Smart Grid Demonstration Platform for Renewable Energy Exchange

M. Mihaylov*[1], I. Razo-Zapata[2], R. Rădulescu[1], S. Jurado[3], N. Avellana[3] and A. Nowé[1]

[1]Vrije Universiteit Brussel, Brussels, Belgium
[2]Luxembourg Institute of Science and Technology, Luxembourg
[3]Sensing & Control Systems, Barcelona, Spain

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1 Introduction

Offsetting cities' dependence on fossil fuels is one of the key factors for meeting the environmental targets set out by the European Commission (EC) by 2020 [3]. The penetration of small-scale renewable resources in domestic households (photovoltaic panels and micro wind mills) empowers dwellings to collectively reduce their carbon footprint. Incentivizing the injection and trade of locally-produced renewable energy is a step towards the decarbonisation of the power sector.

Nowadays many energy retailers apply feed-in tariffs to motivate prosumers to inject their produced energy, in order for the retailer to comply with environmental targets. With the growing decentralization of renewable energy production [4], it is a challenge to offer subsidies that ensure a profitable and balanced grid for all parties involved. There rises the need to design an incentive mechanism that aligns the objectives of individual prosumers, who are aiming for high profits from their investments, with the objectives of governments and policy makers seeking to reduce their spendings while still facilitating long-term positive environmental change.

2 Main purpose

The solution offered so far in the smart grid domain for incentivizing production is to provide payments to prosumers in the form of subsidies. This mechanism comes at a financial burden for governments and policy makers, who seek ways to balance the economic incentives offered to agents with the need for a stable grid. In [5] we proposed the NRG-X-Change concept, which attempts to address this challenge using a novel decentralized digital currency called NRGcoin. When locally-produced renewable energy is fed into the grid, the NRG-X-Change protocol generates new NRGcoins that are awarded to prosumers based on their injected energy. These coins are then sold on a currency exchange market to consumers, who use them to pay their consumption. The billing is performed in real-time by the substation, where the energy cost takes into account total supply and demand in the neighbourhood, rather than the individual's supply and demand, as currently done in practice.

During overproduction prosumers are paid proportionally to the injected energy that covers the total demand in the neighborhood, such that the overproduced energy is not remunerated. This payment protocol incentivizes the balance of local energy supply and demand in the neighborhood. The excess renewable energy is stored in batteries and injected when it is most profitable by relying on an intelligent bat-

*mmihaylo@vub.ac.be

tery control strategy, which incorporates a prediction algorithm.

The NRGcoin currency shares characteristics with Bitcoin and has numerous advantages in the smart grid [5]. Independently from injection and withdrawal of energy, NRGcoins are traded on an open currency exchange market for their monetary equivalent. Agents use Random Forest prediction algorithm to determine the quantity to trade and Adaptive Attitude (AA) bidding strategy [7] to determine the bid/ask price. AA allows agents to continuously update their eagerness to sell or buy NRGcoins depending on the market changes: a short-term attitude translates into profit desire (i.e., selling/buying at high/low prices), while a long-term attitude encourages more transactions (i.e., submitting low/high asks/bids).

The NRG-X-Change concept has been thoroughly tested on a smart grid multi-agent simulator using Repast Simphony [2]. To further validate the NRG-X-Change concept, we deploy it on hardware and use real data of energy consumption in a typical neighbourhood. The aim of our demonstration is fourfold: (i) to raise awareness about the challenges and impact of future smart grid scenarios; (ii) to highlight the potential of NRG-X-Change in decarbonizing the power sector; (iii) to demonstrate the weather influence on monetary incentives and market behavior; and (iv) to illustrate the impact of battery control strategies on the scenario dynamics, i.e., on market evolution and energy prices [6], as well as on prosumers' and substation's profits.

3 Demonstration

Our demo offers four types of interaction. *1) Influence consumption:* Users can change the 'virtual' outdoor temperature, which influences the consumption of all houses. For example, decreasing the outdoor temperature will drive agents to increase their consumption proportionally, relative to their real-world consumption. *2) Reduce production:* Users can cast shadows over the solar panels of prosumers using cardboard clouds. This simulation of weather conditions allows users to observe their effect on the overall energy balance and on the incentives of agents for exchanging renewable energy. *3) Increase production:* Users can install extra panels to observe the influence of big producers on the real-time energy price and on the currency market. Similarly, equipping a consumer with solar panels increases the percentage of prosumers and therefore changes the energy balance in the neighborhood. *4) Install battery storage:* Users will be able to observe the effect of equipping prosumers with battery storage and thereby understanding the influence of storage systems on prosumer's profits and market conditions.

