EcoGrid EU: An Efficient ICT Approach for a Sustainable Power System

Dieter Gantenbein, Carl Binding, Bernhard Jansen, Aditya Mishra, Olle Sundström
IBM Research - Zurich
8803 Ruschlikon, Switzerland
dga@zurich.ibm.com

***Abstract*—The transformation of the electrical power system to higher sustainability involves many challenges. Incorporating high volumes of fluctuating renewables and improving the overall efficiency may benefit from the use of information and communication technology (ICT) to monitor and balance the system, and potentially involve individual consumers to deliver demand-response. This also introduces new risks, given that there are strong requirements regarding the security of the supply. In this paper we report on the approach taken in the EcoGrid EU project, launching a Smart Grid pilot with demonstration on the Danish island of Bornholm. In reviewing the key concepts, we focus on the particular choices that help render the ICT involved efficient, scalable, and secure.**

***Index Terms*—Smart grids, distributed energy generation, energy storage, demand response, intelligent control**

I. Introduction

The objective of the EcoGrid EU project is ambitious, namely, to establish a prototype of the future intelligent power system in Europe. This so-called smart grid will be demonstrated on the Danish island Bornholm, where 2,000, i.e., more than 10% of the households and companies, will adopt a more flexible consumption to show, how Europe can handle its electricity needs in a scenario with more than 50% wind power and other fluctuating and less predictable renewable energy sources [4].

The aim of EcoGrid is to demonstrate an efficient market concept designed to incorporate small-scale, distributed energy resources as well as flexible demand into the existing power-system markets, balancing tools and operation procedures. The concept will remove the barriers that so far have hampered the introduction of distributed energy resources (DER) into the present market structure, e.g., barriers related to size, online monitoring as well as a significant administrative overhead, including bidding on the markets and complying with schedules and financial obligations. Likewise, the market will provide a transparent and simple mechanism, as well as sufficient incentives, for encouraging the participation of small end-consumers [5]. The essential EcoGrid features are

- a large-scale pilot of a real-time marketplace concept,
- integration and incremental refinement of today's operational markets,
- enablement of individual DERs and small consumers,
- an innovative ICT system and market solution for more efficient TSO (Transmission System Operator) balancing services,
- demonstration in a real power system with more than 50% renewable energy, and
- preparation for a fast-track towards European real-time market operation of renewable energy sources and demand response.

In the framework of (an earlier project) the Danish EDISON project [2], we developed an ICT solution for an intelligent system integration of distributed electric vehicles (EVs) plugged into an electric grid, be it at private homes or at charging stations in company and public parking lots [1]. We implemented a uniform interface between the actual EVs and thousands of additional micro-simulated EVs on the one hand and the Virtual Power Plant (VPP) software on the other hand, well-aligned with the IEC 61850 standard for distributed energy resources [11]. A central planning module received the individual EV charging requests, predicted the aggregated energy required and the available flexibility in space and time, optimized the costs according to dynamic energy prices and grid state, and then updated the individual charging schedules involved [12]. Although the demonstration site Bornholm is the same as for the Edison project, the EcoGrid methodology is, as mentioned above, completely different.

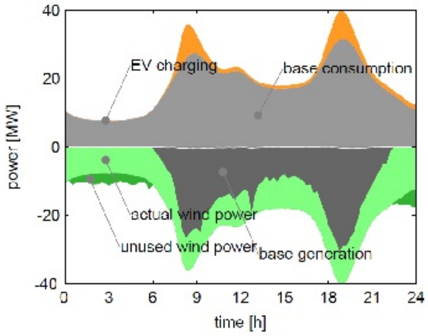
The paper is organized as follows: Section II reviews the merits and limitations of direct control. Section III contrasts it to indirect control using market mechanisms. Section IV describes the end-to-end balancing with a bidless real-time market. Section V summarizes the requirements on the price services, and Section VI explains our selection of the price distribution protocol stack. Section VII details how distributing the right price will also lead to efficient billing and settlement. Section VIII describes the planned demonstration environment on Bornholm in the 2012 to 2014 time frame. Section IX closes with a summary and outlook.

