Bottom-Up Demand Response by Following Local Energy Generation Voluntarily

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Abstract

We present an open-source low-budget hardware and software prototype of a smart plug, and the principles behind its capability to align power demand with a reference signal, e.g. from local renewable energy generation. We envision its use on a platform that combines social-media with energy networks, where users provide bottom-up demand response voluntarily.

This article has two main objectives: 1. to illustrate the concept of voluntary demand response, and 2. to give researchers a tool to test behavioral flexibility assumptions by extending the open source prototype plug with their own concepts, e.g., implementing more complex autonomous decision-making. In contrast to social media based energy-saving contests, which engage the user socially but do not interact with the power flow directly[1], the smart plug hardware contains sensors and a relay. Thus, physical demand response innovations (Palensky and Dietrich 2011) can be tested with this hardware voluntarily.

As a bottom-up demand response innovation, we suggest to transfer the intuitive concept of 'following' from social networks to smart grids: a power generator publishes its energy generation measurements and consumers can choose a target to follow with their flexible loads, e.g. an electric vehicle can follow the owner's or neighbor's solar panel. The flexible loads then aim to balance some of the fluctuation in generation, thus increasing the tolerable penetration limits of fluctuating energy sources.

The proposed proof-of-concept interface of the *Open Energy Exchange* (OEEX) shows details of nearby generators and their operators, from which users select the preferred target. In contrast to Renewable Energy Certificates, which provide market segmentation and price discrimination but are prone to 'greenwashing' (Gillespie 2008), the 'following' concept aligns the real power flows in the network, while building a personal relation with the energy consumed. Comparable approaches either lack the real-time demand mapping or may be used in a single household only[2].

[1] See welectricity.com and social.opower.com.

[2] See vandebron.nl and sunnyplaces.com.

The choices in designing this prototype were thus guided by the following realities:

1. Legislation adapts slowly, often delaying the introduction of innovative concepts. Since 'following' with the prototype is voluntary, it is feasible under current legislation.
2. Power demand measurements may not be available yet. The prototype therefore includes a local measurement of consumption; other measurements (e.g. household- or distribution grid load) could be added to the system if available to improve alignment of demand with supply.
3. Research assumptions may diverge from practical wisdom if the researcher is not exposed to the realities, e.g. a washing machine running at night is an impractical, but common academic example. Both hardware plans and software of the smart plug are open source[3], lowering the threshold for researchers to become part of the system they are studying, which fosters realistic assumptions.

Software

The smart plug software runs on a *Spark Core*, and the proof-of-concept system architecture is build around the private cloud solution provided by the *Spark Cloud*[4]. Figure 1 depicts the interaction of different components schematically: each flexible device is connected via a smart plug that modulates its activation in response to a target signal.

[3] Available on michaelkaisers.com.

[4] For details see www.spark.io.

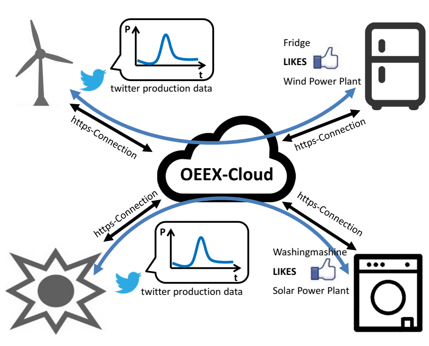

Figure 1: A schema of the OEEX system design principles.

