The role of demand-responsive energy management systems for smart cities

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MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

Instituto de Engenharia de Sistemas e Computadores de Coimbra

MIT Portugal

A multi-disciplinary project

Scientific areas and teams

Main area: Sustainable Energy Systems
Secondary area: Fundamentals of Engineering Systems

Involving expertise in:

- electricity distribution networks
- end-use energy efficiency
- operational research models and algorithms
- multi-criteria decision analysis
- decision support systems

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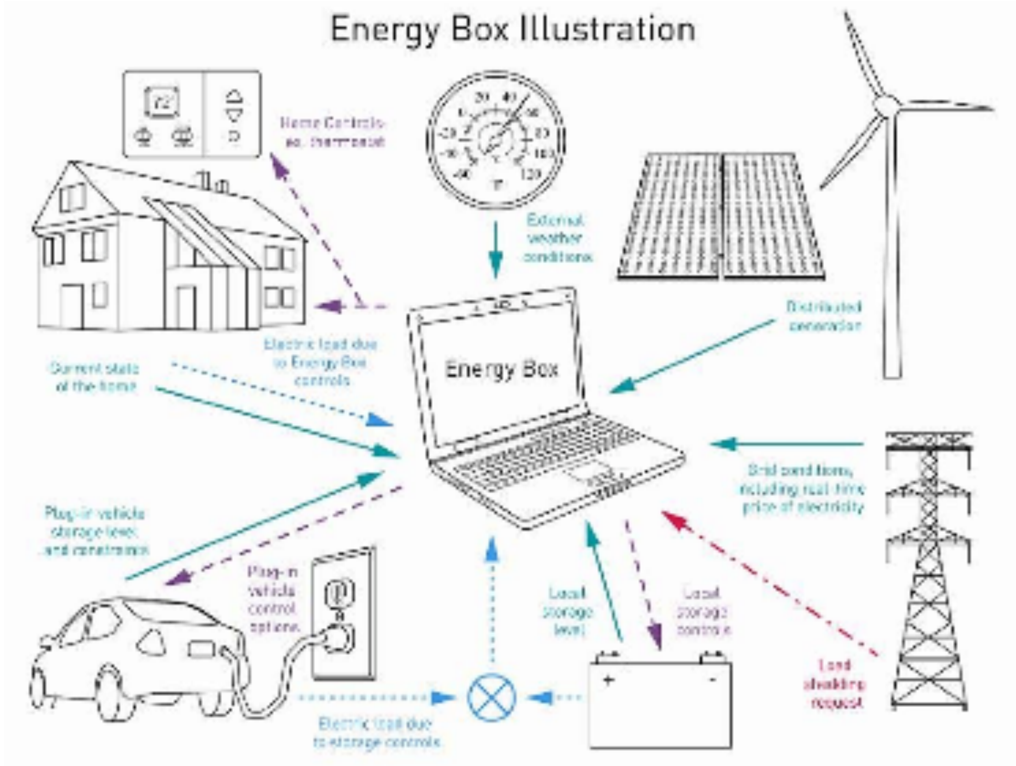
Industrial partner: ISA - Intelligent Sensing Anywhere

Energy Box - development and implementation of a demand-responsive energy management system

Purpose

Further develop and implement in practice the concept of Energy Box as a 24/7 background processor operating on a local computer or in a remote location to manage in an intelligent manner (responding to price signals, comfort requirements, etc.), one's home or small business electrical energy use



Energy Box - development and implementation of a demand-responsive energy management system

Motivation

• Ongoing transformation of electric grids into *smart grids* provides the technological basis to implement demand-sensitive pricing schemes aimed at using the electric power infrastructure more efficiently.

• This creates benefits

- for the end-users by lowering their electricity bill while satisfying their energy service requirements namely regarding comfort levels,
- for the utility by contributing to manage the peak of the load diagram and flattening the aggregate demand curve that may enable to meet forecasted demand growth with the current portfolio of generation sources and grid infrastructures.

Real-time energy management system

- In the context of migration to smart grids, demand-sensitive pricing of electricity will expectedly become the standard pricing mechanism.
- The judicious use of short-term price signals, comfort requirements and user preferences can be engineered to induce changes in the usage of end-use loads and electricity consumer behaviour.
- A real-time EMS is under development, which is aimed at further developing and implementing in practice the concept of Energy Box.
- It will operate as a 24/7 background processor to manage in an intelligent manner electrical energy usage in homes or small businesses.

Real-time energy management system

Automated energy management system able to mimic the individual consumer's decision-making process.

The Energy Box will exploit the flexibility that consumers generally have in the timing of their electricity usage to induce changes in their electricity-consuming patterns through time-varying electricity pricing.

This becomes feasible with the smart grid infrastructure, including two-way communication and short-interval meter reading, complemented with sensor networks.

$\Rightarrow$ To achieve a total system optimal control.

The Energy Box

• Energy management system (hardware + algorithms) coordinating in an autonomous manner for the typical small consumer of electricity (residential and small commerce/services):

- Management of electricity use
- Storage (inc. EV)
- Selling back to the grid

subject to conditions

- of the grid
- in-door comfort and air quality
- occupancy patterns
- weather

Energy Box - development and implementation of a demand-responsive energy management system

Tasks

- Preference modeling and learning
- Characterization of consumer behavior
- Technical issues
- The Energy Box as perceived by the electric utility

Tasks goals

Preference modeling and learning

A critical issue for the success of the Energy Box concept is the degree of acceptance by the users ➔ capturing the preferences of different user profiles, namely concerning the attitudes towards short-term price signals and comfort thresholds.

