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POSTER ABSTRACT P1

Value and Regulation of Local Electricity Markets

Esther Mengelkamp*, Bent Richter, Henrike Maier and Christof Weinhardt

*Correspondence:
esther.mengelkamp@kit.edu
Karlsruhe Institute of Technology

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Local electricity markets (LEMs) provide an innovative market design alternative to the centralized, fossil-based energy system in line with the energy transition. We present a structured analysis of the economic, social, technological, and environmental LEM value propositions in literature and current LEM projects in the DACH+ region. Most LEMs see regulatory barriers as the most crucial challenge. We present the German regulatory niche of a Customer System as one opportunity to implement LEMs. However, it is only a temporary solution as network fees would be propagated towards non-LEM participants if Customer System LEMs became the norm.

Keywords: local electricity market; value proposition; regulation; customer system

1 Introduction

The transition from the former fossil-based towards a sustainable, renewable-based energy system requires the development of new market solutions [1, 2]. Local electricity markets (LEMs) are one solution to this challenge. They provide a platform for trading locally generated electricity within a community. Supply security is typically ensured through connections to a superimposed system (e. g. national grid) [3]. Thus, they allow formerly excluded small-scale electricity customers, i.e. producers, prosumers, and consumers, to participate in the market actively [4]. LEMs can be used to increase the social acceptance of new electricity infrastructure projects, empower a community, and build up local electricity balances [1, 4].

Like any new market concept, LEMs need a clear value proposition to become sustainable and long-term successful. We analyze the economic, technological, environmental, and social value proposition of LEMs in Section 2. Section 3 provides a short overview of current LEM implementation projects in the DACH+ region to discuss their value propositions. The most pressing challenges in all projects are regulatory obstacles. Most projects are implemented within regulatory niches. In Germany, the most promising regulatory niche is the Customer System. We show how a Customer System may limit the usual charges on electricity for LEM participants in Section 4. Finally, Section 5 concludes the work.

2 Value Propositions of LEMs

LEMs follow the need for localization of the current energy system [5, 6] by enabling local and regional electricity balances through local trading. While a LEM adds the market layer to a physical distribution or microgrid, it does not require a specific physical grid. It can also take the form of a virtual market framework on top of any generation and distribution system. Recently, much attention has been given to the market mechanism of LEMs [7, 8]. Despite the active research about LEM designs, a detailed analysis of their actual value propositions has not been conducted yet. We address this knowledge gap and provide a four sectional analysis of the economic, social, technological, and environmental value proposition of LEMs in Table 1.

Table 1 The economic, social, technological, and environmental value propositions of LEMs.

Economic Value	Social Value
• Reduction of transmission/distribution costs [9, 10] • Capture the value of *locality* of generation [11] • Provision of alternative to feed-in tariff for small-scale RES [2] • Opportunity for low cost or premium local electricity prices [3]	• Empowerment of local communities and distributed actors, keep profits and jobs local [4] • Development of (partial) independence from large electricity suppliers/utilities [12] • Provision of access to locally generated electricity from RES [13]
Technological Value	**Environmental Value**
• Reduction of transmission losses [14] • Enticement of demand and generation flexibility [15] • Optimization of grid expansion [9] • Reduction of (re-) dispatch [2] • Adequate integration of distributed RES and, thus, increase of system resiliency and stability [16]	• Enticement of local RES generation to match local demand [15] • Reduction of traditional generation emissions through balancing local demand and RES generation [17] • Use of local resources (e. g. sun, wind) [9] • Preservation of nature [9]

The economic value propositions focus on the reduction of current costs or increase of profits for LEM participants. Technologically, reduction of transmission losses and redispatch and, in the long term, a reduction of grid expansion offer opportunities for improved electricity supply. From a social point of view, the development and empowerment of (partially) autarkic energy communities allow establishing (partial) independence from energy suppliers. Finally, the environmental value is established by increased incentives for RES generation, the use of local resources, and the preservation of nature, e. g. a reduction of deforestation for grid expansion. Future work should extend this analysis to include the political aspects of LEMs.

3 Status of LEM Realization Projects

Several LEM projects have been build in the last years. However, actual analyses and comparisons between the existing projects' are yet to be found. We provide a short comparison of 9 exemplary LEM projects in the DACH+ region in Table 2 and discuss their specific value propositions after [18]. All projects focus on the integration of RES into the energy system, developing new concepts for RES and grid management, and economic as well as social and environmental value.

Table 2 shows that the projects are still in the early development or research and development (R&D) phase. Thus, they strive to implement their value propositions but are still figuring out how and which theoretical value propositions can be translated into real-life. They all focus on less than 600 trading agents.

The most significant challenge for all projects is the missing (or opposing) regulation and the uncertainty over which fees, i. e. taxes and levies, need to be paid in their LEM. Seven of the nine projects reported that they are not implemented in traditional regulatory scenarios ("no") but in regulatory niches. Two projects are implemented within traditional regulation ("yes"). In Germany, the typical regulatory niche for a LEM is the Customer System, which we discuss in Section 4.

Table 2 Overview of 9 LEM implementation projects in the DACH+ region after [18].

	LAMP	pebbles	P2PQ	Quartier-strom	VPP	SoLAR	RegHEE	D3A	Energy Collec.
Time	06/17-12/19	03/18-03/21	08/18-08/20	10/17-03/20	03/17-03/20	05/18-04/21	03/19-02/22	start 11/16	start 07/17
Status	R&D, proto-type	R&D, proof-of-concept	R&D, proof-of-concept	R&D, field test	R&D	demon-strator	R&D, proof-of-concept	R&D, prod-uct dev.	R&D, proof-of-concept
Agents	13-20	8-10	42	38	550	23	15-20	30	21
Fees	no fees	depends, e. g. taxes	VAT, energy-related taxes	distribu-tion net-work fees	tbd	all except net-work fees	tbd	grid fees	network fees, VAT
Regu-lation	no	no	no	yes	no	yes	no	no	no

4 Customer System in LEMs

The Customer System ("Kundenanlage") defined by German law (§3 Nr. 24 EnWG) is the most used current regulatory niche for LEMs in Germany [19]. The Customer System encompasses several end consumers and at least one local generator. They are connected over an electricity grid. The number of participants in this zone is not allowed to be a threat to competition on the national market. The operator must provide residual demand. The main advantage of a Customer System is the removal of part of the typical price components (fees). A LEM in a Customer System is not subject to network and network-related charges[1]. Thus, the LEM price for electricity can drop from the current German electricity tariff of 29,63ct/kWh to nearly 16,32 ct/kWh (see Table 3). Overall, deploying a LEM in a Customer System can save up to 45% of the end consumer price. This economic benefit can be shared between the local producers and consumers to improve the economic and overall attractiveness of LEMs. Thus, the Customer System is a feasible regulatory niche that can exploit the economic value of LEMs, while it does not directly address the technological, environmental, and social value propositions of LEMs. In today's jurisprudence, the range of agents in Customer System goes from about 100 to 450 participants in 2018 legal decisions. Further judgements are expected.

Table 3 Components of the German electricity price in 2018

Cost element	Public Distribution grid	Customer system
Energy retail price	6,61	6,61
Network charges	6,76	0
Metering fees	0,31	0,31
Concession fees	1,61	0
Renewable surcharge	6,79	6,79
Network-related surcharges	0,77	0
Electricity tax	2,05	0
Value-added tax (19 %)	4,73	2,61
Total	29,63	16,32

5 Conclusion

This paper presents an analysis of the economic, social, technological, and environmental value propositions of LEMs in literature. Then, an overview of current

[1] These are charges according to §26 Combined Heat and Power Act and §19 (2) Electricity Grid User Charge Ordinance, offshore liability fee (§17f Energy Industry Act), charges for switchable loads (§18 Regulation on Curtailable Loads) and the electricity tax for generation under 2 MW.

LEM implementation projects in the DACH+ region is conducted. Currently, most LEM projects focus on improving the integration of RES into the grid and economic value. However, due to all projects being in the early development stages (e. g. pilot projects), it is uncertain whether this value proposition, or any other, will be realized as regulatory obstacles are their main challenge in implementation. Currently, most projects operate within regulatory niches to implement a LEM.

The Customer System is a suitable German regulatory niche to implement LEMs. Its main value proposition is the economic value through minimization of network and network-related charges. Overall, up to 45 % of the usual electricity charges could be saved. However, the implementation of LEMs in Customer Systems can only be a temporary solution, as there would be a redistribution of network charges from LEM to non-LEM participants if many LEMs avoided (a large part of) network fees. Thus, we strongly urge current regulators to adapt (inter-) national regulation to support the implementation of LEMs without disadvantaging non-LEM agents.

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POSTER ABSTRACT P2

Towards Price Based Demand Side Management Using Machine Learning

Mischa Ahrens[1*], Jan Müller[2] and Hartmut Schmeck[1,2]

*Correspondence: ahrens@fzi.de
[1]FZI Research Center for Information Technology, Haid-und-Neu-Str. 10-14, 76131, Karlsruhe, Germany
Full list of author information is available at the end of the article

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Abstract
In demand side management, variable electricity pricing is often used to shape the load of electricity consumers and producers. The task of finding the right price profile to realize a target load profile is a bilevel optimization problem that varies in complexity depending on the considered distributed energy resources. Solutions to this problem proposed in the literature usually rely on extensive simplifications and often consider only specific device types or load shaping methods. Simple pricing schemes often fail to induce specific target load profiles due to effects like load synchronization.

This poster abstract extends a machine learning based electricity pricing scheme proposed in previous work. Its objective is to generate price profiles based on knowledge about the behavior of energy resources in response to different price profiles and in various situations. Principally, the presented pricing scheme can be used for any device configuration under the assumption that it offers exploitable flexibility and is governed by an automated energy management system aimed at minimizing energy costs.

Keywords: Demand Side Management; Electricity Pricing; Machine Learning

Introduction and Related Work

The transition from centralized, fossil fuel based towards renewable energy generation introduces a growing share of decentralized energy resources (DERs). DERs transform the traditional energy consumer into a prosumer, i.e., a consumer as well as a producer. This asks for solutions to maintain a reliable and economical operation of the energy system. One of these concepts is demand side management (DSM), which aims to utilize the flexibility of the former demand side to adjust its consumption and generation, in the following referred to as load, to achieve given goals. Demand side flexibility steadily increases with the integration of intelligently managed DERs like photovoltaics (PV), small combined heat and power (CHP) plants, battery energy storage systems (BESSs), air conditioning systems, electric vehicles, heat pumps, and intelligent appliances.

There are different approaches to DSM, for example the direct control of DERs or the use of variable, time-dependent electricity prices. This work focuses on generating price profiles that lead to desired behavior, i.e., the realization of target load profiles by groups of prosumers. The prosumers considered in this work inhabit residential buildings with automated building energy management systems (BEMSs) and local means for energy generation and storage.

The problem of finding a suitable price profile to realize a target load profile is part of a bilevel optimization problem [1]. Buildings react to a certain price profile by optimizing their load profile to minimize their energy cost. The demand side manager (DSMgr) has to find a price profile that leads to a minimum deviation of the aggregated optimized load profiles of the buildings from a target load profile. This problem varies in complexity depending on the considered energy devices. Solutions proposed in the literature usually rely on extensive simplifications and often consider only specific device types [1,2] or load shaping methods like peak-to-average ratio reduction [3]. Other approaches require the ongoing participation of prosumers in the price formation process, which entails continuous communication and computation costs [4–6]. An intuitive approach to shape load profiles would be to use prices that are inversely proportional to the target load, i.e., prices are high when the target load is low and vice versa. However, this method can lead to load synchronization, where new, undesired load peaks emerge as a result of the simultaneous response of many prosumers to the same prices [7]. Note that load synchronization can also happen for individual prosumers with multiple DERs.

This work presents a method to design price profiles in a way that aims to prevent load synchronization and to enable the accurate realization of target load profiles. The approach uses a machine learning model to generate price profiles based on knowledge about the behavior of specific combinations of DERs in response to different price profiles and in various situations. In so doing, this work modifies and extends the approach presented in [8] by introducing a variable feed-in compensation and group pricing, where all buildings in a building group receive the same price profile. The use of machine learning to solve the presented problem is motivated by its wide-spread usage to derive non-linear relations implicitly from noisy training data and its recent utilization in other DSM applications [9–11].

Problem Definition and Approach to Solution

A DSMgr aims at minimizing the deviation between a target load and the aggregated load of a group of buildings by finding suitable prices for all time slots in a particular time period. This can, for example, be useful, if the DSMgr tries to minimize the procurement costs of the predicted required energy. The fundamental optimization problems the DSMgr and the buildings try to solve have been established in previous work [8] and can be extended to also consider time-dependent feed-in compensations to increase the DSMgrs influence on the behavior of the buildings. The relation between the price profiles determined by a DSMgr and the resulting load profiles of buildings optimizing their load profiles according to variable prices is subject to many influences like the flexibility of the devices, weather, time of day and year, inhabitant preferences and stochastic inhabitant behavior. These influences are often too unpredictable to allow analytical solutions to the problem of finding suitable price profiles.

Simulation

Since measured real world data on buildings that optimize their load profiles according to variable electricity prices are very sparse, sufficiently large training data sets for machine learning have to be gathered from simulations.

The Organic Smart Home (OSH) framework [12] is an automated BEMS and building simulation framework that targets the optimization of the energy usage of real as well as simulated buildings. Its simulation capabilities and successful application in real world scenarios [13] make the OSH a fitting tool to generate realistic training data for machine learning applications.

The OSH is used to simulate the behavior of groups of buildings with several different energy devices and installations for a wide range of different price and feed-in compensation profiles. The resulting load profiles, together with the corresponding price and feed-in compensation profiles as well as other state data are used as training data for an artificial neural network (ANN). The objective is that the trained ANN is able to output price and feed-in compensation profiles that induce the realization of target load profiles by the considered building groups. During the computation of new price and feed-in compensation profiles, the model considers the current aggregated state data of the building group.

For individual or small groups of buildings, the load is strongly influenced by short-term choices of the inhabitants. To a certain extent, this can make the load independent from given prices, which can prevent an ANN to learn meaningful dependencies. As a consequence, a larger group size of, e.g., 100 buildings is more suitable to train the model. If all buildings in a group receive the same price and feed-in compensation profiles, short-term choices of the inhabitants in a group of this size are expected to cancel out.

To prevent the ANN from memorizing specific PV generation profiles, different PV profiles are derived by calculating randomly weighted sums of measured PV profiles for a specific day of the year, the two preceding and the two succeeding days and dividing by the sum of the random weights. In this way, an arbitrary amount of new PV profiles can be generated, which approximately resemble realistic progressions for the corresponding time of the year.

Price Data Generation

For the training of the ANN, many different price and feed-in compensation profiles and consequent load profiles are needed as training examples. This data is generated by drawing random price values from a uniform distribution for each hour of the day to create an arbitrary number of day long price profiles with hourly price changes. These price profiles are generated in a way that predefined maximum, minimum and average prices are not violated, which constrains the search space for the ANN and increases the financial fairness among buildings receiving different price profiles.

Reference Pricing Schemes

As points of reference for the performance of the new pricing scheme, simpler schemes are implemented for comparison.

The simplest pricing scheme is *constant pricing*, where the electricity price and feed-in compensation are constant and fixed. It is used to show what happens if no action is taken to shape the load profiles.

Another relatively simple pricing scheme is *load proportional pricing*. This means that prices are high, when the target load is low and vice versa.

Conclusion and Outlook

In this poster abstract, an outlook on the implementation of a machine learning based scheme for variable electricity pricing was given. The scheme is aimed at incentivizing groups of buildings with energy storage and generation capabilities as well as BEMSs to follow target load profiles.

