stores energy generated from PV cells. Director also stores energy from the grid when, or if, necessary. When energy is 'imported' from the grid the system autonomously optimizes the purchase of energy at times when the grid is in surplus. Runners are smaller batteries (144 Wh) which integrate with, and are charged directly from, the Director. Whereas Director acts as a 'buffer' between a home, that home's PV generation, and the grid, Runners are used to directly power individual appliances in that home (figure 2 & 5). The supporting app (figures 3, 4 & 8) is used to monitor and control the system, allowing users to view their retrospective and predicted energy usage, and to control a variety of parameters effecting how the system works. An unseen but imperative element to the system is the ability for each component to collect and share data centrally. As with our contemporary power grid the key to efficacious optimization is the ability to understand usage patterns [1] and to modulate electricity generation accordingly. The Allspark system drastically increases the scope for this optimization by leveraging temporary energy storage, gathering and sharing data in real time, and using this data to 'feed' machine learning algorithms which optimize generation and consumption.

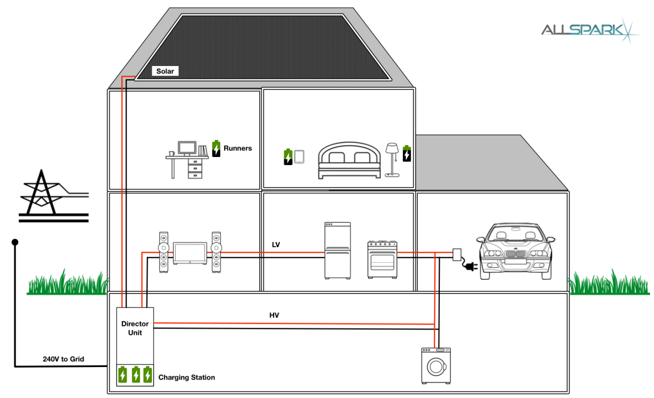


Figure 5. Indicative wiring schematic for an Allspark-enabled house. PV panels on the roof connect to Director, which interfaces with the AC grid as required, charges Runners, and manages high and low voltage wiring within the house.

Within this provocation there is limited scope to explore detailed technical aspects of the system, however we include some notes here to suggest how the system works. Grid connections to homes, and wiring within existing homes remain unchanged at 120v/240v AC systems. Runners are 24v batteries, and hence appliances powered by them would have to be designed to work at that low voltage. Appliances requiring higher

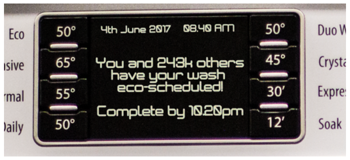


Figure 6. A washing machine control panel interface which is indicative of a move towards integrating energy-temporality into the UX design of household appliances. In this case a user has requested a wash at 8.40am, the appliance indicates that the wash will complete by 10.20pm. This allows the machine to run throughout the day and thus autonomously balance various factors (e.g. figures 3, 4 & 8) to minimize overall peak load on the power grid and cost for the user.

Figure 7. An example of the Runner battery (6000mAh, 24v, 144Wh).

voltage would continue to use AC energy via existing wiring *or* with new high voltage DC wiring direct to a Director (hence there is some backward compatibility and flexibility). Runners, and appliances powered by them, use a communications protocol such as *1-Wire*[1] to allow the Runner to track usage at a device level. This data is shared to the associated Director using a wireless communication protocol within the residence. Directors share an aggregated version of this data to central analytics systems using a long-range communication protocol such as LORA[2] and thus are independent from the residence's own Internet backhaul.

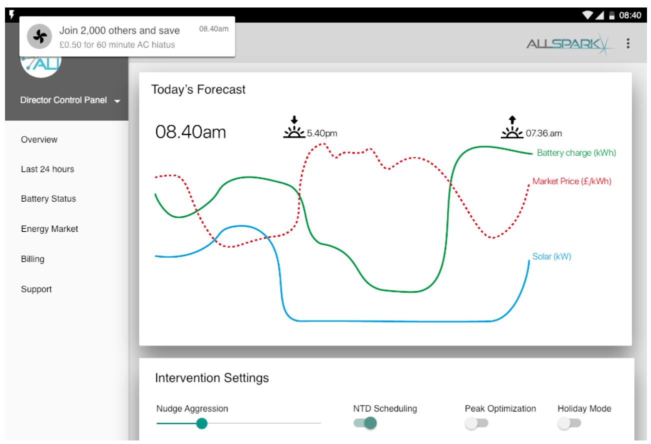


Figure 8. This tablet app shows charge levels, solar generation and market energy price. The settings at the bottom allow the user to choose how aggressively the system attempts to use nudge-theory derived designs to encourage more efficient behaviors. '*Not time dependent'* scheduling allows Director to override when certain devices operate, while *Peak Optimization* allows a central server to temporarily power down compatible devices during a power spike. A notification (top-left) shows that the user is being asked whether they agree to 'join 2,000 others' in disabling their air conditioning unit for 60 minutes.

[1] https://en.wikipedia.org/wiki/1-Wire

[2] https://www.lora-alliance.org/

Discussion

This provocation has taken time to articulate possible system architectures - a process which also played an integral part of the design fiction world building – however, the kernel of this work pivots around the implications for user experience design and interaction design. We envisage that in a future which is increasingly dependent on sustainable energy sources, and where energy optimization/efficiency are paramount, different aspects of 'energy temporality' will become key considerations for designers working outside of today's 'always on' paradigm. We propose the following questions as useful starting points to continue this discussion. How can the impact of energy temporality on a device be reconciled with approaches to quantifying its usability? In order to leverage the potential efficiency gains of energy temporality, to what extent could/should nudge theory (or similar) approaches be used to alter user behavior? What is the role of design and HCI in contributing to a broader move towards collaborative and efficient energy consumption/generation? Our provocation is that the answers to these questions lie in extending and augmenting design fictions such this, and in using them to explore the implications for adoption of technology.

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