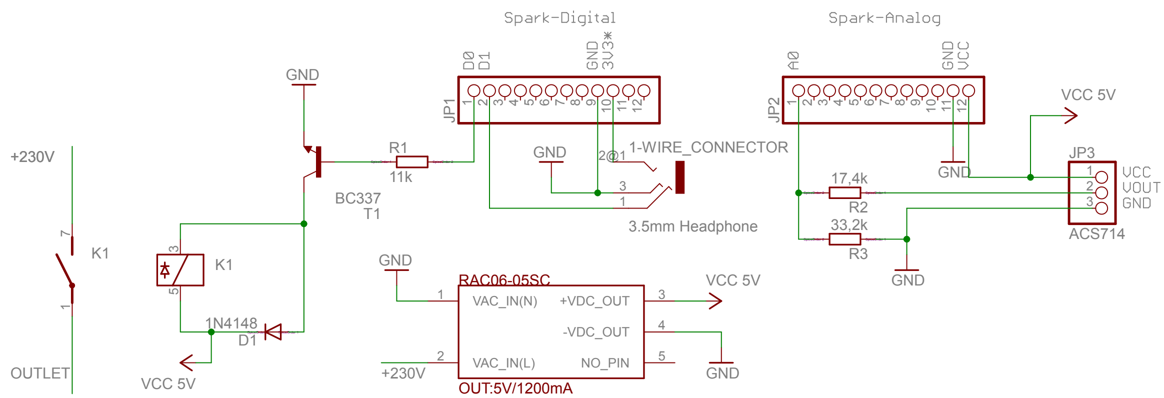

Figure 2: Smart plug circuit diagram.

OEEX Concept Server Functionalities

The OEEX-Cloud features a database for storing general device information like generator descriptions as well as operational boundaries for devices and all inter-device relations. It receives device status information asynchronously from the individual devices, and provides a reference signal. The reference signal represents the expected excess of energy produced by the target generator that is 'followed' by possibly several smart plugs. Furthermore the server calculates how well the reference signal has been followed, rewarding the user with statistics on the estimated CO_2 reduction.

Smart Plug Device Firmware

Using the *TI CC3000 Simple Link* wifi chip on board of the *Spark Core* it is possible to connect the device to the OEEX-Cloud by means of a simple smartphone app. The firmware features an online and an offline mode. When a connection is available, it gathers sensor data and reports it to the OEEX-Cloud. After receiving the reference signal it decides on switching the connected appliance, considering given thresholds based on the device controlled as for example a minimum on-time, for preserving the fridges compressor, or a maximum internal temperature, for preserving the stored goods. When offline, it operates within the given boundaries, e.g. with the heuristic of incurring as few switching operations as possible.

Hardware

The *Spark Core* is used for local information processing and control on the one hand and on the other hand for connecting to the OEEX-Cloud via WiFi. By using off-the-shelf microcontroler- and sensor-boards the effort for hardware-engineering, assembly and testing is held down while still offering space for future expansions. The design is intended to be as simple and low-cost as possible in order to enable people with limited experiences in electronics to build their own OEEX-Plugs and extend them as desired.

The hardware consists of a *Spark Core* micro-controller board, a *RECOM RAC06-05SC* AC/DC-converter, an *Allegro ACS714* current sensor breakout board and a relay for switching the connected load. We implemented the *Dallas One-Wire* bus interface on a digital I/O of the Spark Core to connect external sensors and actuators, in this case the *Maxim* temperature sensor *DS18B20*. Other use-cases are possible by connecting alternative *One-Wire* components, e.g. switching a washing machine with a servo motor, charging electric vehicles with a voltage control or monitoring a water heater's temperature and water-level. The wiring diagram can be found in Figure 2 pointing out the robustness and low-cost character of the device.

Conclusion

The open source smart plug facilitates testing innovative demand response solutions, such as voluntarily following distributed renewable energy sources. The open hardware implementation is kept as simple as possible, but it contains the essential elements (current and environment sensor, relay) and is thus extensible to a number of different use-cases. The OEEX system concept merges social- and energy networks, giving non-experts the power to participate in the green energy revolution. The prototype aspires to be used as a tool for research and innovation in collective demand response in the distribution network and below, which has been identified as a key priority in smart grid research (European Technology Platform SmartGrids 2013). In the near future we plan to evaluate the reliability of the OEEX system and publish step-by-step assembly instructions to further ease joining in.

References

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