The proposed pricing scheme utilizes an ANN to learn the relationship between price and feed-in compensation profiles and realized load profiles from training data generated by simulating a group of 100 buildings. Simpler reference pricing schemes were described as tools for the evaluation of the new scheme.

Future work will detail already obtained evaluation results providing a performance comparison of the new pricing scheme and the reference pricing schemes for varying weather conditions and times of year.

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Availability of data and materials
No additional data is available.

Author's contributions
Mischa Ahrens developed the presented approach and wrote all chapters except the introduction. Jan Müller provided support and feedback during all stages of the presented work and wrote the introduction. Hartmut Schmeck provided continuous support, feedback and funding.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]FZI Research Center for Information Technology, Haid-und-Neu-Str. 10-14, 76131, Karlsruhe, Germany.
[2]Karlsruhe Institute of Technology (KIT), Institute AIFB, Kaiserstr. 12, 76131, Karlsruhe, Germany.

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POSTER ABSTRACT P3

A Concept for Standardized Benchmarks for the Evaluation of Control Strategies for Building Energy Management

David Wölfle[1*], Kevin Förderer[1] and Hartmut Schmeck[1,2]

*Correspondence: woelfle@fzi.de
[1]FZI Research Center for Information Technology, Haid-und-Neu-Str. 10-14, Karlsruhe, 76131, Germany
Full list of author information is available at the end of the article

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Abstract

Given the expected high penetration of renewable energy production in future electricity systems, it is common to consider buildings as a valuable source for the provisioning of flexibility to support the power grids. Motivated by this concept, a wide variety of control strategies for building energy management has been proposed throughout the last decades. However, these algorithms are usually implemented and evaluated for very specific settings and considerations. Thus, a neutral comparison, especially of performance measures, is nearly impossible. Inspired by recent developments in reinforcement learning research, we suggest the use of common environments (i.e. benchmarks) for filling this gap and finally propose a general concept for standardized benchmarks for the evaluation of control strategies for building energy management.

Keywords: building energy management; building control; environment; benchmark; evaluation; reinforcement learning

Introduction

In order to limit the unpredictable and potentially devastating effects of global warming, the governments of most countries have committed themselves to drastically cut CO_2 emissions by 2050 [1]. Consequently, the federal government of Germany has enacted the "Klimaschutzplan" [2] (literally "climate protection plan") defining concrete measures to achieve this ambitious target, including a complete decarbonisation of the German electricity production and an extensive electrification of the heat and mobility sector ("Sektorenkopplung"). While it seems to be consensus that high shares of renewable energy production will lead to an increased demand for energy flexibility [3, 4, 5], it also appears that buildings, in particular the heating, ventilation and air conditioning (HVAC) components of these, are especially suited to provide such energy flexibility [2, 6].

Thus, it is not very surprising that the optimization of energy consumption patterns of buildings is a common research topic. A review on control systems for building energy management [7] lists 121 publications, of which the vast majority optimize HVAC components. Albeit these control strategies appear unrelated to the provisioning of energy flexibility at first glance, both concepts can be connected by dynamic pricing strategies, as suggested, for example, in [8, 9].

Given the need for energy flexibility and the vast and diverse set of potential control strategies to provide such with buildings, the question arises how to evaluate which approach is best suited for a particular task. Following up we will thus investigate the current state of the art regarding the comparison and evaluation of control approaches for building energy management.

State of the Art

While reviewing the existing literature, it was possible to identify qualitative and quantitative approaches for the comparison of control strategies for building energy management. General reviews like [7, 10, 11] use rather qualitative measures and thus focus on a meta level. The contrasting of control strategies is carried out using general topics, such as the implemented algorithms, the applied control schemas, the utilized simulation tools, and/or the considered devices. Albeit these publications are very useful in general, they provide no objective comparison of the achieved performance of the reviewed control strategies.

On the other hand, in publications following the second approach, it is common that the authors evaluate one or more control strategies in a very specific setting using rather quantitative metrics. For example, Salpakari & Lund [12] developed a complex model consisting of a heat pump with storage, photovoltaic panels, a battery and smart appliances inspired by an existing low energy house. Using that model, the authors compared a rule based based control (RBC) strategy to cost optimal behavior with respect to energy costs and self-consumption rates. Both Lösch et al. [13] and Faßnacht et al. [14] developed an algorithm for the scheduling of heat pumps based on a dynamic electricity tariff. The algorithms have been compared against the default hysteresis control strategy in a simulation with energy cost as performance measure. Oldewurtel et al. [15] compared RBC with two MPC approaches utilizing a custom developed simulation model on 1280 test cases with respect to energy usage, thermal comfort and temperature dynamics.

We were able to identify numerous publications following a similar schema to the ones introduced above. However we refrain from giving a more extensive review at this point, as it is out of this paper's scope. Concerning the main topic of this work, the evaluation of control strategies for building energy management, we identify two major issues. First and although many publications use similar metrics like energy usage or energy costs, it is not feasible to compare different approaches in a quantitative manner. This is due to the usual procedure of not reusing the simulation models of others, which may also be caused by the uncommonness of open source publications of these. The second issue arises if one considers the provisioning of electric flexibility through buildings on larger scales, which obviously leads to the utilization of numerous, potentially very diverse, buildings. However, the current procedure of evaluating control approaches against one simulation model alone leaves no indication how well the evaluated strategies generalize to other buildings.

Standardized Benchmarks in Reinforcement Learning

In reinforcement learning, a field closely related to control theory [16], several benchmarks have been published for the development, evaluation and comparison of algorithms. These benchmarks, commonly referred to as environments, have been widely adopted, which allows the direct performance comparison of newly developed algorithms with existing approaches, e.g. in [17, 18, 19]. Popular examples are often based on computer games, like the Arcade Learning Environment [20] while other environments focus on the control of robots [21] or implement "classic control" problems like balancing a pole on a cart [22]. It appears especially noteworthy that the Arcade Learning Environment in fact consists of 57 games and that reinforcement learning algorithms, e.g. [17, 18, 19], are often routinely evaluated against all of those. The distribution of scores is thereby considered a measure for the generalization abilities of the proposed algorithms, that is, an indication of the expected performance on related tasks.

The interaction with the environments follows the schema of observations, actions and rewards, which is generally well suited for control problems [16] and has been applied successfully to challenging domains, like e.g. aerobatic helicopter flight [23]. Consider the Atari game of space invaders as an example, in which the player can control a space ship at the lower end of the screen and receives points for shooting alien space ships approaching from the top, which is actually part of the Arcade Learning Environment. As common in reinforcement learning, the environment is processed in discrete time steps. In every time step, the environment emits a frame of the gameplay, called observation, as well as the current score referred to as reward. Observation and reward are then passed to the evaluated algorithm, which is usually named agent in reinforcement learning. The agent is queried for the next action, i.e. the control input to the environment, like e.g. move left, move right, shoot or do nothing. Once the action is passed to the environment, it will advance one time step, emitting a new observation and reward. These steps are usually run as a loop until a terminal state is reached, i.e. game over, while the accumulated reward is commonly used as metric to evaluate the performance of the algorithm.

Proposal

In order to overcome the issues identified in the current State of the Art, we propose the establishment of standardized and shared benchmarks for the evaluation of control strategies for building energy management following the example of environments used in reinforcement learning. We propose the following:

- To allow the development of building energy management approaches that can be applied to large number of diverse buildings, the benchmarks should be a collection of distinct building simulation models. These should focus on different optimization targets, e.g. heating, cooling or appliances, as well as varying objectives like e.g. own consumption or energy costs.
- All benchmarks should be published as open source projects to allow widespread usage and verification.
- The communication between algorithm and benchmarks should be standardized in order to limit the effort to execute a benchmark to the necessary minimum. The interface should follow the schema of observations, rewards and actions, as it is well established and allows the usage of available reinforcement learning algorithms for comparison.

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Author's contributions
DW developed the initial concept and wrote this article. KF and HS contributed discussion, feedback and revision.

Competing interests
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Author details
[1]FZI Research Center for Information Technology, Haid-und-Neu-Str. 10-14, Karlsruhe, 76131, Germany.
[2]Karlsruhe Institute of Technology, Institute AIFB, Kaiserstr. 12, Karlsruhe, 76131, Germany.

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POSTER ABSTRACT P4

Modeling approach for thermal dependencies in complex industrial energy supply system

Thomas Kohne*, Philipp A. Becker, Thomas Weber, Niklas Panten and Eberhard Abele

*Correspondence:
t.kohne@ptw.tu-darmstadt.de
Institute of Production Management, Technology and Machine Tools, Technische Universität Darmstadt, Otto-Berndt-Straße 2, 64287 Darmstadt, Germany
Full list of author information is available at the end of the article

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Abstract
Rising digitization in industrial production sites and processes offers the opportunity to implement optimization approaches for operational strategies of decentralized energy supply systems (DESS). Current model-based approaches like mixed integer linear programming (MILP) often neglect modeling temperature dependencies and thermal inertia in complex thermal grids in production sites. In this paper a modular MILP model is presented in a model predictive control (MPC) approach which integrates temperature dependencies and thermal inertia in complex DESS. The validation by simulation shows that the approach manages to map thermal dependencies successfully and reduce energy consumption and cost of the DESS by optimizing temperature levels. Hence the approach enables a stable optimized control of complex DESS.

Keywords: Industrial energy supply systems; Thermal dependencies; MILP; MPC

Introduction

Rising digitization in industrial production sites and processes offers the opportunity to implement optimization approaches for operational strategies of decentralized energy supply systems (DESS)[1, 2]. Typical DESS consist of energy converters and storages within thermal and electric grids[2]. Although detailed mathematical model-based approaches such as mixed integer linear programming (MILP) of converters exist (part load behaviour[3], ramp up[4]), current research often implements energy grids as power balances[5, 6, 7, 8]. This assumption fits for the electric grid in the energy network, but lacks of modeling complex thermal grids in production sites due to missing implementation of temperature dependencies and thermal inertia [9]. Some work already deals with such behaviour for example thermal inertia [10] and temperature in thermal grids [11, 12], but it is not tested in a complex DESS by using simulation models or real systems. The goal of this work is to integrate existing approaches which model thermal inertia and temperatures in thermal grids of complex systems and extend the approach by implementing a linear correlation between temperature in thermal grids and converter efficiency.

Model

In this section, the MILP model as a model predictive control (MPC) approach is introduced. The model consists of energy converters - defined by modular equations defining inputs (gas, electricity) and outputs (electricity, heating, cooling) - as well as storages which define the thermal grids for heating and cooling of the production processes.

Table 1 Parameters and variables of the model. (C: continuous, B: binary, t: time step)

Parameter	Unit	Explanation	Variable	Unit	Explanation
g	-	Thermal inertia factor	$C_t^{\mathrm{el/gas}}$	E	Energy cost (C)
$\mathrm{P}^{\mathrm{out,min/max}}$	kW	Converter power out	$C_t^{\mathrm{switch\_on}}$	E	Switch on cost (C)
$\mathrm{T}^{\mathrm{min/max}}$	$^\circ$C	Converter temp.	$P_t^{\mathrm{in/out}}$	kW	Power in/out (C)
$\mathrm{T}^{\mathrm{min,dem}}$	$^\circ$C	Min demand temp.	P_t^{set}	%	Converter set point (C)
$\mathrm{T}^{\mathrm{min/max,grid}}$	$^\circ$C	Thermal grid temp.	$T_t^{\mathrm{int/ext}}$	$^\circ$C	Converter/grid temp. (C)
α^{loss}	-	Thermal loss factor	T_t^{top}	$^\circ$C	Storage layer temp. (C)
$\eta^{\mathrm{nom,el/th}}$	-	Nominal efficiency	δ_t^{on}	-	Converter state (B)

Thermal storage and grid

A thermal grid as stratification model of a heating storage - described in [12] - is used as connection between energy converters and thermal energy demands (Figure 2). The power input provided by the converters is summed up and integrated in the top layer feeding the demand. The bottom temperature is returned to the converters. This allows to divide flow and return temperatures and thus integrate dependencies regarding the efficiency of converters into the optimization problem. Despite the min/max temperatures a min demand temperature for the production processes is introduced: $T_t^{\mathrm{top}} \geq \mathrm{T}_t^{\mathrm{min,dem}}$. The model is adapted to cold water as well.

Energy converters

The equations (eq) 1 to 5 describe energy converters depending on the power in- and outputs such as gas and heating in a condensing boiler. The converters can be operated between a minimum and maximum power. By separating a set power to the actual power output (eq 2) thermal inertia can be modelled with the factor g (eq 3) [Q11]. Moreover, ramp up behaviour for electric power output is implemented and switch on costs are considered.

$$\mathrm{P}^{\mathrm{out,min}} \cdot \delta_t^{\mathrm{on}} \leq P_t^{\mathrm{in}} \cdot \eta^{\mathrm{nom,el/th}} \leq \mathrm{P}^{\mathrm{out,max}} \cdot \delta_t^{\mathrm{on}} \tag{1}$$

$$P_t^{\mathrm{set}} = \frac{P_t^{\mathrm{in}} \cdot \eta^{\mathrm{nom,el/th}}}{\mathrm{P}^{\mathrm{out,max}}} \tag{2}$$

Due to the return temperatures of the thermal grid, thermal efficiency dependencies are modelled (eq 3). The temperature effect is exemplary shown in Figure 1. To satisfy MILP requirements, it must be differentiated between internal (converter) and external (grid) temperatures (eq 4-5) [13]. Moreover these equations ensure that a converter can only be switched on if the thermal grid fits temperature requirements. The shown equations apply to heating; the same approach is modelled for converters which supply cooling power.

$$P_t^{\mathrm{out,th}} = (\mathrm{g} \cdot P_t^{\mathrm{in}} + (1 - \mathrm{g}) \cdot P_{t-1}^{\mathrm{in}}) \cdot \eta^{\mathrm{th}} - \frac{T_t^{\mathrm{int}} - \mathrm{T}^{\mathrm{min}}}{\mathrm{T}^{\mathrm{max}} - \mathrm{T}^{\mathrm{min}}} \cdot \alpha^{\mathrm{loss}} \cdot \mathrm{P}^{\mathrm{out,max}} \tag{3}$$

$$\mathrm{T}^{\mathrm{min}} \leq T_t^{\mathrm{int}} \leq (\mathrm{T}^{\mathrm{max}} - \mathrm{T}^{\mathrm{min}}) \cdot \delta_t^{\mathrm{on}} + \mathrm{T}^{\mathrm{min}} \tag{4}$$

$$(1 - \delta_t^{\mathrm{on}}) \cdot (\mathrm{T}^{\mathrm{min,grid}} - \mathrm{T}^{\mathrm{min}}) \leq T_t^{\mathrm{ext}} - T_t^{\mathrm{int}} \leq (1 - \delta_t^{\mathrm{on}}) \cdot (\mathrm{T}^{\mathrm{max,grid}} - \mathrm{T}^{\mathrm{min}}) \tag{5}$$

Overall model and objective function

The converters and thermal storages/grids are connected as shown in Figure 2 while electric and gas grids are modeled as power balances. The overall model

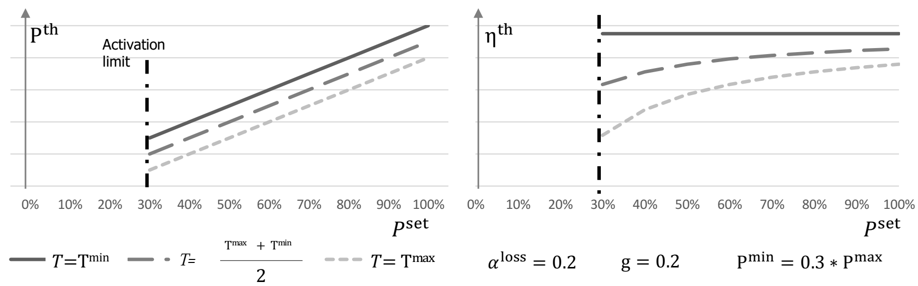

Figure 1 Effect of equation 5 on thermal power output (left) and converter efficiency (right).

