Monitoring and Controlling Energy-positive Public Lighting: The E+grid System

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The concepts of smart cities and self-sustaining renewable energy systems are revolutionizing the world of public lighting. This paper presents the architecture of a novel, adaptive and energy-positive outdoor lighting system, as well as the IT solutions that control and monitor the operation of the whole system.

This research was motivated by the potential opportunities to use renewable, solar energy in public lighting services via the appropriate combination of LED luminaries, energy generation and storage, as well as sensor technologies with novel data processing, communication and control methods. To this end, an industry-academy consortium formed by GE Hungary, the Budapest University of Technology and Economics, and two institutes of the Hungarian Academy of Sciences (MFA and SZTAKI) developed a so-called energy-positive community microgrid (E+grid). E+grid balances energy demand against production and guarantees the required level of street lighting even at times of moderate-duration power outages. In this article, we outline the key aspects of the information, communication and control features of the E+grid system.

System architecture

The E+grid system reduces the energy consumption of street lighting by using LED luminaries that regulate their lighting levels according to the surrounding environmental conditions, thus providing just the required level of lighting at all times. This is achieved by mounting motion sensors and smart controllers to each light pole, which are then connected by wireless communication. A positive yearly energy balance is achieved by photovoltaic (PV) energy generation, whereas protection against power outages is guaranteed by battery storage. The system has a bi-directional grid connection, which enables trading with electricity and can be used to exploit variable energy tariffs. Energy flows are monitored by smart meters. A local weather station collects weather data and hosts a twilight switch which allows for the lighting periods to respond to the current environmental conditions. The overall system (Figure 1) is monitored and controlled by a central computer (CC): black connectors indicate power flow while red lines show information flow (smart meters are not depicted).

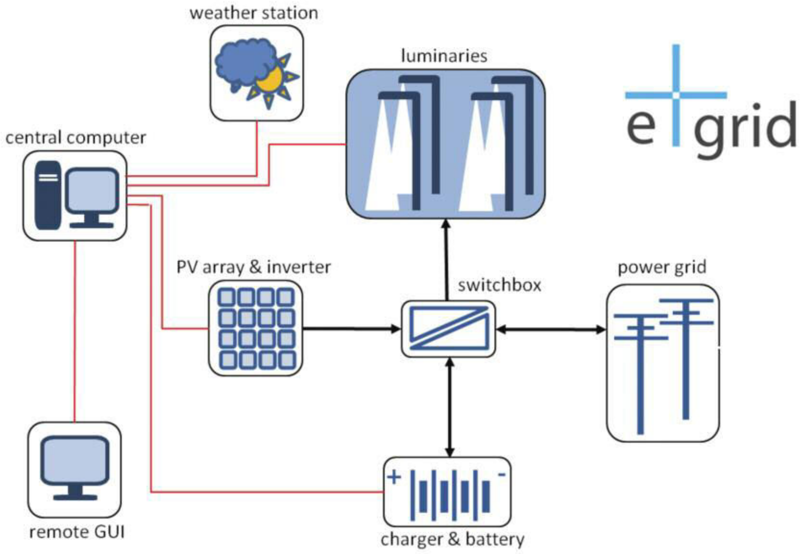


Figure 1: Architecture of the E+grid system

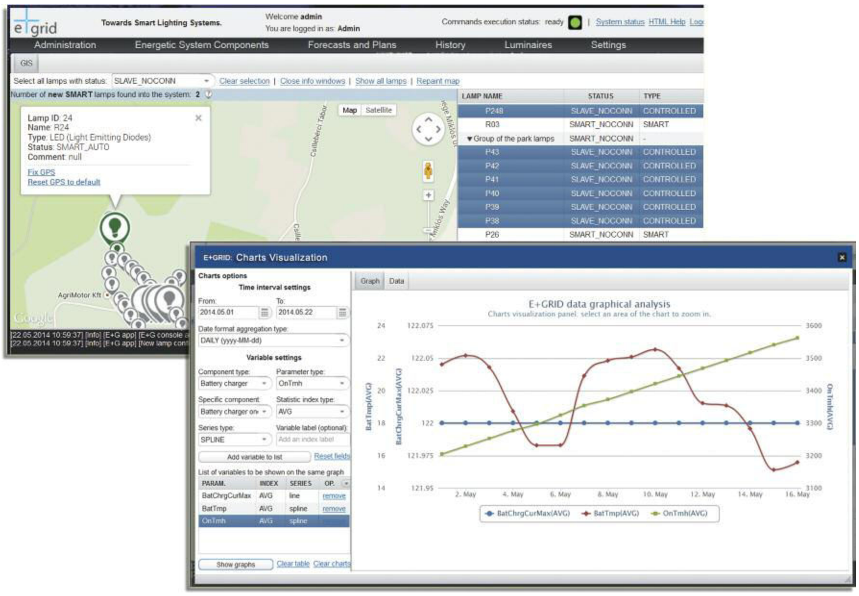
The central computer

The CC of E+grid, an innovative cloud-deployed software application, is one of the key orchestrators of the system, enabling the adaptive lighting behaviour. Its core functions include:

- which are delivered by a web application and the extensive use of JavaScript. The graphical user interface (GUI) (Figure 2) provides friendly access to, among others, the geographic information system (GIS) of the installed luminaries, the management of the energetic components and the visual analysis and export of the collected data; and
- which enable the outer platform components to communicate with the CC. These are provided through a dedicated layer which is responsible both for handling the connections and validating the semantics. Each component is assisted by a proper data synchronization process, whereas the control of the outdoor lighting system is delegated to a specific lighting scheduler.