II. Relative Merits of Coordinated Planning

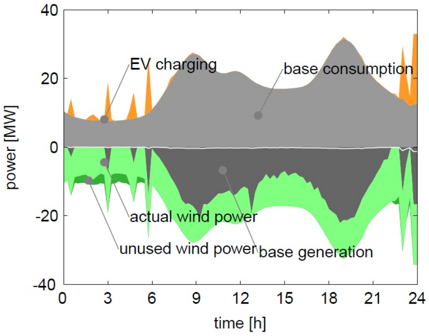
In the EDISON VPP, we implemented flexible charging optimization for EVs [1]. The graphics in Figure 1 depict three scenarios (A, B and C) for Bornholm with 10,000

978-3-901882-46-3 ©2012 IFIP

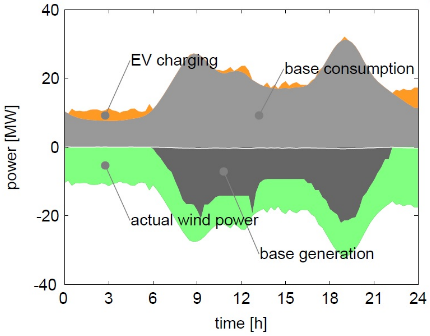
simulated EVs. Shown on the x-axis is a 24-hour day and on the y-axis the power, consisting of the daily base load curve (gray, positive), the additional load due to the charging of the EVs (orange), the matching base generation (black, negative), and the wind power (actual in light green, unused in dark green).



(a) Plots for Scenario A



(b) Plots for Scenario B



(c) Plots for Scenario C

Fig. 1. Optimal smart-charging by communication between grid and consumer

Scenario A (Figure 1(a)) explains what happens with constant prices, i.e., if there is little incentive for planning. Charging happens immediately to minimize the risk of being late - hence the morning and evening peaks increase in alignment with the corresponding base increases. Note that in this classical mode, the base generation has to react to any system imbalance.

Scenario B (Figure 1(b)) explains what happens with dynamic prices, but no coordinated planning. Each price-aware and flexible consumer shifts load, e.g., into the cheap night hours. This leads to new artificial spikes in the time raster of the pre-announced price changes. Again, these aggressive switching imbalances are compensated day and night by the base generation, which may at some point not be able to match the ever growing regulation requirements.

Scenario C (Figure 1(c)) shows the optimal situation, with coordinated adaptive planning. While flexible consumption typically shifts to night time to benefit from unused wind power and low prices (orange "lake"), it is also ready to pick up all renewable power available (note the absence of dark green areas), and is dispatched as needed also during daytime to level out the base generation and absorb any occurring imbalance.

Coordinated planning allows for the data/information to be distributed across multiple participants. It has been shown how the different regulatory roles, including the Retailer, and Distribution-System Operator (DSO), can interact with the charging service providers to exchange and, if required, iteratively converge on the best charging schedules [12].

While coordinated planning with its access to the global knowledge can dynamically react to unexpected renewables and other imbalance situations, there are some issues with the data exchange this requires. Firstly, the EU-mandated de-regulation of the stakeholder roles (marketplace, generation, TSO, DSO, retailer, meter responsible, etc.) inherently increases the information-exchange complexity. Secondly, well coordinated planning needs access to the thermal and electrical consumption and resource models, and the corresponding reasoning does not scale when centralized. Thirdly, there may be competitive or privacy issues that render an open exchange of all required information undesirable.

III. A REAL-TIME MARKET REFINING TODAY'S MARKETS

In contrast to direct control, market concepts have the advantage of being device-type agnostic, given that the device price-responsive agents offload the central computation in a distributed fashion.

Markets are seen as an efficient way to meet the challenge of balancing the power grid. Flexible production and consumption, when coordinated through a market, are seen as the best solution to address the ever growing volatility and expected balancing costs in the system. They also represent an efficient instrument for the promotion of a widespread adoption of small-scale end-users and prosumers, while increasing the competition on the power markets: Small-scale end-users can realize economic benefits, and the TSOs get access to alternative balancing resources [9].