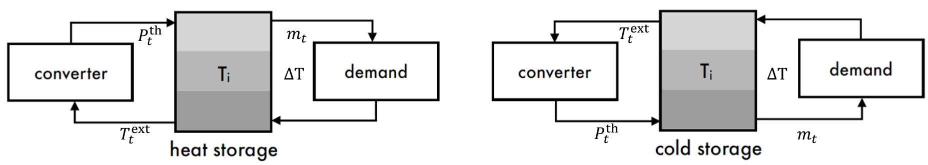

Figure 2 Connection between energy converters, thermal storages/grids and demand. The demand mass flow ($\dot{m}_t$) is calculated with a constant ΔT on the demand side [12].

is optimized by minimzing total cost consisting of costs for gas, electricity and virtual start up costs: min $C = \sum_{t=0}^{Horizon}(C_t^{\mathrm{el}} + C_t^{\mathrm{gas}} + C_t^{\mathrm{switch\_on}})$. The MPC controller as mathematical model is set up in the python framework Pyomo that offers modularity by dividing component library, data input and the overall model while the simulation model is implemented in Modelica.

Case study

To validate the model, data on energy demand, weather information and energy prices of a real automotive production site of 2018 were collected. The energy demand is supplied by a system consisting of combined heat and power (CHP) unit, condensing boiler (B), immersion heater (IH), heat pump (HP), photovoltaic system and hybrid cooling with compression chiller and cooling tower. As energy storages and grids between energy converters and demands a battery and two thermal storages for cooling and heating are implemented. On several typical work days, the DESS is optimized considering 24 hours as time horizon. The results conclude that the MILP-MPC controller enables a stable optimized control of the simulation model in terms of grid temperature and demand satisfaction. Moreover, as shown on an exemplary optimization run of a 24 h time horizon in Figure 3, the controller operates the thermal system on optimal temperatures to minimize efficiency losses. At relatively low electricity prices the heating storage is heated up with the IH to use the heat during times of high electricity prices. Thus, compared to a hysteresis and rule based controller, the energy cost are reduced overall by 6.5 %.

Conclusion

This work presents an approach to model temperature dependencies and thermal inertia in complex DESS while being modular applicable to different converters and

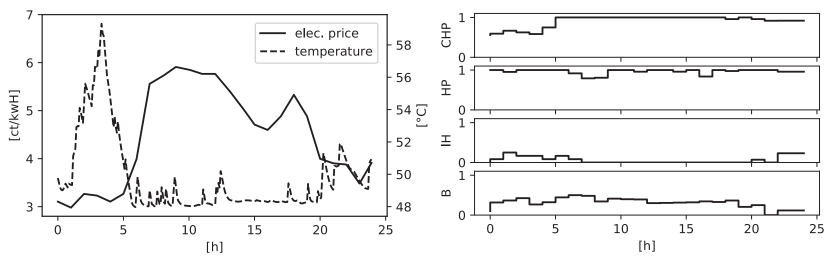

Figure 3 Exemplary results for the heating grid in grid temperature and converter set points

use cases. The validation shows that the MILP-MPC approach is able to keep a simulation model stable. Moreover, it optimizes temperatures in the thermal grids due to the variety in electricity prices. Thus, the approach manages to reduce energy costs compared to a typical rule based controller. In future work, the parameters should be further trained on real data sets so that the approach can be tested in real environments.

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Availability of data and materials
The data sets analyzed during the current study are available from the corresponding author on reasonable request.

Author's contributions
T. Kohne and P. A. Becker significantly conceptualized, implemented and validated the model. T. Weber and N. Panten gave important input. All authors provided feedback and helped shape the research, analysis, and manuscript.

Competing interests
The authors declare that they have no competing interests.

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POSTER ABSTRACT P5

Estimation of the Regional Electricity Mix

Philipp Danner[1*] and Hermann de Meer[2]

*Correspondence:
philipp.danner@bayernwerk.de
[1]Bayernwerk AG,
Lilienthalstraße 7, 93049
Regensburg, Germany
Full list of author information is
available at the end of the article

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Abstract

In future electricity systems, flexibility is seen to be the counterpart to the volatile renewable energy resources like photo-voltaic or wind plants. A flexible usage of mobile (e.g. electric vehicles) and immobile loads (e.g. electric heating systems) could be utilised in order to maximise the usage of energy from renewable sources without neglecting the power limits of the grid. Beside the temporal differences, also the spatial difference of the energy mix is important. Consumption of local renewable energy as near as possible to the actual generation helps to reduce the amount of energy transmission and thus grid capacity needs and power losses. Spatial electricity mix calculations have only been performed on high level (country, control area or bidding zone) so far. In this work, we propose a method to estimate the electricity mix by modelling the energy demand and supply on municipal level. This is done by utilising statistic data sets and suitable profiles (e.g. standard load profiles) or (simple) generation models in order to incorporate temporal differences. Finally, the dynamic supplies and demands are assigned to high voltage to medium voltage substations using the geographically k-nearest substations and a suitable distance metric in order to create a computable power grid model.

Keywords: Renewable Energy; Energy Data Analysis; Electricity Mix Estimation

Introduction

In the course of the energy transition to renewable energy sources, more and more volatile generation plants are integrated into the power grid. In particular, these include on/off-shore wind, bio-gas, hydro power and Photovoltaic (PV) plants. PV systems, bio-gas and hydro power plants are usually small and distributed in the grid in contrast to traditional power plants. A first goal to optimally use the volatile renewable energy is the temporal matching of power supply and demand through flexibility in generation and consumption. Second, a spatial matching of power supply and demand reduces the grid loading and thus power losses. This is due to the fact that generated electric power is not transmitted over long distances but consumed as locally as possible. The focus in this work is on regional level (municipals).

In this work, we present a concept on how to derive a regional model for approximating the electricity mix on temporal and spatial level. The model uses statistical data sets and publicly available data on electricity consumption and renewable power plants in order to parameterize suitable profiles for consumers and models for energy producers. The gathered data serves as input for a computable power flow model by assigning the dynamic supplies and demands with a distance metric to high voltage (HV)/medium voltage (MV) substations, e.g. the k-nearest substations.

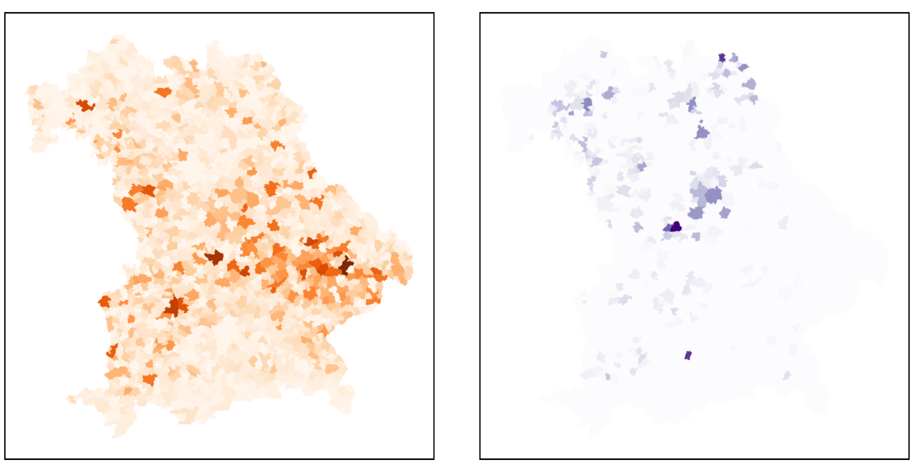
Related work for Electricity Mix Estimation

There have been several efforts in research and industry to prepare available data in order to model and visualize the energy mix on spatial level.

For estimating the electricity mix in the national power grid, control areas or bidding zones, power generation and consumption data from the Transmission System Operators (TSOs) and energy spot markets have been used. Beside the German platform SMARD.de [1], the European Network of Transmission System Operators (ENTSO-E) provide a transparency platform [2] as a central collection and publication of electricity generation, transportation and consumption data and information for the pan-European market. A qualitative analysis on the ENTSO-E data was performed in [3]

The open source project of electricitymap.org [4] visualizes the carbon intensity (gCO2eq/kWh), low-carbon energy as well as renewable energy generation in the electricity system by utilising ENTSO-E data. Spatial aspects are therefore only considered on country and sometimes on control area or bidding zone level.

The Bavarian government provides a platform, called *Energieatlas Bayern*, in which the renewable energy sources with their peak power are allocated according to their registered address [5]. From the data of this platform it can be seen that there are big differences between the different energy generation sources within Bavaria as Figure 1 exemplarily visualizes with PV and wind peak power installations on low and medium voltage level (peak power <10 MW). The *Energieatlas Bayern* energy mixing tool only provides yearly total consumption and production of energy and completely neglects the volatility of renewable energy sources.



(a) PV peak power (b) Wind turbine peak power

Figure 1: PV and wind peak power installations per municipal in Bavaria

Methodology

In order to estimate the electricity mix of the power grid, both power supply and demand need to be considered. We also propose to include the distance of the electricity resources (supply and demand) to the next HV/MV substations in the calculation of the electricity mix in order to better fit to the topology of the grid.

1. Energy Supply and Demand Modelling

In the first step, the peak power of the different renewable energy sources as well as the power demand is allocated on a geographical map. For power plants, the registered location or data from OpenStreetMap or Open Power System Data [1] can be used. The peak power and weather data serve as input to PV and wind generation models in order to handle the dynamics of the volatile energy production (e.g. similar to renewables.ninja [2]). Bio-gas and hydro power plants are considered with a constant power generation over time. The yearly energy consumption of a region (e.g. municipal) can be estimated using the method of "Bayerisches Landesamt für Umwelt", described in [6]. Available total electricity consumption of households, manufacturing industry and other employees in Bavaria is subdivided to the single municipals using the number of inhabitants, number of employees in manufacturing sector and the rest of employees per municipal respectively. Standard load profiles are mapped to the yearly energy consumption of the households (BDEW H0), manufacturing sector (BDEW G1) and other employees sector (BDEW G0) in order to add the temporal dynamics of their usual behaviour [7].

2. Power Grid Assignment

In a second step, the gathered power generation and consumption data is mapped to the power grid. For each electricity resource (power supply and demand), the dynamic amount of power per type is added up to the geographically k-nearest HV/MV substations weighted by its Euclidean distance. Figure 2 visualises this procedure in a part of Lower Bavaria. As result, we obtain a list of substations and their aggregated and dynamised amount of power per type of renewable (PV, wind, bio-gas, hydro) and type of load (households, industry, other employees sector).

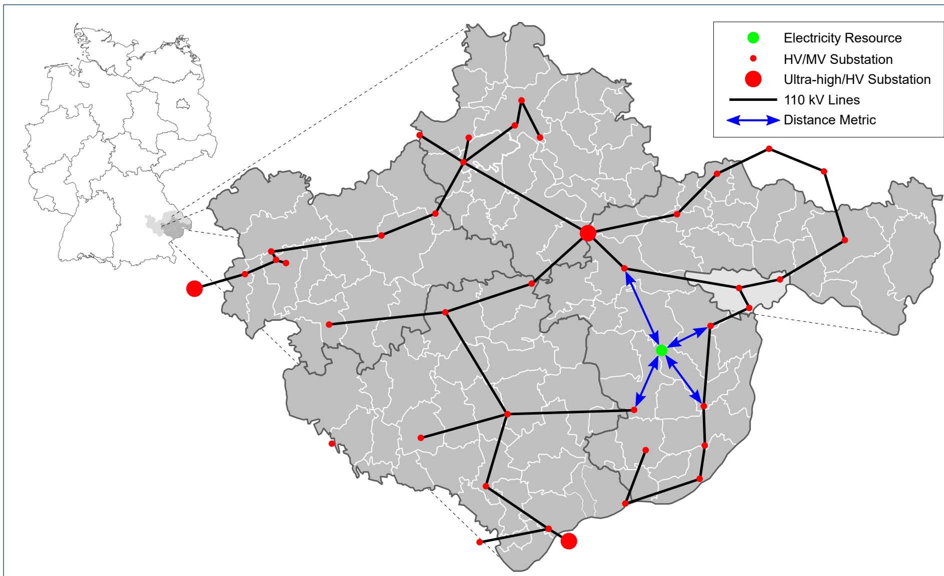


Figure 2: Mapping of electric resources to k-nearest HV/MV substations, k=4

[1] https://data.open-power-system-data.org/
[2] https://www.renewables.ninja/

3. Estimation of Electricity Mix

For the request of the electricity mix at a certain point, the weighted electricity mix of the geographically k-nearest substations is used (similar to the distribution of power supply and demand in the previous step). The mix is then calculated by the regional supply demand matching of the substations and, in case of demand from the upper grid, incorporating also the power flow calculation of the remaining grid, which is parameterized with the power supply and demand of all substations on high voltage level and the next HV/ultra-high voltage connection as swing bus.

Conclusion and Outlook

In this work, we propose a method to estimate the regional electricity mix on municipal level by utilising statistical data sets and publicly available grid topology data on high voltage level. This is done by creating a temporal and spatial depending model of regional power supply and demand.

In future work, an evaluation of the model as well as some model limitations will be addressed. The actual electricity mix also depends on the power flow on ultra-high voltage level, which has been put aside in this model so far. Possible improvements could be a better distance metric for assigning the electricity resources to substations (e.g. the measured impedance to the substation). In addition, the model could be extended with a calculation of CO2 emission as described in [8] to also distinguish between the different CO2 footprint of non-renewable power plants.

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Availability of data and materials
Raw data are available at the mentioned platforms, processed data are available from the authors on request.

Author's contributions
PD did main research on related work and developed the method for the estimation of the electricity map on regional level. PD also wrote the poster abstract. HdM contributed in conception and revision of the general idea and the poster abstract. All of the authors have read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Bayernwerk AG, Lilienthalstraße 7, 93049 Regensburg, Germany. [2]University of Passau, Innstraße 41, 94032 Passau, Germany.

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POSTER ABSTRACT P6

Disruptive Business Models Enabling Large Battery Energy Storage System Deployment

Egor Mazourenko[1*], Philipp Heer[2], Dr.Elena-Lavinia Niederhaeuser[3] and Dr.Dimitri Torregrossa[4]

*Correspondence: egor.mazourenko@aurorasgrid.com
[1] Aurora's Grid, EPFL Innovation Park, Route Cantonale, 1015 Lausanne, Switzerland
Full list of author information is available at the end of the article

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Abstract
The paper focuses on the economic profitability of Battery Energy Storage System (BESS) in distribution grids, accounting for interests of local Distribution System Operator (DSOs) and Prosumers equipped with photovoltaic (PV) panels. Measured data from a small distribution grid was analyzed and multiple scenarios simulated. Its economic performance of the storage was analyzed for CAPEX in 2019 and 2030. Business model extensions have been accounted for identifying profitability for the mayor stakeholders. It was found that for BESS located at a Prosumer side most of the benefit accumulates for the DSO. If optimized for joint interests, negative IRR result.