Within the demo we use real-life data, provided by Eandis — a Belgian Distribution System Operator (DSO). For this demo we have selected a typical Belgian neighborhood consisting of 6 prosumers and 56 consumers (cf. Figure 1). To find a typical substation in the data, we applied a two level clustering that considers global features such as total trimester consumption, and local features such as daily consumption [1]. The measurements that we use in this demonstration are collected between 1st of March 2014 and 31st of May 2014.

The substation and the six prosumers are represented by software agents running on individual Raspberry Pi boards. Prosumers produce energy in real-time using mini solar panels. A dimmable spotlight projector is automated to simulate the day/night cycle using a z-Wave controller. All 56 consumer agents are running in individual threads on two Raspberry Pi boards. Energy consumption of both prosumers and consumers is read from the real data. The boards allow agents to submit orders for buying and selling NRGcoins to an online market hosted and running in Azure Cloud. Orders are matched in real-time using continuous double auction, as employed by the New York Stock Exchange. Thus, our demo represents a multi-agent system that autonomously exchanges renewable energy using the NRG-X-Change incentive mechanism. Since the currency market is hosted in the Cloud, it allows agents to place bids from anywhere in the world. Thus, multiple neighbourhoods running in different parts of the world can seamlessly interact in the same scenario and demonstrate the scalability of our concept. All software agents are developed in Java, while the ex-

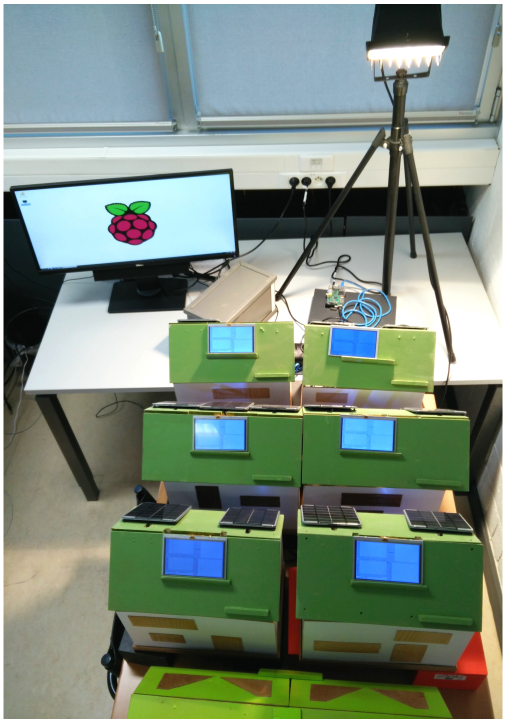

Figure 1: Demo setup

change market is developed in C# using Azure Service Bus for synchronizing actions. All components communicate using the RESTful Microservice architecture.

Each prosumer is equipped with a 3.7V lithium-polymer (LiPo) rechargeable battery of 2.6Wh. We scale the capacity of the physical batteries in software with factors between 1500 and 5000 to match that of real commercial batteries, which can range between 4kWh and 13.2kWh. The battery is charged by the mini solar panels and discharged using a heater resistor to simulate self-consumption or injection in the grid. The battery control strategy infers at every time slot whether it is most profitable to inject the excess green energy in the grid or to store it in the battery for later use, depending on the predicted energy balance in the neighborhood.

Prosumer houses have LCD screens showing in real-time: (i) individual energy production and consumption in kWh; (ii) NRGcoin balance of prosumer; (iii) NRGcoin transactions and payments; (iv) market orders for buying and selling the currency; and (v) the state of charge of the battery. Likewise, substation's screens show aggregated information about: (a) total energy production and consumption of all houses; (b) NRGcoin balance of the substation; (c) all unmatched buy and sell orders in the currency market; (d) the evolution of the NRGcoin price.

While in reality measurements are taken every 15 minutes, we speed up our demonstration by a factor of 300 to arrive at 3-second time slots. Thus, charts are updated every 3 seconds, allowing users to observe in less than 5 minutes the behavior of a real neighborhood in a whole day. Users are also able to pause the execution of the entire demonstration (including the day/night cycle) in order to analyze the plots. This functionality is available via the user interface in the substation's LCD display.

4 Conclusions

We present here a demonstration setup of a smart grid scenario showing how green energy exchange can take place in a typical neighborhood, under the NRG-X-Change incentive mechanism, using real life consumption data. We also highlight the effect of weather conditions and battery control strategies. Incentive mechanisms for local energy trade are a vital stimulus in the race to meet our environmental targets. We believe digital currencies for energy are a promising newcomer in the smart grid scene and may prove to be an important ingredient in the design of future-compatible incentive mechanisms.

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