The EcoGrid real-time market is a bid-less market, as explained in Section IV. Figure 2 illustrates how it fits into today's operational market and regulation mechanisms. The design of an EcoGrid prototype real-time market place is a realistic approach because it "merely" extends the

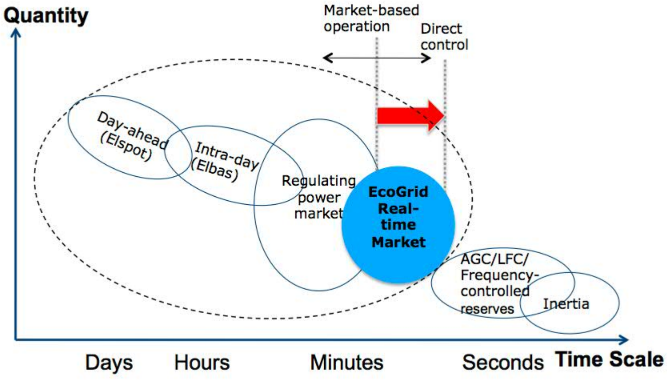


Fig. 2. The scope of a real-time market [7]

scope of the current power market systems. There are subtle differences, however:

In the current system, the TSOs obtain a certain quantity by selecting/accepting bids. Qualifying for this are only large producers, large consumers, and aggregated smaller units (e.g., minimum of 10 MW[1]). Loads are "updated" every 15 min.

With the new real-time market, there are no restrictions on the size of units (in terms of MW). The TSOs set a price every 5 min, resulting in a certain number of faster responses from smaller units.

Previous and ongoing trials of similar market concepts exist in the US Pacific Northwest GridWise projects [6] [7], although not featuring the EcoGrid operational integration.

IV. A BID-LESS REAL-TIME MARKET

Figure 3 illustrates the novel overall architecture around the EcoGrid real-time market. The fundamental idea is that the market allows regulation of flexible resources through price signals without directly measuring the individual DER response [9].

Well aligned with today's operation, in which the TSO manages the transactional markets (includes the day-ahead and intraday bids, selection, activation), the TSO in EcoGrid detects the residual need for correcting the system balance and calculates the price that will re-establish equilibrium.

The price is published and retrieved by the market actors; hence producers and consumers receive real-time prices and can adjust their services accordingly. The TSO monitors the impact to verify that equilibrium has been established. Some call this the open-loop response to dynamic prices. Individual prosumers with their price agents and device models are immaterial and treated as black box. The TSO observes the aggregated result and computes a new price based on the achieved sensitivity. This process is repeated every 5 min [9].

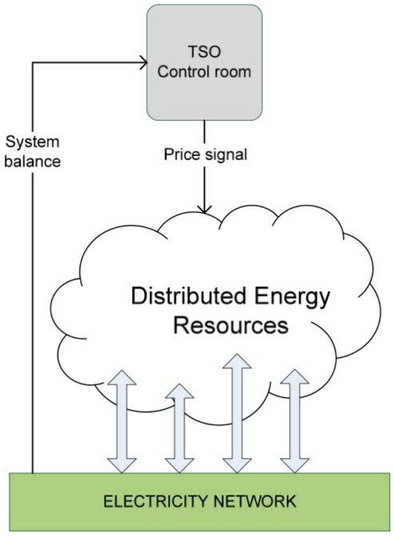


Fig. 3. The fundamental idea of the EcoGrid EU Concept [9]

V. REQUIREMENTS ON ICT SERVICES FOR PRICE DISTRIBUTION

In this section, we summarize the functional and non-functional requirements that need to be addressed by the ICT for the non-transactional EcoGrid real-time market price-distribution services. Further details are available in a separate report [8].

A. Data

The real-time market actors need the following data:

- the real-time market price for buying electricity,
- the real-time market price for selling electricity back to the grid,
- the currency of the real-time market price for buying electricity,
- the currency of the real-time market price for selling electricity,
- the energy unit of the real-time market price for buying electricity,
- the energy unit of the real-time market price for selling electricity,
- the start and end time for which the real-time market price for buying is valid (UTC),
- the start and end time for which the real-time market price for selling is valid (UTC),
- the forecast for the real-time market price for buying electricity consisting of any number of forecast values comprising
  - real-time market price forecast,
  - the currency for the real-time market price forecast,
  - the energy unit for the real-time market price forecast,
  - the start and end time for a which the real-time market price forecast is valid.

---

[1] The value may change with location/region

- the forecast for the real-time market price for selling electricity consisting of any number of forecast values comprising
  - real-time market price forecast,
  - the currency for the real-time market price forecast,
  - the energy unit for the real-time market price forecast,
  - the start and end time for a which the real-time market price forecast is valid.

B. *Security*

The distributed real-time market price is public information; hence there is no need for encryption. However, although there is no need to protect the information per se from being read by the public, other security requirements need to be fulfilled:

- Authenticity - The origin of the price information is trusted.
- Integrity - The price information is not altered while being transported.
- Non-repudiation - The source cannot deny the published price information.
- Non-re-playability - The price information distributed cannot get injected at a later point in time for another time period.