Keywords: BESS; Interest formulation; Prosumer; Peak shifting; Self consumption; Ageing aware operation

1 Introduction

Many European Countries introduced climate policies to comply with the Paris Agreement introduced in 2015. The Swiss federal council developed a policy package called the "Swiss energy Strategy 2050". In addition, a development of PV systems due to cost reduction and subvention for renewable energies leads to an increased installation rate[1]. PV boosts production volatility and creates a time mismatch between energy production and consumption. The potential to overcome this mismatch results in an interest in BESS. The main issue with the installation of BESS is the high capital expenditure (CAPEX) per kWh. There is a need to increase the profitability of this investment trough 1) a reduced ageing, 2) increased utilization and 3) new business models.

The paper is organized as follows. Section 2 introduces the stakeholders in a distribution grid and BESS characteristics. Section 3 shows the case setup and the results. Section 4 presents the analysis and discusses a new business model. The conclusion highlights the main contributions and future outlook.

2 BESS and Stakeholders

BESS Characteristics

A generic parameter set is given in Table 1. The current cost of a BESS is based on quotations on LiFePo Storages whereas the forecasted cost of 500 CHF/kWh for 2030 is based on the historical decreasing trend[2]. Battery sizes of [4,6,8,12] kWh were considered with a bounded SoC and a Norm (dis-)charge Rate of $C_{norm} = 0.5\frac{kW}{kWh}$ to account for the ageing mitigation. An ageing aware operation of BESS allows to increase its lifetime[3].

Table 1 Considered BESS parameters from [4]

Category	Descriptor	Value	Unit
Cycles at rated DoD	$cyc_{80\%}$	6'000	–
Round Trip Efficiency	η_{RT}	80	%
Depth of Discharge	DoD	80	%
Calendar Life	T_{cal}	13	yr

Main Stakeholders

DSOs relay electrical energy from the transmission system to end customers on medium and low voltage levels. Additionally, they maintain the necessary grid infrastructure and extend it when necessary.

Prosumer communities are one or multiple neighboring end-customers aggregated together. They consume energy from the grid or consume self-produced energy.

Economic Evaluation

The IRR (internal rate of return) is taken as economic performance indicator, as it can be easily compared with the WACC (Weighted Average Cost of Capital) of DSOs. For given yearly total benefit $B(t)$, yearly total cost $C(t)$, and an evaluation-horizon, in this case equal to the calendric lifetime of a storage system T_{cal}, the internal rate of return IRR defined as a value fulfilling:

$$\sum_{t=0}^{T_{cal}} \frac{B(t) - C(t)}{(1 + IIR)^2} != 0$$

3 Case Study

The provided yearly load profile of the residential building has a total consumption of 97'000 kWh and the installed PV system produced 94'000 kWh. Each case was simulated with BESS in new conditions and BESS at 90% and 80% capacity respectively to incorporate ageing effects over its lifetime. Figure 1 shows the monthly distribution of benefit to each stakeholder with a new 12 kWh BESS. One can observe that the benefit does not distribute equally. Over a year 64.6% of the benefits accumulates at the DSO, whereas 35.4% at the Prosumer. The dashed lines show

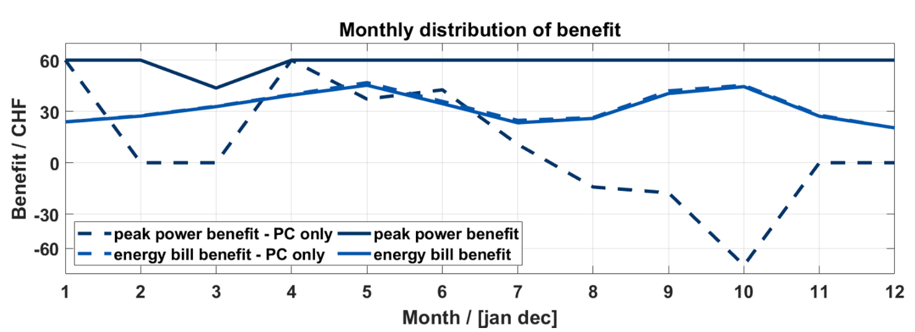

Figure 1 Monthly distribution of benefit

the Prosumer and the DSO benefit with a "Prosumer only optimization". The solid lines represent a "combined optimization". With such a setup the overall benefit is not necessarily increased, as for example at times when the BESS is already discharged at evening hours due to high consumption and charges as soon as low tariff times start. At these hours, typically, the major peak in the overall grid occurs and consequentially the peak power in the distribution grid is larger with BESS than without BESS. This scenario can be observed in month 8, 9 and 10. The BESS which are only controlled to Prosumer interests (dashed case), the power peak is increased, which leads to a negative benefit for the DSO.

4 Discussion

The simulations from the case study in Section 3 lead to negative IRR for BESS sizes of 4, 6, 8, and 12kWh capacity, installed at 2019-CAPEX. In Figure 2 one can observe an increasing IRR for increasing BESS sizes. One can argue that this is caused by two factors: 1) decreasing CAPEX for increasing BESS capacity and 2) a higher potential benefit to reduce DSO power peaks. To cover the DSO interest with even larger BESS, the subsequent power rating still increases, but the potential energy that needs to be stored/released grows over-proportionally due to the shape of power peaks in distribution grids. These peaks are observed to broaden over-proportionally towards the base of the peak. One can observe a significant increase in economical performance when multiple interests are included in the control of the BESS (e.g from $IRR_{PC}^{19} = -12.9\%$ to $IRR_{comb}^{19} = -2.8\%$ for 12kWh capacity). The performance increases further for 2030-CAPEX simulations (e.g from $IRR_{comb}^{19} = -2.8\%$ to $IRR_{comb}^{30} = 10.51\%$ for 12kWh capacity). There is only a small decrease in the Prosumer benefit for the combined case. If only Prosumer interests are optimized, the BESS is under-used. So, it is possible to shift BESS usage within high tariff/low tariff times which leads to small reductions in benefit for Prosumers, but with significantly increased benefit for DSOs.

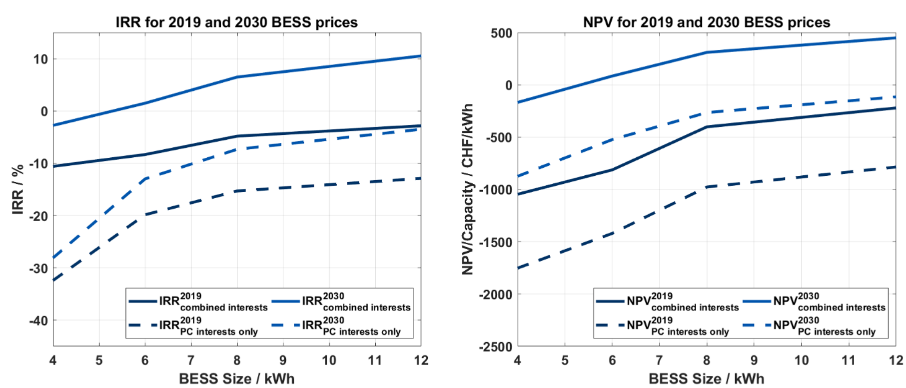

Figure 2 Internal Rate of Return - for varying BESS sizes and interests

Business Model

Multiple Business Models focusing on prosumers have been computed, BESS as a leasable good showed the most promising results without the need of a big change in the economical environment. Prosumers profit from the time value of money and therefore redistribute the costs over the BESS lifetime. Figure 3 shows the reachable

IRR depending on the retail and feed-in tariffs with this model. 66 out of the 121 scenarios are leading to a positive IRR which represent 54.55% of IRR>0% while only 8.26% are positive in a case of initial front payment. This analysis highlights

IRR Leasing Battery		Retail - Tarrifs (CHF/kWh)										
		0.2	0.21	0.22	0.23	0.24	0.25	0.26	0.27	0.28	0.29	0.3
Feed - In Tarrifs (CHF/kWh)	0.00	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%	4.03%	4.57%	5.10%	5.62%	6.14%
	0.01	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%	4.03%	4.57%	5.10%	5.62%
	0.02	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%	4.03%	4.57%	5.10%
	0.03	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%	4.03%	4.57%
	0.04	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%	4.03%
	0.05	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%	3.48%
	0.06	-3.46%	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%	2.92%
	0.07	-4.20%	-3.46%	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%	2.34%
	0.08	-4.98%	-4.20%	-3.46%	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%	1.76%
	0.09	-5.79%	-4.98%	-4.20%	-3.46%	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%	1.17%
	0.10	-6.63%	-5.79%	-4.98%	-4.20%	-3.46%	-2.74%	-2.04%	-1.36%	-0.71%	-0.07%	0.56%

Figure 3 Internal Rate of Return - Leasing Case

the fact that BESS are becoming more profitable in a high retail and low feed-in environment.

5 Conclusion

The paper focused on economic profitability of a small distribution grid composed of a local DSO and a residential building equipped with PV panels and a Li-Ion BESS.The case study showed that the main benefit is accumulated by the DSO. A split in terms of CAPEX and OPEX with the same percentage as the benefit split could lead to higher installation rates for distributed BESS. Additionally, business models linked with BESS operation can increase the profitability. Currently, under the considered value streams, no profitable operation of small scale BESS can be found. Due to the proposed business model positive scenarios arise. The leasing model offers up to 6.14% IRR and yield up to 62.81% positive cases. Yet, this profitability is conditional to the future market environment and the industry ability to increase efficiency and reduce BESS price (CHF/kWh).

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Author details
[1] Aurora's Grid, EPFL Innovation Park, Route Cantonale, 1015 Lausanne, Switzerland. [2] Empa, Überlandstrasse 129, 8600 Dübendorf, Switzerland. [3] Aurora's Grid, EPFL Innovation Park, Route Cantonale, 1015 Lausanne, Switzerland. [4] HEFR, Boulevard de Pérolles 80, 1700 Fribourg, Switzerland.

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POSTER ABSTRACT P7

Asset Logging – transparent documentation of asset data using a decentralized platform

Andreas Zeiselmair[1*], Michael Hinterstocker[2], Alexander Bogensperger[1] and Serafin von Roon[2]

*Correspondence: azeiselmair@ffe.de
[1]Forschungsstelle für Energiewirtschaft e.V., Am Blütenanger 71, 80995, Munich, Germany
Full list of author information is available at the end of the article

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Abstract
Documentation of asset data often shows inconsistent approaches. Due to missing standards, especially the exchange of asset-specific information in the energy sector is a big challenge. The paper describes the current challenges in the energy system, fields of application, the requirements for a standardized platform as well as a proposal for such a system based on blockchain technology.

Keywords: asset logging; blockchain; asset management; documentation

Introduction

Documentation and verification of asset data in the energy sector often shows inconsistent approaches, different levels of digitization and levels of detail. Especially within processes in the energy sector that include several participating parties, there is a demand for standardized data provision and unified interfaces for the exchange of asset-specific information. As business models change due to digitalization, the increasing relevance of asset sharing and service applications results in more frequent data exchange between stakeholders [1]. In order to provide a transparent, traceable and tamper-proof middleware, the concept of a blockchain-based energy data platform for "Asset Logging" has been developed [2], [3]. Therefore, it can provide a middleware for a whole field of applications with a special focus – but not limited – to the energy sector. [4], [5]

Asset Logging platform

There are hardly any standardized processes regarding asset documentation. This gap could be filled by a platform with a comprehensive collection, maintenance and provision of uniform data records. Processes that are linked to data exchange can therefore potentially be stored in a decentralized, tamper-proof and traceable data repository (cf. [6]). The basic structure of such a platform includes a selection of possible assets and the path of the data to the distributed data storage via auditing bodies, i.e. service providers or a trusted "(smart) metering system" on the one hand. On the other hand, applications or business cases can be set upon the provided data by the companies involved (see fig. 1).

Fields of application

The number of possible applications based on the data provided range from third-party services such as insurance or maintenance over standardized interactions with

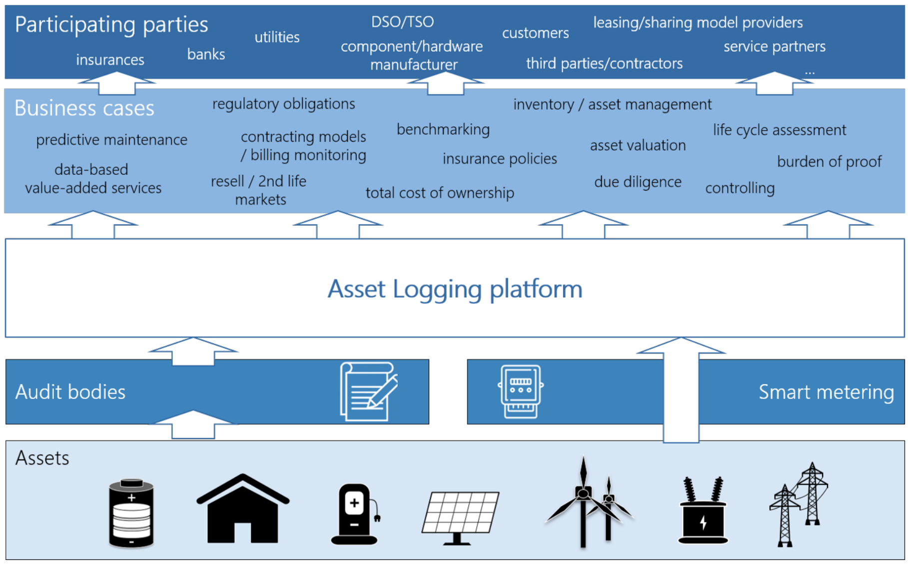

Figure 1 Schematic illustration of an Asset Logging platform

other market participants or regulators to in-house usage of the data. One example are resell and 2nd life markets, where the operating history, in addition to the current condition, is decisive for an objective evaluation of the asset value. Using a tamper-proof data basis, the information asymmetry can be eliminated and a comparable evaluation of supplier and buyer side is possible. Especially within the energy sector, technical due diligence plays an important role. All information on utilization and operation that is included in the assessment is therefore particularly relevant. Within the increasing relevance of leasing and contracting models, a common database is of particular interest not only for billing purposes, but also with regard to proof of performance or efficiency. Furthermore, technical risk management as well as maintenance strategies can be derived from this. [5], [7]

Requirements analysis

The described use cases in the field of asset logging have specific requirements regarding the characteristics of the underlying software platform which are necessary to provide a reliable data basis. A suitable structure and architecture for this platform can subsequently be deduced from these characteristics and features. The platform has to fulfill four essential properties, in order to serve for secure inter-organizational processes [8]: *1. Time-discrete data storage:* The chronological order of events and measurements has to be represented reliably in the stored data, *2. Immutability:* Subsequent changes to or manipulation of stored data has to be prevented by the system *3. Transparency:* All authorized stakeholders have access to their relevant data, *4. Multiple write access:* Decentralized data acquisition allows concurrent storage of multiple measurements or other data sets;

Concept for blockchain-based implementation

The identified requirements can be fulfilled by developing an appropriate data management infrastructure for decentralized data acquisition, immutable storage as well

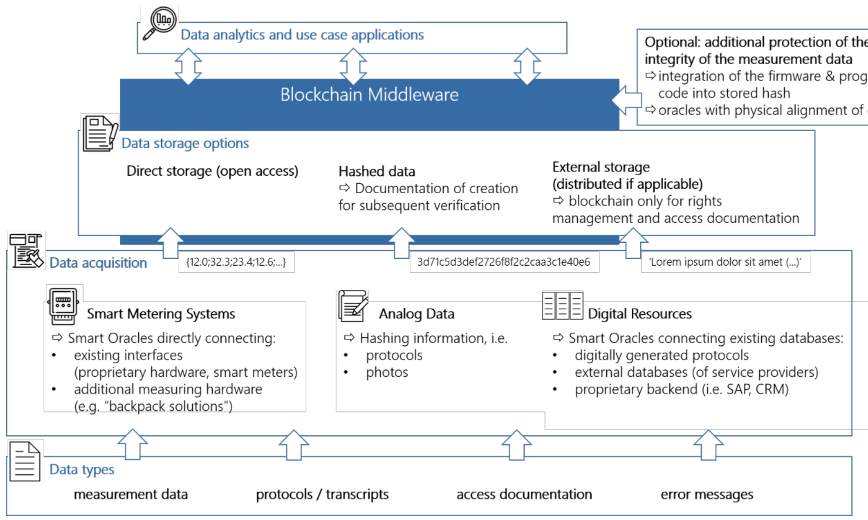

Figure 2 Technical concept of a blockchain-based Asset Logging platform

as automated and transparent evaluation based on blockchain technology [9], [10]. This technology evinces several distinctive features, which correspond to the demanded properties, and therefore, allows implementing this system. The overall concept is schematically depicted in fig. 2. Data from several sources is collected and written to the blockchain-based data platform. The decentralized structure enables all stakeholders to directly access the platform and to reliably verify the data integrity. Smart contracts on the blockchain platform automatically verify, analyze and evaluate the data and therefore, provide the basis for use cases and applications which utilize this data basis.