Learning distinct patterns of use (rates of occupancy, comfort requirements, etc.) ➔ dynamically adapting to them when responding to changes in prices.

➔ study how to model the preferences of different user profiles in a way they can be used as an input to the optimization algorithms providing optimal decisions

- to shed loads (which loads, when, how long),
- to manage storage (charging or discharging an EV),
- to sell electricity back to the grid if a local generator is installed.

✚ sensor information fusion and short-term decision making.

Tasks goals

Characterization of consumer behavior

Behavioral issues can emerge at distinct levels, ranging from market positioning to product development to the fostering of attitude changes towards large scale, overarching concerns (e.g., environmental awareness, public policies).

➔ to address relevant behavioral processes trough a cognitive modeling strategy, resting operationally on recent variants of conjoint analysis and best-worst scaling.

➔ discrete-choice variants of the experiments will allow contrasting the Energy Box concept with alternative energy-saving investments.

➔ assessing consumer's reaction to different pricing strategies, as well as induced changes in overall conservation patterns and consumer's standpoint regarding energy public policies.

Tasks goals

Technical issues

- electric and thermal storage

- characterization of the main end-use loads (physically-based models)

- battery load control and management with laboratorial experiments with a prototype electric vehicle.

- battery technologies, inc. voltage, connectors and communication between the vehicle and the grid

- multiple energy sources

Tasks goals

The Energy Box as perceived by the electric utility

- Study the effects of the Energy Box as perceived by the electric utility, as a function of its market penetration.

- How the demand response automated by means of a multitude of Energy Boxes with different parameterizations according to distinct user profiles and preferences affect the grid, including instability issues?

- What should be the statistical characterization of these random delays to achieve the desired effects of maintaining network stability and yet changing the load status as soon as possible?

- Can traditional utility operated remote load control actions complement the Energy Box decisions (dual mode)?

Tasks goals

Algorithms

- Determining the global optimum control of using, storing and selling electricity ➔ sequential decision-making process that balances the end-user's comfort, cost and lifestyle preferences in the face of uncertain conditions regarding the price of electricity, weather conditions, and electricity available from weather-dependent generation sources.

- Stochastic dynamic programming framing for determining optimal control decisions (process of sequential decision-making under uncertainty), e.g. automated real-time response by space conditioning appliances with respect to spot pricing for electricity .

-Optimal policy ➔ finding a sequence of decisions that maximizes the expected value of

$$\max_{d_i} \; E_{s_i}\Big[\sum_{\mathbf{j}} \lambda_i^j u_i^j (s_i, d_i) \Big]$$

Tasks goals

Algorithms

$$\bar{j} = comfort, lifestyle, cost$$

$$s_{i+1}^{home} = f_{i,i+1}^{home}(s_i^{home}, d_i^{use}, d_i^{store}, d_i^{sell})$$

$$s_{i+1}^{home.temp} = \begin{cases} s_i^{home.maxTemp} & if\ d_i^{use.temp} > s_i^{home.maxTemp} \\ d_i^{use.temp} & s_i^{home.minTemp} \le d_i^{use.temp} \le s_i^{home.maxTemp} \\ s_i^{home.minTemp} & if\ d_i^{use.temp} < s_i^{home.minTemp} \end{cases}$$

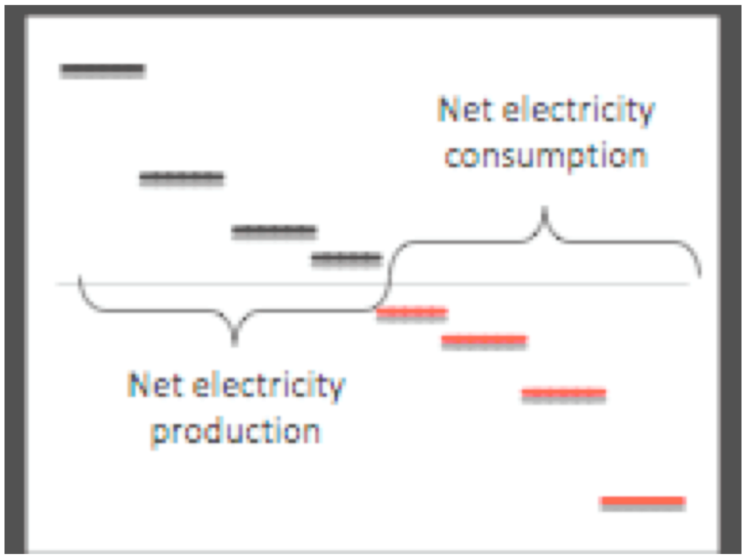
$$s_{i+1}^{home.store} = \begin{cases} s_i^{home.store} + 1 & if\ d_i^{store.battery} = \textbf{charge and the battery is not full in stage i} \\ s_i^{home.store} - 1 & if\ d_i^{store.battery} = \textbf{discharge and the battery is not empty in stage i} \\ s_i^{home.store} & \textbf{otherwise} \end{cases}$$

Tasks goals

Algorithms

Utility measure regarding buying and selling electricity

Cost preference function $u_i^{\text{cost}}(s_i, d_i)$



$s_i^{\text{home.bill}}$

Patterns of use vs. quantity of use

Pattern of use: influencing usage despite appliances are efficient or not (e.g. deviate consumption of an inefficient washing machine to lower tariff periods)

Quantity of use: suggesting more efficient appliances to lower consumption without downgrading the energy service provided (e.g. provide information about savings that could be obtained with a more energy efficient washing machine)