C. *Scalability*

The system should scale from a few thousand market actors to very large numbers. The upper limit is the number of private households and participating companies in the control area of a TSO. In Denmark, for example, there are about 2.51 million private households under control of Energinet, the Danish TSO.

D. *Availability*

The availability of the real-time price signal is a crucial for ensuring a functioning market. As the number of market actors increases, unavailability of the price signal might also affect the overall system stability.

Known outages of the price distribution are less critical as the TSO can act and take timely countermeasures, activating traditional regulation power. Outages in price distribution - for a significant number of market actors - which are unknown to the real-time market and the TSO are critical as the predicted reaction may deviate significantly from expectations. If the error situation persists, the TSO may adjust the sensitivity computation. Such unknown outages can be caused by ICT service and Internet Service Provider (ISP) outages for market actors, by systematic distributed equipment failure (e.g., firmware errors in routers, gateways, and demand-responsive resources and their agents), and, of course, by denial-of-service attacks.

VI. Proposed Communication Protocol for Price Distribution

Figure 4 shows the proposed ICT architecture for real-time price distribution in Ecogrid. Real-time electricity prices for both selling and buying electricity are generated at the real-time price generation module every five minutes. The price-generation module takes inputs from TSO, electricity spot market, historical metering data, and weather forecast for computing the real-time price (for both buying and selling electricity) and a real-time price forecast over the next few hours. Generated prices and price forecasts are sent to the price-distribution system which uses a combination of publish-subscribe and IP multicast technologies for broadcasting the real-time price information to (potentially) millions of customers. The real-time price-distribution system provides the price signals to the subscribed ISPs using publish-subscribe technology, and the ISPs push the price information to the customers in their networks using UDP (User Datagram Protocol) over IP multicast [3]. However, as UDP is a connectionless and non-reliable protocol, additional mechanisms need to be implemented at the higher network layers to provide reliability and sequencing of the datagrams.

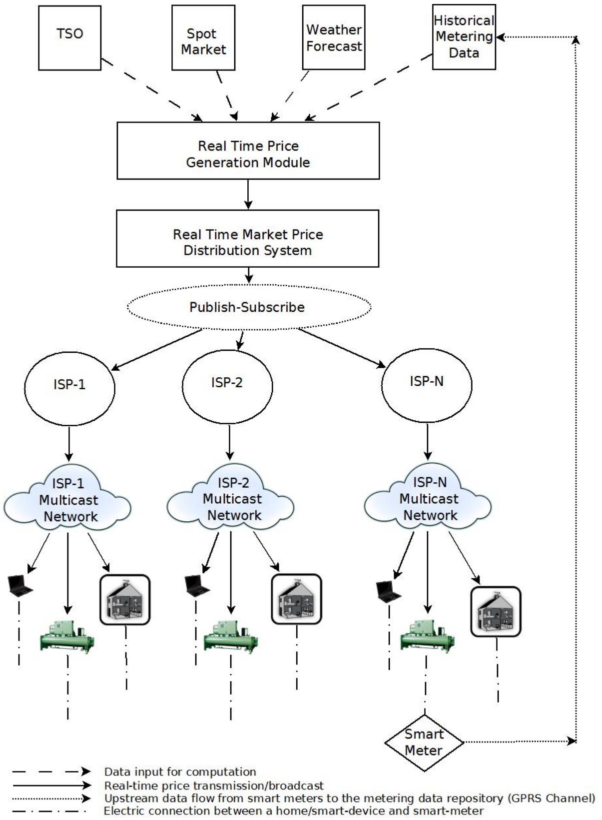


Fig. 4. Proposed real-time price distribution architecture for EcoGrid

End-nodes or smart devices adjust their planned consumption according to the price information received. All households are connected to a smart electricity meter, which measures the power consumption of the device/devices every five minutes. The measured power consumption data is uploaded to the historical metering data repository once every 24 h.

VII. Choice of Price Communication Protocol Stack

In this section, we present a summary of the survey (performed in [10]) of various communication protocols and data models for transferring process data and supervisory control information between networked devices and/or computer applications. An overview of the suitability of these protocols for application in real-time price exchange between the DER and the aggregator is presented in Table I. Data/information models and protocols compared in the table include the IEC 61850 information model, the MMS (Manufacturing Message Specification), GOOSE (Generic Object Oriented Substation Events), CIM (Common Information Model) standards, the US Olympic Peninsula GridWise price exchange protocol [6], and the proposal of a Hierarchical Transactive Control system [7]. Further details on the comparison and the proposed optimal protocol are available in [10].