Data types, acquisition, storage and access

Besides *measured data*, which are recorded directly at the plant by integrated or separate measurement technology (i.e. smart meters), *protocols* (i.e. control inspection, maintenance or repair logs) that have already been recorded digitally or analogously by the responsible authorities can be included. Also *access documentation*, i.e. proof of reading, changing or deleting data can be recorded either in the system or at the communication interface. Additionally, validation logic can be implemented, e.g. by means of consensus oracles, which can further increase data integrity. Handling and storing the acquired data according to the usage and privacy demands ranges from direct storage on the blockchain (on-chain and open access) to hashing the information for documenting existence and creation date (for subsequent verification) or even storage in an external (distributed) database and use of the blockchain only for rights management and access documentation. The integrity of the data is either ensured by trusted sources (i.e. certified smart meters) or by the utilization of smart contract oracles. While data on the blockchain is tamper-resilient, querying outside sources could potentially cause inconsistent states due to minor differences in latency, leading to different results for the same query. To overcome this and ensure consistency, smart contract oracles work as a recipient of transactions for external sources and change their state according to transaction contents [11]. Different implementations of smart contract oracles further ensure the quality by using multiple external sources [12]. The energy sector has certified, calibrated and trusted smart meter gateways that can act as a secure and trusted interface for smart contract oracles [13]. The connection of these two realms has yet to be established.

Conclusions

The proposed Asset Logging platform offers the possibility to securely store documentation data and to provide relevant stakeholders with traceable and tamper-proof information. Nevertheless trustworthy data acquisition and transmission is the basis for trustworthy data management. A uniform definition of the interfaces (APIs) and the associated technological openness is decisive for the broadest possible application. Finally, the possibilities are by far not limited to energy applications. Ultimately, proof of a decentralized platform could develop into the industry standard in the future. In order to address these points, FfE is currently setting up a research and implementation project , combining both asset logging and proof of origin of energy flows in cooperation with 11 project partners [14].

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Author's contributions
AZ developed the main ideas and the implementation concept with support by MH and AB. AZ and MH wrote the paper with contributions by AB. SvR supervised the project. All of the authors have read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Forschungsstelle für Energiewirtschaft e.V., Am Blütenanger 71, 80995, Munich, Germany.
[2]Forschungsgesellschaft für Energiewirtschaft e.V., Am Blütenanger 71, 80995, Munich, Germany.

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POSTER ABSTRACT P8

Sector Coupling with Optimization: A comparison between single buildings and combined quarters.

Lena Heidemann[1*], Denis Bytschkow[2], Alexandre Capone[1], Thomas Licklederer[1] and Michael Kramer[1]

*Correspondence: lena.heidemann@tum.de
[1] Technical University of Munich, Munich, Germany
Full list of author information is available at the end of the article

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Abstract

The combination of building technologies with renewable energies, storage systems and low carbon technologies, like Combined Heat and Power (CHP) and heat pumps, demands to consider different energy networks in building energy management systems (BEMS) to enable sector coupling. This and the observation that energy equipment in buildings is often oversized and seldom used to its full potential during most time of the year calls for a holistic approach to establish sustainable multi-energy neighbourhoods. In this work, we introduce a model for a district energy system with sector coupling that integrates BEMS and compare the results of this model for the optimized operation of single buildings and the integrated solution to quantify the possible saving potential.

Keywords: Sector Coupling; Multi-Energy Prosumers; Optimization and Model Predictive Control; Building Energy Management Systems; Quarters and Energy

Introduction

Our future requires a sustainable energy system. It needs to be holistic and cover all kinds of energy related sectors, including electricity, heating and mobility. It is inevitable, that the interdependence between different energy networks becomes stronger with the availability and penetration of renewable energies, storage systems, low carbon technologies, including Combined Heat and Power (CHP), heat pumps, Power-to-X systems and electric vehicles. The tight integration of sectors is mathematically described by multi-vector energy systems, as described by Liu and Mancarella [1], Geidl et. al [2], Orehouning et. al [3] and others. They introduce models to describe the energy system as an input to output relation. They use those models to optimize the operation and planning in districts.

Current buildings with energy supply equipment, be it photovoltaics, solar thermic heat production, CHPs, heat pumps and also cooling are planned to deliver the required energy even under harsh weather conditions. Consequently, the installed capacity often is larger than required during the most time of the year. Because of that, the equipment operates either in a non-optimal energy efficiency range, or turns on and off too often leading to high maintenance costs. When we consider only the operation, two possible solutions exist to improve the situation. First, single buildings can be optimized as much as possible using an intelligent building energy management systems (BEMS), as shown by [4]. The second option is the interconnection of the neighbourhood, as suggested by [1, 3]. This introduces the possibility to exchange energy between the entities and use the potential of the connected buildings much better. This work compares the two operational possibilities.

Model

Our model describes a decentralized multi-energy system at district level. Instead of modeling the district as a sum of demands and power generation, each building is modeled with its own demand and devices, which supply energy only for this particular building. We use the general power flow model:

$$\boldsymbol{L} = \boldsymbol{C}\boldsymbol{P}, \tag{1}$$

$$\boldsymbol{P}_{LB} \leq \boldsymbol{P} \leq \boldsymbol{P}_{UB}, \tag{2}$$

$$\boldsymbol{G}\boldsymbol{P} \leq \boldsymbol{h}, \tag{3}$$

where $\boldsymbol{L}$ denotes demand, $\boldsymbol{C}$ the coupling matrix, $\boldsymbol{P}$ the generation, $\boldsymbol{P}_{LB}$ and $\boldsymbol{P}_{UB}$ its boundaries, $\boldsymbol{G}$ and $\boldsymbol{h}$ temporal constraints to model storage capacities. To enable power exchange between buildings, we extend the power input vector by the power flow vector $\tilde{\boldsymbol{P}}$ and the coupling matrix $\boldsymbol{C}$ which results in the new load vector $\tilde{\boldsymbol{L}}$:

$$\tilde{\boldsymbol{L}} = \underbrace{\begin{bmatrix} \boldsymbol{C} & \boldsymbol{C_{HDN}} \end{bmatrix}}_{\tilde{\boldsymbol{C}}} \underbrace{\begin{bmatrix} \boldsymbol{P} \\ \boldsymbol{X_{HDN}} \end{bmatrix}}_{\tilde{\boldsymbol{P}}}$$

$\boldsymbol{X_{HDN}}$ and $\boldsymbol{C_{HDN}}$ describe the heat distribution system with losses that are described by the line efficiencies. The heat flow between buildings becomes visible and distinguishable, which allows for an individual loss calculation. The model is designed not only for single optimization, but rather as an input for a model predictive controller (MPC) that runs on an aggregation platform[5].

Main Results

We model five buildings using typical demand profiles and equip each building with a set of common components that have certain benefits to see some variation. The scenario is explained in more detail by [5]. We calculate the expected operational costs of each building individually and compare it to a holistic district optimization using MPC with perfect predictions assumed. For the simulation we use a co-simulation framework[1].

The simulation results show the impact of different prediction horizons on the cost savings of the buildings operated with individual MPCs. In the exemplary scenario a single building can improve its costs with optimization depending on its equipment from 0% (without storage) up to 10% (with batteries). The savings are less on cloudy days and only slightly better on sunny days. The introduction of other external factors, for instance dynamic pricing, further improves the optimization of the individual buildings.

In contrast to single buildings the interconnected district reaches savings of around 20% in our scenario even with a one time step MPC horizon of one hour, independent of fixed or dynamic pricing. The major reason is that inefficient components, like oil and gas boilers, are substituted by more efficient ones. Surprisingly, the savings are not improved with longer MPC horizons, since in the interconnected case

[1] URL: https://github.com/SES-fortiss/SmartGridCoSimulation

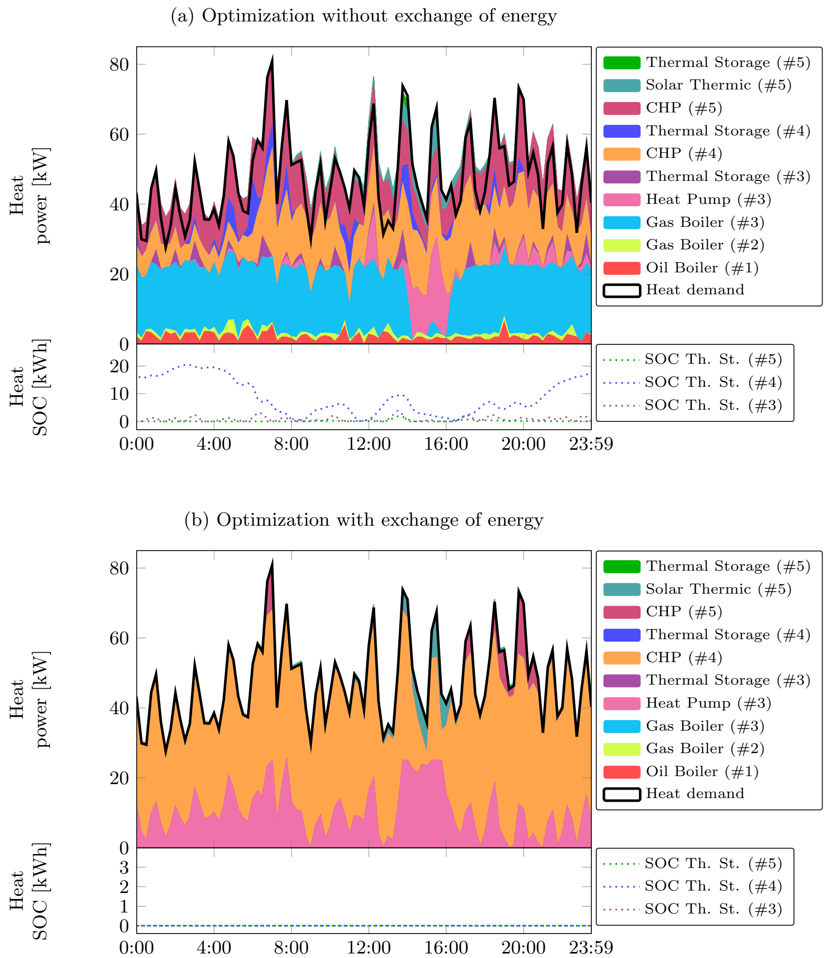

Figure 1 Comparison of the reference scenario (a) without exchange of energy and our system (b) with exchange of energy, 1h prediction horizon, fixed electricity price.

of the investigated scenario no storages are used and no foresighted loading or unloading is possible. Therefore, longer MPC horizons do not affect the optimization. Storages are not used because of two aspects: The PVs, CHPs and heat pumps establish a very self-sustaining system, that is able to cover the demand in every time step. Additionally, the parametrization of the scenario makes energy exchange more efficient than storing. Therefore in every time step the demand is covered by instantaneous generation and distribution. The appearance of such phenomena is an indicator for the plausibility of the underlying model.

The combination of CHPs and heat pumps also reveals one large limitation of our system: CHPs and heat pumps typically provide heat at totally different temperature levels (e.g. 80°C vs. 40°C). Therefore, they are hardly compatible in a common district heating network. Low temperature heat networks or multi-pipe networks with different temperature levels could be an approach therefore. Our model can be easily extended to these options, however this opens many technical questions with respect to the hydraulic implementation.

On top, there are also economical questions rising: in the interconnected case efficient components consume more fuel than before, while inefficient components do not consume fuel at all. Hence, the cost savings shift the overall financial obligations and requires new business model for compensation. Further research will be carried out in this direction.

Conclusion

We introduced a district energy system with sector coupling and exchange of energy with the goal to exploit the full potential within the district and decrease operational costs. By means of a comparison to single buildings, we explored the behavior of the systems in the interconnected case. Our system achieved a considerable cost reduction by using the district's devices in a more efficient way. Our model builds on the energy hub approach proposed by Geidl et al. [6, 2], but extends it to a neighborhood level. Orehounig et al. (2015) [3] take a similar approach, but their focus is on the design and sizing of a decentralized district energy system, less on the operation. Losses for energy distribution are considered on a network level. Our model can identify the paths and amount of heat flow between the buildings with its heat distribution network. The system is modeled in a simplified manner, but detailed heat networks can easily be included in the model and used for a more sophisticated calculation of transport losses. It is also not limited to the presented example. The modular approach allows to adapt our scenario to other network topologies and a different set of devices.

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Availability of data and materials
The data, models and the co-simulation environment used for this work are available as open source under the URL: https://github.com/SES-fortiss/SmartGridCoSimulation

Author's contributions
All authors contributed to this work. Author #1 implemented the presented work in the co-simulation environment, carried out the comparison study with the network losses and wrote the major part of this paper. Author #2 implemented the co-simulation environment including the initial version of the presented work (without network losses). Author #3 developed the initial version of the model, helped in transferring this concept into the co-simulation. Authors #4 and #5 have proof read the work, carefully analyzed and interpreted our simulation results and made several suggestions for the improvement of the scenario.

Competing interests
The authors declare that they have no competing interests.

Author details
[1] Technical University of Munich, Munich, Germany. [2] fortiss GmbH, Munich, Germany.

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POSTER ABSTRACT P9

Load management for idle capacity of power grids

Vincent Layec* and Holger Wache

*Correspondence:
vincent.layec@fhnw.ch
Institute for Information System, School of Business, University of Applied Sciences and Arts Northwestern Switzerland, Riggenbachstr. 16, 4600 Olten, Switzerland
Full list of author information is available at the end of the article

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Abstract

A major issue hampering a rapid substitution of fossil fuels by electricity from sustainable sources is the fear of congestion of the power grid and of associated costs of their reinforcement. The conventional approach prevents any rapid raise of electricity demand by encouraging other energy carriers and sector coupling. However, no approach investigates the utilization of the full capacity of the power grid alone, which are kept idle to provide sufficient reserve for the case of a failure. Therefore, we test a load management approach designed to utilize this reserve capacity. We verify in this paper the correct functionality of the system made of a device manager for cost optimization of schedules and of a grid manager to enforce the respect of power limits of the grid. This novel approach contributes to reduce emission of greenhouse gases without grid reinforcement.

Keywords: power grid capacity; load management; congestion; sector coupling

Introduction

Energy systems are undergoing transformations towards a reduction of emissions of greenhouse gases. A reduction of on-site consumption of fossil fuels in energy intensive industries may be encouraged by policies raising the taxes on CO_2, under the condition that adequate alternative supplies becomes available. The progresses and drop of prices make decentralised energy conversion (like Power–to–X units), storage and automation technologies good candidates to become these alternatives. Under the prerequisites summarized in Figure 1, we assume that many new flexible loads will be installed within a short time frame, which may increase the risk of a congestion of the power grid. We concretize then a load management system designed, by a better utilization of existing capacities, to avoid a grid reinforcement.