Controlling the energy flow

One of the main roles of the CC is controlling the energy flow, not only for minimizing the total energy cost, but also for ensuring the robustness against power outages through the use of battery storage. To achieve this, energy production and consumption must be forecasted. This is carried out by fitting time series models to the available data [1]. An assessment of several different models showed that good predictions of energy production can be obtained using nonlinear autoregressive exogenous (NARX) models. These models use wavelet-type nonlinearities, where the exogenous components come from a clear-sky model. Efficient energy consumption forecasts can also be achieved using Box-Jenkins type models, where the exogenous inputs come from averaged historical data. The controller itself uses a model-predictive approach



Select all lamps with status: SLAVE_NOCONN

Number of new SMART lamps found into the system: 2

Lamp ID: 24
Name: R24
Type: LED (Light Emitting Diodes)
Status: SMART_AUTO
Comment: null

LAMP NAME	STATUS	TYPE
P248	SLAVE_NOCONN	CONTROLLED
R03	SMART_NOCONN	SMART
▾Group of the park lamps	SMART_NOCONN	-
P43	SLAVE_NOCONN	CONTROLLED
P42	SLAVE_NOCONN	CONTROLLED
P41	SLAVE_NOCONN	CONTROLLED
P40	SLAVE_NOCONN	CONTROLLED
P39	SLAVE_NOCONN	CONTROLLED
P38	SLAVE_NOCONN	CONTROLLED
P26	SMART_NOCONN	SMART

```
[22.05.2014 10:59:37] [Info] [E+G app] [E+G console a
[22.05.2014 10:59:37] [Info] [E+G app] [New lamp con
```

From: 2014.05.01
To: 2014.05.22
Date format aggregation type: DAILY (yyyy-MM-dd)
Component type: Battery charger
Parameter type: OnTmh
Specific component: Battery charger on
Statistic index type: AVG
Series type: SPLINE
Variable label (optional): Add an index label

List of variables to be shown on the same graph

PARAM.	INDEX	SERIES	OP.
BatChrgCurMax	AVG	line	remove
BatTmp	AVG	spline	remove
OnTmh	AVG	spline	

Figure 2: A graphical user interface (GUI) of the central computer

and works on a rolling-horizon where each time step involves solving a linear optimization problem [1].

Prototype system

The E+grid system design has been validated through simulation experiments which confirmed that the system can achieve a slightly positive yearly energy balance. A physical prototype, containing 130 luminaries and 152 m2 of PV panels is currently being deployed at the campus of the MFA Institute of the Hungarian Academy of Sciences. This prototype adopts three different battery technologies and four types of PV panels in order to evaluate their long-term performance under real-life environmental conditions.

Acknowledgement

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Reference:

[1] B. Cs. Csáji, A. Kovács, J. Váncza: "Prediction and robust control of energy flow in renewable energy systems", in proc. of the 19th IFAC World Congress, to appear, 2014.

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Demand-Side Management in Smart Micro-Grids: An Optimization Perspective

by Talbi El-Ghazali

With the smart grid revolution, the energy consumption of houses will play a significant role in the energy system. Indeed, home users are responsible for a significant portion of the world's energy needs but market prices for this energy remain inelastic (i.e., energy demands do not follow energy prices). Thus, the performance of the whole energy generation and distribution system can be improved by optimizing the management of household energy use. There are a number of challenges associated with this goal including cost, the environmental considerations, user comfort and the presence of multiple decision makers (e.g., the end users and energy operators).

The smart micro-grid is an integrated system which supports distributed energy resources and multiple electrical loads but operates as a single power grid [1]. It is a smaller version of the traditional electrical grid or the smart digitalized grid which working independently of, or interconnected with, a larger existing power network. Smaller scale grids can deliver a wide range of improvements including greater reliability, fewer line losses, better fail recoveries, increased energy efficiencies, carbon emission reductions, reduced demands on the transmission infrastructure, cost reductions. Finally, it introduces the possibility of using alternative energy sources because more localized sources of power generation can be relied on. The global interest in reducing fuel consumption in favor of renewable energies has been a catalyst for the growth in the use of smart micro-grids. They are an ideal way to integrate renewable resources at the community level and allow for customer participation in the electricity enterprise. They enable electricity to be locally generated, distributed and electricity flows to consumers to be regulated.

A smart building system has its own micro-grid and some decentralized resources (e.g., a wind generator, CHP generator, boiler, thermal storage and electrical storage), to provide the basic electricity needs (Fig.1). It may also feature a grid connection which allows it to obtain electricity during peak hours or sell electricity (back to the grid) when surplus electricity is generated. Electric micro-grids are also regarded