TABLE I

Comparison of Price Distribution Protocols

	Communication Pattern	Transport Protocol	Real-time price information exchange	Scalability to millions of customers	Security
IEC 61850	Client-Server	TCP,OSI	Yes	No	yes
MMS	Client-Server	TCP,OSI	Yes	No	No
CIM	NA	Any	Yes	Implementation dependent	No
Olympic Peninsula	Client-Server bidding	Any	Yes	No	No
Hierarchical Transactive Control	Hierarchical Communication	Any	Yes	No(large message overhead)	No
GOOSE	Publish-Subscribe on multicast or broadcast MAC addresses	ISO/IEC 8802-3 (Ethernet)	Yes	No	NA
Proposed price distribution protocol	IP Multicast + Publish-Subscribe	Any	Yes	Yes	Yes

VIII. Efficient Billing and Settlement

As elaborated in Section IV on the bid-less real-time market, the TSO establishes proper response through an appropriate price signal. In this section, we discuss an innovative aspect of the particular choice of the price level as proposed by Energinet [9].

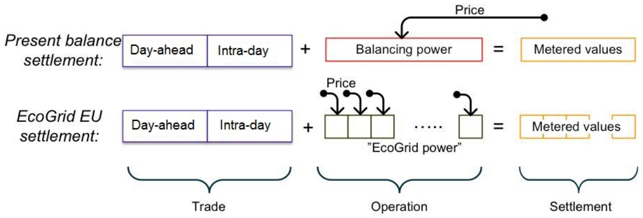


Fig. 5. EcoGrid price based on expected marginal balancing (Source: Preben Nyeng/Energinet)

Figure 5 (top) shows today's best practice, where the price paid for the balancing power required to bring the system back to equilibrium is related to the metered values of the actual imbalances relative to the negotiated schedules. This settlement may happen at the end of the month.

Figure 5 (bottom) shows the proposed EcoGrid real-time market settlement. The distributed price is based on the present and expected system balance costs as well as on the forecasts of price elasticity. With the right price-forecast algorithms, the incremental 5-min prices multiplied with the achieved real-time demand-response represent the same integrated economic settlement, although now distributed to individual DERs and accomplished in real time.

IX. Demonstration On Danish Island Bornholm

For the real-world demonstration of the European smart-grid pilot in the 2012-2014 time frame on Bornholm, advanced meters and other smart appliances will be installed at the homes and company premises of the 2,000 participants. These appliances will enable them to control their consumption more or less automatically by being actors on the EcoGrid real-time market.

Figure 6 shows the power grid of Bornholm island, which is connected to the Nordic Power System via a high-voltage interconnect, but has the ambition of self-controlling the available but fluctuating renewable energies by means of a more flexible consumption of the participants in the demonstration.

X. Summary and Outlook

The efficient non-transactional EcoGrid real-time marketplace concept, integrating and extending today's operation, along with the proposed lean price distribution service and protocol stack, as well as the elegant no-extra-measurements-required integrated energy billing and regulation service settlement are seen as having an enormous potential.

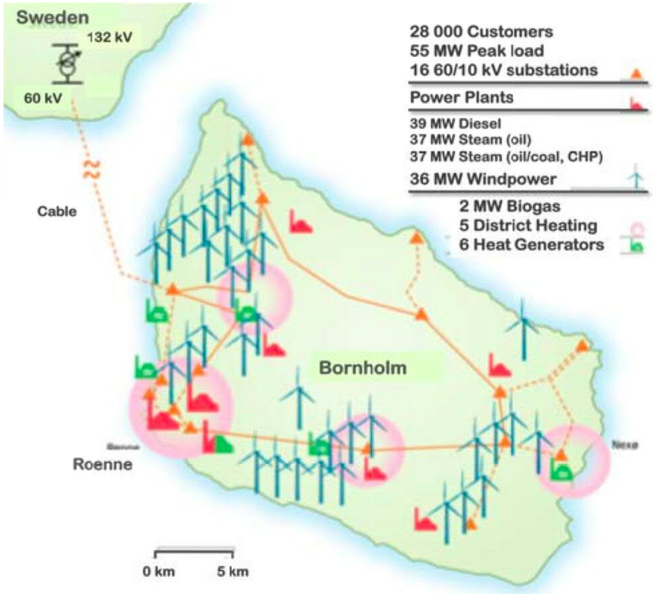


Fig. 6. Bornholm is a part of the Nordic Power System [6]

The pilot implementation and demonstration on Bornholm are only just starting, thus more time is needed to report on results.