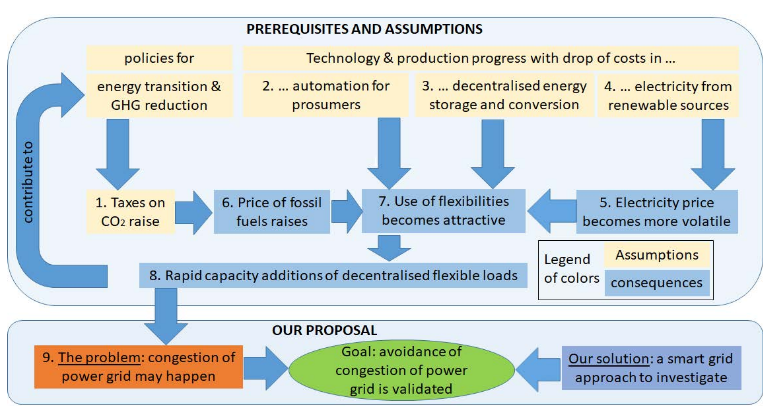

Figure 1 Prerequisites and assumptions in the context of the project

State Of the Art and Utilization of the Unused Grid Capacity

The selection and operation of available technologies of oil, gas, heat or electricity supply, their conversion or storage at end-customers and at distribution system operators (DSO) should be cost efficient. [1] and [2], which answers also the network design question, proposed a first solution for the coupled operation of several energy networks, but still can not be applied for real-sized grids. Our opposite approach is a total switch of energy carriers into only electricity. But this switch could in worst-case roughly double the load on the electricity grid and the fear of a grid congestion which would disqualify our approach. The risk of congestion, as known from high voltage grids in [3], is less documented in middle and low voltage grids where grids are designed larger than the minimal required capacity as cables are cheaper than workforce [4] and DSO would be obliged to reinforce their grid as soon as new loads are installed at their end-customers. Assuming a congestion due to new heat pumps, [4] quantified that a strong reduction of maximal capacities of each customer (from 17 to 6 kW) combined with shifts lowers the system load by only 1.5 % whereas a virtual power plant (VPP) contributes to 8.5 %. However, none of the methods utilizes the idle capacity of power grid kept for the security of supply. Indeed, the grid structure of open ring with two branches (Figure 2) supplies electricity to industrial customers in middle voltage grid. In case of a failure of one asset of the grid (the N-1 case), the power supply to its customers is guaranteed by the redundancies of the other branch (right side of Figure 2). The full capacity of power grids, designed for coping with the rare failure of one asset, has potential for flexibilities. [5] utilize the existing flexibilities with a "Traffic Light" to indicate their current limitations: major (red), some (amber) or none (green). They introduced a new category of loads, the "conditional loads" at reduced tariff (PAT), designed for all flexible loads like power-to-X units, heat pumps and batteries that do not require the security of supply. This security of supply remains hereby unchanged in all existing loads necessary to run the business (machines, ICT), renamed "unconditional loads".

Implementation

We implement the traffic light system of [5] enforcing that the sum of conditional loads is lower than a predefined part P (normally $P \leq 50\%$) of the grid capacity (green light, otherwise amber). A grid manager (GM) acts on behalf of the DSO with grid limits and a device manager (DM) on behalf of the customers with parameters of their aggregates. The day-ahead process of agreeing on schedules contains four steps of DM (DM1 - DM4) and one in GM:

1. **DM1:** DM optimizes schedules of local, conditional loads with new daily data.
2. **DM2:** As the solution schedule might not fulfill necessarily the limits of the grids yet, DM submits it (as "initial schedule") to GM for further controls.
3. **GM1:** In case of excess (yellow), GM curtails the "accepted power" in each customer involved, otherwise (green) it returns unchanged values to DM.
4. **DM3:** DM adapts the schedules of its aggregates when power was curtailed.
5. **DM4:** DM communicates with local devices and sends the last values of "accepted schedules" to the controller of each of its aggregates.

In the N-1 case (red light), the conditional loads are switched off in both branches until completion of reparation, whereas unconditional loads of the affected branch restart like up to now as soon as both branches get connected.

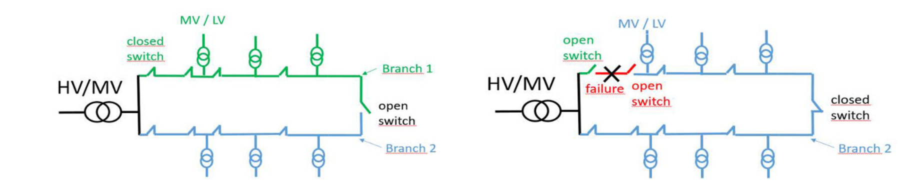

Figure 2 open ring grid structure (left) and supply (right) with closed switch in N-1 case

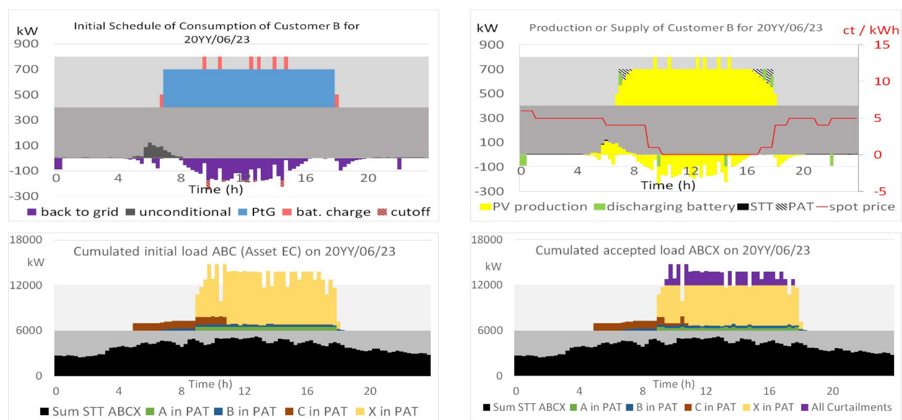

Figure 3 Initial schedules for B (top) and initial / accepted cumulative ones (bottom left / right)

Simulation settings and result

The daily simulation is based on data from real pilot industrial customers A, B and C and illustrated for B, with a planned extension of PV capacity to 700 kW, and a combination of new 100 kWh battery (with 100 kW) and an existing gas tank with a new Power-to-Gas (PtG) unit of 300 kW to increase the part of PV production consumed on site instead of feeding it back to the grid and reduce the import of fossil fuel. Figure 3 displays on top initial schedules i.e. the power value (consumption by usages left, production or supply right) of a full day. The consumption is split in the lower part, containing unconditional loads (dark grey), an upper part with conditional loads (blue for PtG, rose for battery charge) and a negative part (fed back to the grid). On the right graph, two sources of supply from the grid are displayed in black, standard tariff (STT, full) black and reduced conditional tariff (PAT, brindled). Production includes PV (yellow) and battery discharge (green).

To illustrate a grid congestion case, we assume that the three customers are located in the same branch of a middle voltage grid with 12 MW of capacity, out of them only 6 MW are reserved for unconditional loads. With its peak of cumulative unconditional at 5228 kW, and with timely coincidence between unconditional and conditional loads, the June 23rd is selected. Without the concept of the conditional load, the asset at the entry of the branch have 6931 kW from at 11 a.m. The split in 5031 kW unconditional and 1900 kW conditional is possible. To verify also the handling of a congestion within the conditional loads, we assume an ad-hoc customer X without unconditional loads but with up to four PtG units of 1 MW resp. 2 MW. The bottom left side of Figure 3 displays the cumulative initial schedule of all four customers including X in yellow: from 9 to 11 a.m. all conditional loads reach 8.9 MW and exceed the grid limit of 6 MW by 2.9 MW: all customers will have a reduced "accepted schedule", as shown on the bottom right side of Figure 3. This reduction is split over each concerned customer according a point system (see poster). The curtailed part (of all customers) is displayed in violet color.

On average over all 365 days, the N-1 band is utilized at a rate of 1.5 % with values from 0.0 % on January, 23^{rd} to 8.7 % on May, 20^{th}. In absence of customer X, no conditional load is curtailed. With customer X, the average utilization of the N-1 band raises to 7.3 % with values from 0.4 % on November, 7^{th} to 80.7 % on May, 20^{th}. Conditional loads are cut on 72 different days, at most by 17.1 % of the N-1 band on the worst-case day December, 19^{th}, but with a yearly average of only 0.9 % of the band. As the connection of additional customers in the same branch of the grid is less probable, the curtailment does not significantly damage the end-customers nor increase their cost by load shifts to other time slots.

Discussion and Conclusion

The approach was evaluated in scenarios with provoked grid congestions. Daily schedules of new flexible load connected as conditional loads were simulated with cost minimization. If all three customers would be located in the same branch of a middle voltage grid with peaks already just under 50 % of the capacity, the grid would become congested with the addition of new loads if unconditional, but not if conditional. In worst case for the grid, we simulate the entry of an opportunistic new customer X with a large power for conditional loads and Figure 3 show a congestion of the full capacity band reserved for the N-1 case. The curtailment mechanism by the grid manager is the ultimate protection against this kind of grid congestion. In all simulated 365 days, the accepted schedules respect the constraints of the customers and the cumulative schedule of all customers respects the capacity limit of the grid. Future work will evaluate some economic aspects of the concept in the perspective of end customers, like the profitability of investing in these new loads.

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Availability of data and materials
Input data are only the tariff system, the installed capacities, and the timeseries of spot price, of PV production and of electrical consumption from our project partners. Data are stored in the internal repository of the project.

Author's contributions
Analysis, investigation and writing by author 1, review and supervision by author 2.

Competing interests
The authors declare that they have no competing interests.

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POSTER ABSTRACT P10

Application Lifecycle Management for Smart Grid Use Cases in the Intelligent Secondary Substation

Stephan Cejka[1*], Florian Kintzler[1], Lisa Müllner[1], Felix Knorr[1], Marco Mittelsdorf[2] and Jörn Schumann[2]

*Correspondence: stephan.cejka@siemens.com
[1]Siemens AG Österreich, Siemensstraße 90, 1210 Vienna, Austria
Full list of author information is available at the end of the article

Energy Informatics 2019, 2(Suppl 2):P11

Introduction

It is of utmost importance to provide mechanisms for the installation or update of software on devices in the field. This requirement is further increased since the transition to the Internet of Things (IoT) introduces a high number of affected field devices that are required to be maintained. Our previous projects in the Smart Grid and Smart Building domain led to the requirement for a device and application management mechanism [1–3]. Important components in the affected parts of the electric power grid are the secondary substations located on the borders between the medium and the low voltage grid to connect local commercial and residential users to the power grid. The transition from the traditional grid to the Smart Grid includes equipping those traditionally passively operated isolated secondary substations with improved computational power and communication abilities, easing interaction with them and reducing maintenance efforts and costs (intelligent secondary substation – iSSN). Within the LarGo! project, we are investigating processes for the large scale rollout of software applications for energy and grid management [4]. The vast number of application modules, as well as the high number of substations a distribution system operator (DSO) has to maintain requires to issue typical application lifecycle management tasks from the remote site without staff required on-site.

Requirements and Tasks

The main requirements for the iSSN's application lifecycle management are:

- R1 Scalable device management by a central control center
- R2 Automatic deployment of software components to the devices
- R3 Modular system to easily compose required features on demand
- R4 Module dependency management
- R5 Automatic updates and configuration

The system's architecture is expected to consist of the DSO's central backend and control system, responsible for the management of the field devices' software components. Many target devices are controlled by this backend system; they are connected with the backend by a communication channel on which messages and artifacts are exchanged. Target systems allow for modular applications, thus the number of concurrently executed applications may be high [2]. Listed application lifecycle tasks [1] are issued on this backend system:

- T1 Installation of a software module
- T2 Start of this software module
- T3 Stop of this software module

T4 Uninstallation of this software module

T5 Update of this (possibly running) software module

T6 Configuration of this (possibly running) software module

T7 Information on the current state of the software modules (e.g., health check)

A resulting simplified application lifecycle graph is shown in Figure 1. Note that, T5 basically is a sequence of stopping and uninstalling the old version, and installing and starting the new version (T3-T4-T1-T2, if the module is currently running, or T4-T1, if not) with the old persistent state reused, in contrast to T6 which should not require a restart. Transitions to a *failed* state could occur at any task; they are left out in the figure for simplicity reasons.

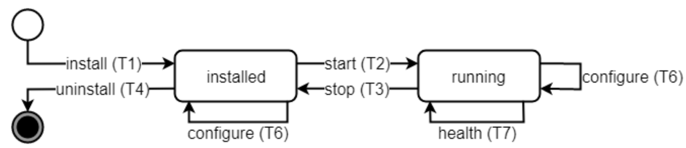

Figure 1 A simplified application lifecycle graph

State-of-the-art Evaluation and Implementation

The implementation of applications can differ depending on the use case (e.g., OSGi modules, Docker containers). As there exist no domain-specific solutions for software management, existing IoT solutions (Apache ACE[1], Apache Felix[2], Apache Karaf[3], balena[4], Eclipse hawkBit[5], Eclipse Virgo[6], Gridlink Application Framework Provisioning [1], SWUpdate[7], and cloud-provider solutions, such as AWS IoT Greengrass[8], and Azure IoT Edge[9]) were evaluated regarding the listed requirements and tasks. While the list is not exhaustive, it provides a good overview over the spectrum of currently available solutions. However, not all requirements and tasks can be fulfilled by the frameworks in evaluation: Most of the frameworks have only limited support of deployable components' types or they do not allow a central management of multiple devices. Furthermore, most of the frameworks show only limited support for the expected lifecycle tasks: an installation task usually already includes the start of the module, and modules cannot be stopped once running.

In result, the support for some of the defined main lifecycle tasks is limited. Thus, special challenges in the domain of Smart Grid application rollouts require a tailored solution. The architecture of a generic implementation for application lifecycle management in Industrial IoT (IIoT) use cases [3] is shown in Figure 2, including an optional *App Store*. In contrast to consumer IoT solutions, in IIoT use cases it needs

[1] https://ace.apache.org/

[2] https://felix.apache.org/

[3] https://karaf.apache.org/

[4] https://www.balena.io/

[5] https://www.eclipse.org/hawkbit/

[6] https://www.eclipse.org/virgo/

[7] https://github.com/sbabic/swupdate/

[8] https://aws.amazon.com/greengrass/

[9] https://azure.microsoft.com/services/iot-edge/

to be necessarily avoided that external systems have any access to field devices, especially since the App Store may not be within the sphere of the operator. Thus, purchased applications are first downloaded by the *Application Lifecycle Management Service (ALMS)* to the *Local Application Repository*, all situated within the operator's backend. The operator manages the several field devices by use of an *User Interface (UI)* on the backend side; there the enumerated application lifecycle tasks are issued. They are communicated to the *Application Lifecycle Management Agent (ALMA)* on the device, which executes specific shell scripts based on the file type and the task (Table 1). Those shell scripts can be implemented for any file type, thus the implementation shows to be very flexible and extendable.

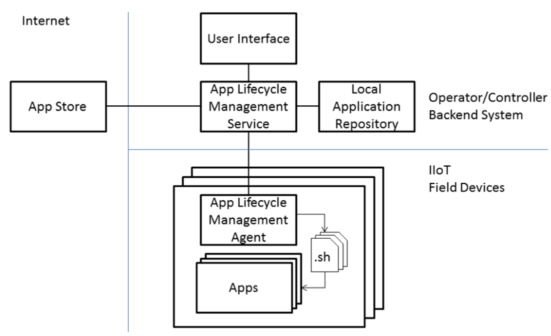

Figure 2 Generic Application Lifecycle Management Implementation

		Docker containers	**Docker container compositions**
Task	**Shell scripts**	`docker-◯.sh`	`compose-◯.sh`
install (T1)	`▽-install.sh`	`docker image load` `docker container create`	`docker-compose up --no-start`
start (T2)	`▽-start.sh`	`docker container start`	`docker-compose start`
stop (T3)	`▽-stop.sh`	`docker container stop`	`docker-compose stop`
uninstall (T4)	`▽-uninstall.sh`	`docker container rm` `docker image rm`	`docker-compose down`

Table 1 ALMA calls shell scripts named `▽-◯.sh` (▽: file type, ◯: task; e.g., `docker-install.sh`). Simplifications of the steps called by the according shell scripts are shown for Docker containers, and for compositions of multiple Docker containers.

For the main app-lifecycle tasks (T1–T4) – $\star$: install, start, stop, uninstall – the following five steps are executed:

1 The operator initiates the $\star$ task of an app using the UI on the backend site.
2 ALMS informs ALMA to $\star$ the app. Further steps may be executed by the ALMA; for example, for T1, ALMA downloads the app, and extracts it.
3 ALMA runs the use-case specific configured $\star$ shell script (cf. Table 1).
4 ALMA replies to the ALMS with a message indicating success or failure. In cases of failures, the *failed* state is entered.
5 The result of the $\star$ process is shown in the UI to the operator; for example, after T1, the app is added to the list of installed apps.

Conclusion and Outlook

We enumerated several requirements and tasks an application lifecycle management in the Smart Grid domain needs to fulfill. Unfortunately, an evaluation of suitable-seeming customer-grade IoT tools showed to be not applicable for this purpose due to not implementing all of the desired functions. We thus introduced a solution for the iSSN's application lifecycle management and tested it successfully. LarGo! furthermore includes the domain of Smart Buildings utilizing a building energy management system (BEMS). Work is ongoing for application lifecycle management on the OSGi-based development of the BEMS fulfilling the listed requirements and tasks. Management systems to roll out software to more devices cover different levels and areas of dependency management. However, some dependencies go beyond of what state-of-the-art software rollout systems support; for example, none of the analyzed systems is able to include knowledge about the physical environment and the functions of the software into software rollout planning and execution. We are thus currently working on a knowledge-based software management layer, utilizing knowledge about the grid's setup and its components for the planning process, including knowledge about the underlying software deployment processes themselves.

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Availability of data and materials
No additional data and materials are available.

Author's contributions
This paper is a joint work of all listed authors.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Siemens AG Österreich, Siemensstraße 90, 1210 Vienna, Austria. [2]Fraunhofer-Institut für Solare Energiesysteme ISE, Heidenhofstraße 2, 79110 Freiburg, Germany.

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POSTER ABSTRACT P11

An improved grey model for power outages prediction in medium-voltage distribution system

Yang Zhang[1*], Andrea Mazza[1], Ettore Bompard[1], Emiliano Roggero[2] and Giuliana Galofaro[2]

*Correspondence: yang.zhang@polito.it
[1]Department of Energy, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy
Full list of author information is available at the end of the article

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Abstract

The number of outages in a medium-voltage distribution system directly affects the reliability and resilience of power grid. An accurate prediction of the outages is critical for the planning, operation and maintenance of electric power system. In this paper, the grey model GM(1,1) was introduced to investigate the pattern hidden in the total number of outages in every month. Different from the traditional grey model, the parameter in GM(1,1) was optimized with the Genetic Algorithm (GA). To avoid the dramatic increase of errors due to multi-steps prediction, a rolling mechanism is also adopted in the grey model to capture the latest trend in the data. The proposed method was applied to predict the outage number in an urban distribution network. The method was verified with the accurate predictions.

Keywords: distribution system; outages; grey model; genetic algorithm; rolling mechanism

Introduction

Unlike the power transmission system, the distribution network usually faces the challenges due to the large number of equipment, complex structure and various customers, which raise the possibilities of power supply interruptions to a large extent [1]. In the meanwhile, the complicated causes and unclear relations bring difficulties to an accurate outage prediction. Since the consumers' satisfaction is deeply dependent on the number of interruptions, the Distribution System Operators (DSOs) have been seeking a reliable way to forecast the number of outages for a better maintenance plan and operations [2].

In order to deal with this problem, there are some researches trying to analyze the impact of external factors to the outage in power grid in statistical models. In theory, with the information of all the potential causes collected, it becomes possible to build a regression model to predict the number of outages under a certain condition. For example, the adverse weather conditions are usually taken as an important factor for the reliability assessment in power system [3]. However, due to the fact that most of the utilities focus more on the fast repair of electrical equipment rather than detailed investigation of failure causes, there are typically limited information to investigate the real reasons behind an outage [4]. Moreover, as the majority of feeders in an urban distribution network, the underground cables are not as sensitive as overhead lines to the external factors, which weakens the performance of traditional regression models.

The grey model, which is a classic theory for uncertain issues with limited sample size and poor data information, is a promising solution for the outage prediction problems. As a frequently used prediction technique, GM(1,1) has been applied to various engineering problems [5, 6], including the electrical load forecasting, wind power prediction, and so on. In our study, an improved grey model was adopted to forecast the number of outages due to the absence of causes and external information. Compared to the typical basic grey model, the GA optimization was introduced to determine the proper parameter with an objective as the minimum error between predictions and real values. Furthermore, a rolling mechanism was applied to track the latest trend of data dynamically and improve the precision of estimation.

Method

Basic grey model GM(1,1)

GM(1,1) is a classic prediction model based on the grey theory, which could uncover the inherent regularity from discrete data series with limited samples. It decreases the randomness of the trend by accumulating the original data series. Given the nonnegative original data sequence $\mathbf{x^{(0)}}$ as $x^{(0)} = \left[x_1^{(0)}, x_2^{(0)}, ..., x_N^{(0)}\right]$, where N is the length of data sequence. Then each element of the monotonic increasing data sequence $\mathbf{x^{(0)}}$ could be obtained by accumulating the first k elements of the original data: $x^{(1)} = \left[x_1^{(1)}, x_2^{(1)}, ..., x_N^{(1)}\right]$, $x_k^{(1)} = \sum_{i=1}^{k} x_i^{(0)}, k = 1, ..., N$.

The k-th background value z_k in the above equation is defined as the average value of the k-th and (k-1)-th accumulated data as $z_k = \mu x_{k-1}^{(1)} + (1-\mu)x_k^{(1)}, k = 2, ..., N$.

Given the original data, the parameters a and u could be determined with the least square method as follows:

$$\begin{bmatrix} a \\ u \end{bmatrix} = \left(\begin{bmatrix} -z_2 & 1 \\ -z_3 & 1 \\ ... & ... \\ -z_N & 1 \end{bmatrix}^T \times \begin{bmatrix} -z_2 & 1 \\ -z_3 & 1 \\ ... & ... \\ -z_N & 1 \end{bmatrix} \right)^{-1} \times \begin{bmatrix} -z_2 & 1 \\ -z_3 & 1 \\ ... & ... \\ -z_N & 1 \end{bmatrix}^T \times \begin{bmatrix} x_2^{(0)} \\ x_3^{(0)} \\ ... \\ x_N^{(0)} \end{bmatrix}$$

The estimation of the accumulated values could be obtained as below from the solution of white differential equation [7]

$$\hat{x}_{k+1}^{(1)} = \left(x_1^{(0)} - \frac{u}{a}\right) e^{-ak} + \frac{u}{a}$$

Optimization of μ by GA

In traditional grey model GM(1,1), the weight μ for calculating background values are fixed as 0.5, which means that the background values are equal to the average of two continuous accumulated data [7]. However, the value of μ is possible to be varying within the interval [0,1]. An optimization of μ could be carried out for building a better grey model. In this paper, the GA technique is used for finding the optimized value of μ and improve the flexibility of the grey model.

The GA optimization [8] originated from the theory of natural evolution and mimics the process of natural selection, including mutation, crossover and selection. It starts with a population of randomly distributed solutions in the given domain. Each candidate solution corresponding to the value of μ differs from the others. In our case, the objective of the optimization process is to minimize the errors between the estimated values and real values. Therefore, the Mean Absolute Percentage Error (MAPE) is used as the objective function, which is defined as below:

$$MAPE\left(\mu\right) = \frac{1}{N}\sum_{k=1}^{N}\left|\frac{x_k^{(0)} - \hat{x}_k^{(0)}\left(\mu\right)}{x_k^{(0)}}\right|$$

Rolling Mechanism for GA-based GM(1,1)

In practical cases, the trend inside a data sequence is typically significant in a limited period. Since only the latest data reflect the development trend, the rolling mechanism with a sliding window for the building of GM(1,1) is an effective method to deal with the seasonal data.

In the rolling mechanism, the GA-based GM(1,1) is always built on the p original data points $\left[x_1^{(0)} \quad x_2^{(0)} \quad ... \quad x_p^{(0)}\right]$ to predict the following q data points $\left[x_{p+1}^{(0)} \quad x_{p+2}^{(0)} \quad ... \quad x_{p+q}^{(0)}\right]$. In this case the length of sliding window is p. Once the new information is acquired, the predicted q data points will be replaced with the real values. Then most updated p real values $\left[x_{q+1}^{(0)} \quad x_{q+2}^{(0)} \quad ... \quad x_{p+q}^{(0)}\right]$ will be utilized to predicted the next q values $\left[x_{p+q+1}^{(0)} \quad x_{p+q+2}^{(0)} \quad ... \quad x_{p+2q}^{(0)}\right]$. These steps will be literately implemented over all the data set.

Case Study

In our study, the 5 yesrs' records of outage in the local urban distribution network have been collected and used for building the grey model. From 2008 to 2012, the number of outages in every month increased during summer and decrease in winter. The possible reason is that during summer, the higher temperature and less precipitation bring chanllenges to the insulation of power equipment. The aging process of electrical devices accelerates during such critical weather conditions. However, there is also a potential increasing trend in the annual total number of outages. If we focus only on the summer period, the outage number has seen a slight increase during the 5 years. It may be caused by the more frequent heat waves in summer. Meanwhile, the warmer summer encouges more families to install the air-conditioners in their houses, which significantly increase the load in power grid. Outages are prone to happen in the overload state.

Building the GA-based GM(1,1) with rolling mechanism

The monthly outage number in the urban distribution network among the five years will be predicted by empoying the GA-based GM(1,1) in this section. In order to capture the lateest trend of the change in outage numbers, the rolling mechanism is applied. The length of sliding window p will be tested on different values with comparison of forecasting errors. The length of prediction data q is always set as 1 in our simulation. The prediction results are shown in Figure 1.

Conclusion

In this paper, an improved grey model is proposed to forecast the number of outages in the urban distribution network. An accurate prediction of the outage number provides a useful indicator for the maintenance plan and investment in the construction

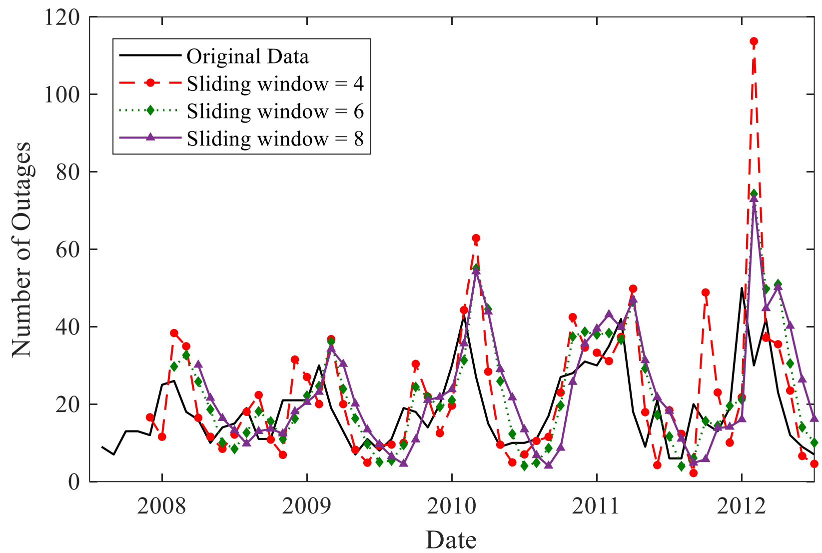

Figure 1 Results of monthly outage prediction with different sliding windows

for a stronger power grid. The parameters for building the traditional grey model GM(1,1) is first improved with the optimization techniques. Since the monthly outage number is a seasonal data sequence, the rolling mechanism is introduced to improved the ability of capturing the change of trend.

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Author's contributions
YZ implemented the prediction model and analyzed the results. AM and EB contributed in the novelty of the model. ER and GG participated in the design of the study.All authors read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

Author details
[1]Department of Energy, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129 Turin, Italy. [2]IRETI SpA, Strada Pianezza, 272/A - 10151 Turin, Italy.

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DEMO ABSTRACT D1

Funergy, a hybrid game for energy awareness

Piero Fraternali[1*], Spartaco Albertarelli[2] and Sergio Luis Herrera Gonzalez[1]

*Correspondence:
piero.fraternali@polimi.it
[1]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, IT
Full list of author information is available at the end of the article

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Abstract
In this demo we present FUNERGY, a hybrid game, consisting of a card game enhanced with a digital mobile application. FUNERGY aims at promoting energy knowledge and awareness in children and their family, integrating best practices of board and digital game design. Attendees will play a round with the game designers and learn the principles at the base of the construction and evaluation of the game.

Keywords: energy saving; serious games; game design

Introduction

Energy saving is a social and collective effort and thus energy efficient habits should be taught as early as possible, to become part of people's lifestyle. Games are powerful educational tools, because they foster user enjoyment and at the same time improve knowledge retention and sparkle change in mindset and behavior[1]. Digital games exploit a wide variety of platforms and devices: websites, mobile apps, personal computer and consoles; the design process of such sophisticated products is complex and costly. For educational purposes, a purely digital game strategy targeting children is ineffective, because the commercial offer of digital entertainment is so huge that capturing the users' attention, with a limited budget, is almost impossible. Board games have a potentially stronger impact on millennials, because they create an original (for them) form of interaction among players, who must sit around the same table and compete and cooperate face-to-face. The above considerations, and the lessons learned from a previous project[2], motivate the design of FUNERGY, a card game with a digital extension aimed at children (age 6+) and families. When playing with FUNERGY, children are exposed to fundamental energy saving concepts, but the didactic purpose does not compromise the fun part: the game is challenging, exciting, and at the same time stimulates the curiosity to discover more about energy and its uses. The demo will involve the attendees in the game design process of the FUNERGY card game and of its digital extension, discussing the essential design decisions that led to the concept of FUNERGY, while playing with it.

Related work

Games have been applied in different ways for environmental awareness. An example is Power House[3], an online game in which the player must assist the other characters by overseeing turning on and off appliances (lights, TV set, etc.) and keeps track of the activities of every member of the family to reduce waste. A similar approach is used in ecoPet [4], where the player must take care of a virtual pet's needs in a energy efficient way. EnerGAware [5] is mobile simulation game in which the objective is to reduce the energy consumption of a virtual house. The player can execute actions such as changing the location of the lamps in a room or turning off appliances. At the end of every week, the players receive points based on the energy saved. Funergy differs from these games in the possibility of playing the game in an integrated manner with the Funergy non-digital, card game.

FUNERGY

FUNERGY was designed in the context of the enCOMPASS project, an EU funded project under the Horizon 2020 research programme. It is a simple and engaging card game, coupled to a mobile app, designed to inform children and their families about the European Energy Scale and to improve their awareness about energy and sustainable consumption.