However, the prospects for EcoGrid EU to create a “win-win” situation, enabling small and large electricity customers to save money on their electricity bill, while also relieving the power system, are good. And in the longer term, this will also reduce investments in grid reinforcements and new grids.

The savings at a European level have not yet been estimated, but the Danish electricity sector and Energinet.dk have calculated a direct socio-economic saving of at least DKK 1.6 billion when using smart-grid solutions in Denmark. Furthermore, an extra bonus will be the environmental benefit, Denmark will achieve by improving the integration of environmentally-friendly electricity and power savings.

ACKNOWLEDGEMENTS

The authors at IBM are indebted for the opportunity to participate in this visionary project, teaming with our partners at SINTEF, Energinet, Oestkraft, DTU-CET, Siemens, EnCT, ELIA, TECNALIA, AIT, TNO, EANDIS, TUT, EDPD, and Landis+Gyr.

Many of the key concepts described in this paper were developed by the original EcoGrid core team. Some of the dissemination material used was assembled by Maj Dang Trong of MDT Analysis, Preben Nyeng of Energinet, and the project coordinator Ove Grande of SINTEF.

The research leading to these results has received funding from the European Union Seventh Framework Programme under Grant Agreement no 268199.

REFERENCES

[1] P. Andersen, E. Hauksson, A. Pedersen, D. Gantenbein, B. Jansen, C. Andersen, and J. Dall. Smart Charging the Electric Vehicle Fleet. *Smart Grid - Applications, Communications and Security*, pages 381–408, April 2012.

[2] The Danish Edison project. www.edison-net.dk, 2009-2012.

[3] S. E. Deering and D. R. Cheriton. Multicast routing in datagram internetworks and extended LANs. *ACM Transactions on Computer Systems (TOCS)*, 8, May 1990.

[4] EcoGrid EU FP7 project. http://www.eu-ecogrid.net/, 2012.

[5] EcoGrid Newsletter. http://www.eu-ecogrid.net/images/Documents/120322EcoGridEU_Newsletter_nr.%201_February%2029_2012.pdf, February 2012.

[6] D. Hammerstrom et al. Pacific Northwest Gridwise Testbed Demonstration Projects: Part 1. Olympic Peninsula Project. Technical Report PNNL-17167, Pacific Northwest National Laboratory, Richland, WA, October 2007.

[7] D. Hammerstrom, T. Oliver, R. Melton, and R. Ambrosio. Standardization of a Hierarchical Transactive Control System. In *Grid Interop*, Denver, Colorado, 2009.

[8] B. Jansen, C. Binding, and A. Mishra. Input on the Real-Time Price distribution protocol for Ecogrid EU WP 3 Task 3.6. http://www.zurich.ibm.com/pdf/ecogrid/price_distribution_protocol_1.1.pdf, July 2012.

[9] J. Jorgensen, S. Sorensen, K. Behnke, and P. Eriksen. EcoGrid EU; A Prototype for European Smart Grids. In *Proc. IEEE Power and Energy Society General Meeting*, pages 1–7, 2011.

[10] A. Mishra, C. Binding, D. Gantenbein, B. Jansen, and O. Sundström. Initial Inputs to Ecogrid Task 3.5 on DER and Aggregator Communication and Standards Contributions. http://www.zurich.ibm.com/pdf/ecogrid/SOTA_price-protocols.pdf, July 2012.

[11] A. B. Pedersen, E. B. Hauksson, P. B. Andersen, B. Poulsen, C. Traeholt, D. Gantenbein, and B. Jansen. Facilitating a Generic Communication Interface to Distributed Energy Resources: Mapping IEC 61850 to RESTful Services. In *1st IEEE Int’l Conf. on Smart Grid Communications - IEEE SmartGridComm*, October 2010.

[12] O. Sundström and C. Binding. Flexible Charging Optimization for EVs Considering Distribution Grid Constraints. In *IEEE Transactions on Smart Grid*, volume 99, pages 1–12, 2012.