The card game does not require any specific knowledge about the topic to be played, but at the same time introduces concepts such as positive energy attitudes, shared responsibility, etc. through the game mechanics and the card illustrations, which meaning is explained in the rule booklet of the game. The mobile digital extension provides useful energy saving information in a concise and entertaining way, without distracting the attention from the ongoing gameplay.

The card game and the mobile app interact during the play; the rules reward players for their acquired knowledge and promote both competition and collaboration, to convey the principle that energy saving is a collective and societal effort.

Gameplay

The game rules were designed to avoid arithmetic operations during gameplay and show that sharing good and bad things affects all players. The game is divided into seven rounds, one round for every Energy Scale Level. The game begins with the G level (the lowest one) and finishes when players reach the A level (the highest one). At the beginning of the game, seven decks of cards with the letters and colours of the Energy Scale are placed on the table(Fig.1), as score points, then each player receives seven cards from the playing deck, the rest of the cards are put at the centre of the table as the drawing deck. The objective of the players is to form a combination of cards numbered from 1 to 7(Fig.1), discarding as soon as possible all the "negative" cards (representing old appliances) and exploiting wild cards. The player in turn draws from the deck and exchanges a card with another player, to complete the hand. If she completes the combination from 1 to 7, she closes the round, shows her cards, picks up the scale cards of the current level, keeps the card with the highest score, and distributes the other cards, with lower values, to the other players. The values of the scale card increase level by level, so winning the last one can be crucial for determining the winner of the game.

When the player closes the round using wildcards, she uses the mobile app to answer an energy quiz; she scans the QR code on the card and receives a quiz with 2 possible answers; she makes her choice and the app gives feedback and displays a brief, yet informative, explanation of the quiz topic. If the answer is correct, the player keeps the card for herself; otherwise, she must "donate" it to another player.

Figure 1: Left: European Energy Scale Cards, Right: Playing Cards

At the end of the 7 rounds, all players reveal their score showing the scale cards received during the game and adding 3 points for every wildcard in their possession. The winner is the player with the highest score.

Digital Game Extension

FUNERGY is a quiz game that challenges the players with energy questions. There are 3 levels of difficulty: as the player improves, the questions become harder.

There are 2 modes in the digital game:

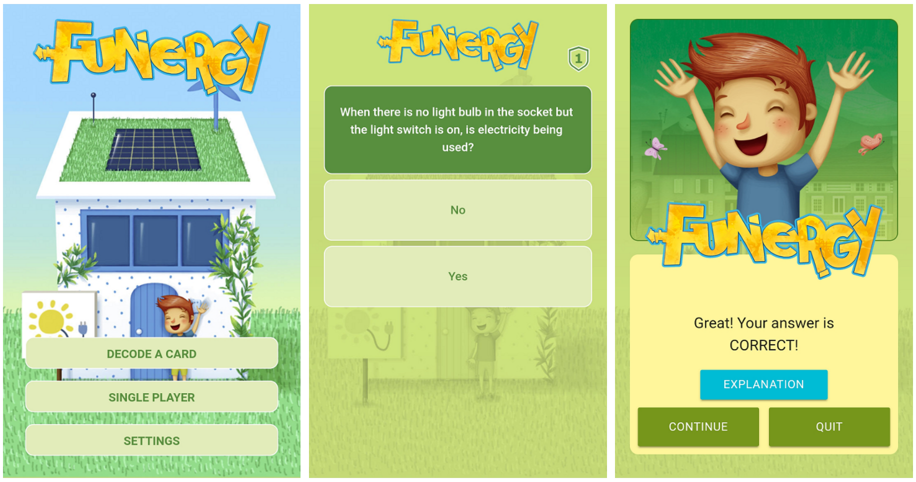
- Decode a Card: When a player closes a round using an enCOMPASS wild card, she must use the app to decode the QR code on the card, and answer the quizz shown by the app.
- Single Player: The player receives a series of questions; as the game progress, the difficulty level will increase if the user answer correctly or decrease otherwise.

Both modes and the settings option can be reached from the Home screen of the app(Fig.2a). On the Quiz screen (Fig.2b) the app presents the quiz and the 2 possible answers, a badge with a number on the top right corner of the screen represents the players current level when the player levels up or down a pop-up will notify about the change and the badge number will be updated.

The application gives feedback to the players whether the answer was right or wrong(Fig.2c). On the feedback screen, the players can read an explanation about the topic of the question, which helps them understand why they were right or wrong; the explanation is short but precise, to be easy understandable and to avoid interruptions in the play.

Evaluation and conclusions

FUNERGY is currently under evaluation in an experiment supported by the behavioral research on the determinants of energy consumption performed in the PENNY H2020 Project; the field test involves 89 classes of 10 primary and first intermediate schools in Italy and Switzerland. A total of 1500 children, from 6 to 14 years old, with their families have been engaged; 480 children more have been recruited as a control group. The experiment settings comprises 3 stages:



(a) (b) (c)

Figure 2: FUNERGY Digital Game App.

- Initially the children and their parents fill out a questionnaire, which assesses their knowledge and attitude towards energy saving.
- The second stage consists of an activity at the school, where project representatives present the objective of the game and explain the rules; then a game session of 30 to 45 min takes place. After the intervention, a copy of the game is given to all pupils, so that they can play with their family and friends.
- Finally, a second questionnaire is provided to the children and their parents, to measure the changes in the family attitude towards energy saving due to the experience with the game.

The evaluation stage is currently ongoing and a significant increase in energy awareness in children and families is expected. At the time of writing, around 70% of the pupils downloaded the app autonomously, to continue playing autonomously at home.

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Author details
[1]Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, IT. [2]Kaleidos Publishing Srl, Viale Lunigiana 46, 20125 Milan, IT.

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DEMO ABSTRACT D2

enCOMPASS, demonstrating the impact of gamification and persuasive visualizations for energy saving

Piero Fraternali* and Sergio Luis Herrera Gonzalez

*Correspondence:
piero.fraternali@polimi.it
Dipartimento di Elettronica, Informazione e Bioingegneria, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan, IT
Full list of author information is available at the end of the article

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Abstract

In this demo we present the enCOMPASS energy awareness app. The app is designed to turn the raw data of smart meter and sensors, installed at the premises of the consumers, into tools for behavioral change and customer relationship management. Sensed data are presented to the user in multiple visualizations, exploited to disaggregate consumption into end-uses, estimate user activity and comfort levels, and ultimately deliver contextual and personalized energy saving recommendations.

Keywords: energy saving; energy efficiency; gamification; persuasive technology

Introduction

Energy is a limited resource, most of the current methods to generate it have a direct impact in the environment, therefore it should be used efficiently to minimize the negative effects. To effectively create awareness in energy consumers they need to be presented with a relatable measure of the impact of their consumption habits and be informed about the alternatives they have so they can have long-lasting behavioural changes. Combining Internet of Things technologies like smart-meters and persuasive technologies has been increasingly research as they are powerful tools for providing user with feedback about their consumption and engage them into energy saving activities, but in order to create an effective behavioural change platform it should be designed around the users' needs and comfort, and provide recommendations tailored for the user and his context. enCOMPASS was created to address energy efficiency and awareness from a user-centered perspective considering user profile and levels of comfort. The demo will involve the attendees in enCOMPASS awareness application features and the rationale behind its gamification and visualization designs.

Related Work

The deployment of smart meters in an increasing number of households has boosted research on methodologies for inducing behavioural change based on energy consumption feedback systems. Studies suggest that incorporating different types of feedback with motivational techniques and energy saving advices improve the impact of the systems[1]. It must also be designed to consider different types of customers and to be presented at the right moment and provide actionable suggestions, tailored to a given user and context[2].

Several energy saving applications embedded in users' environment have been proposed [3], [4], using consumption feedback visualizations and gamified social interactions to motivate the adoption energy-efficient attitudes. The focus of the applications are different some are data-oriented (e.g. bar charts of consumption [5]), some are connected to the real consumption context (e.g. floor plans [5]), others metaphorical (e.g. traffic lights [5]), or playful and ambient[6]. Saving tips and recommendations are common strategies to motivate energy saving like in [7], sometimes provided in a contextualized manner but rarely shown in direct relation to the actual consumption. enCOMPASS aims at closing the gap between the consumption feedback visualization, the provided recommendations and the user comfort by providing tailored recommendations considering user consumption habits and preferred comfort settings.

The enCOMPASS Project

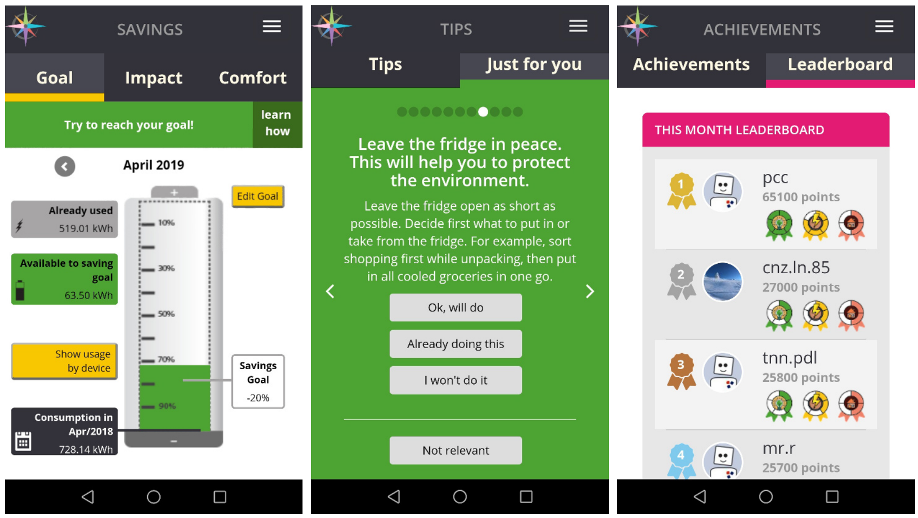
enCOMPASS is EU funded project under the Horizon 2020 programme, which aims at implementing and validating an integrated socio-technical approach to behavioural change for energy saving by developing innovative tools to make energy consumption data available and understandable for different type of users like residential consumers, school pupils and public building employees, empowering them to collaborate in order to achieve energy savings and manage their energy needs in efficient, cost-effective and comfort-preserving ways [8].

Using smart meters and sensors, which include temperature, humidity and luminance, the project integrates the user consumption and indoor climate with user-centered visualisations in a gamified mobile app. The enCOMPASS Awareness Application is designed to improve engagement and to provide users with general and personalized energy saving tips. The gamification aspects of the platform focus on 3 main areas: “Energy Saving”, “Learning” and “Profiling”.

The “Energy Saving” area focuses on the actual energy saved by users, they are encouraged to set a saving goal every month and monitor their progress periodically. The comparative baseline for the goals is the total energy consumed on the same month of the previous year, such information has been collected and provided to the platform by the utility companies participating in the pilots. The “Goal” section shows an energy saving metaphor of a battery, as displayed in Fig.1a, where users can keep track of their consumption and progress towards reaching their goal. On this screen, users can also set their energy saving goal and see the disaggregated energy consumption by device. The default energy goal is set to 20% reduction with respect to the baseline, the users can choose a custom goal in a range from 10% to 30%.

Gamification in this area is focused on the competition, users that reached the saving goal receive points depending on their target goal and the top 2 ranked users receive prizes from the utility companies. Also, users receive achievements(badges) when certain saving levels are reached. User can monitor their achievement progress in the “Achievement” section along with its position on the monthly and the overall leaderboards.

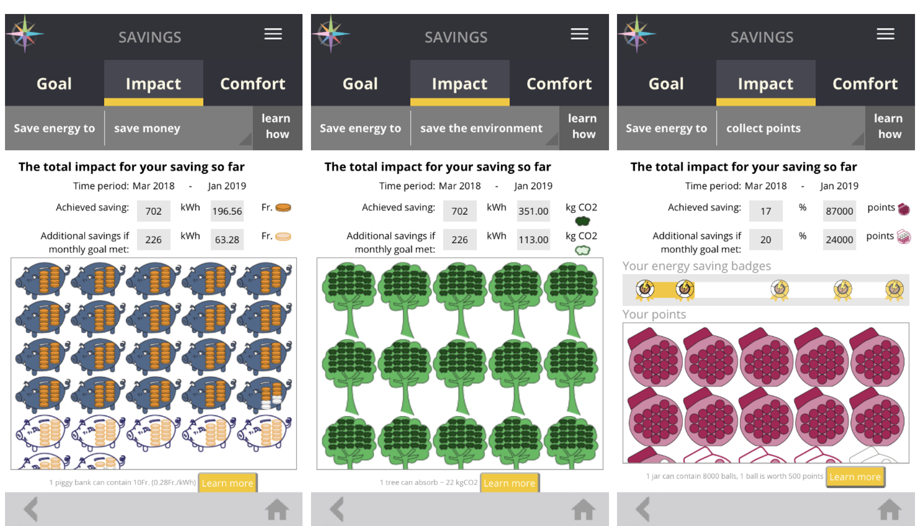
User can also choose to inspect their consumption details at different levels of granularity; or visualize the impact of their consumption through visuals metaphors, to



(a) (b) (c)

Figure 1: enCOMPASS Goal, Personal Recomendations and Leaderboard

help users relate energy savings to things which are important to them, the "Impact" section presents the impact of achieved energy savings using three different metaphors: monetary (Fig.2a), environmental(Fig.2b) and hedonic(Fig.2c). Monetary and environmental impact visualizations show the cumulative savings that the users have achieved translated into money and CO_2 values, respectively; whereas the hedonic impact visualization shows the points that the users have achieved for saving energy.



(a) (b) (c)

Figure 2: enCOMPASS impact visualization metaphors

The second area is the "Learning" area that focuses on energy efficiency education, through the "Tips" section users receive generic energy saving tips and personal recommendations (Fig.1b). Personal recommendations are generated by a machine learning algorithm that uses energy consumption, sensor data, and user profile information to select suitable tips. The gamification of this area consists of awarding points to the user for every tip they read, extra points are awarded if the user provides feedback about the accuracy of the tip. The points of this area add up to the total score for the competition, and award achievements when certain levels of points are reached.

The profiling thematic area aims at collecting user profile information that can be used for tuning the recommendations and the comfort inference. A "Household Profile" section collects information about user's household configuration like the orientation of the windows, the more information the users provide the more points they get, another section of the application shows the user the indoor climate information collected from the sensors, the user gets points by providing feedback about the comfort perception in the current conditions.

Conclusions

The enCOMPASS platform has been deployed to 3 pilot sites in Switzerland, Germany and Greece, each pilot consists of around 100 participating households and at least one public building and one school. The intervention period, which duration is 12 months, is currently ongoing. The evaluation of the platform impact will consist on measuring the energy consumption reduction during the intervention period. The first analysis results suggest a 10 to 12 % consumption reduction for the residential consumers that participate in the project in comparison with the control group. A complete analysis will be done after the intervention period is completed, to understand the overall effect of the platform in households, public buildings and schools.

Acknowledgements
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DEMO ABSTRACT D3

BIM4BEMS

Anna Shadrina[1*], Milos Sipetic[1], Max Blöchle[1], Georg Suter[2], Maryam Monatzer[2], Stefan Gaida[3], Wolfgang Kastner[3] and Christian Schiefer[4]

*Correspondence: anna.shadrina@ait.ac.at
[1]Austrian Institute of Technology
Full list of author information is available at the end of the article

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Abstract
The proposed demonstration is a prototype of an interactive data visualization tool developed during a research project entitled "Building information modelling for building energy management systems" (BIM4BEMS)[1]. The prototype is designed as an integrated semantic data model which combines geometric data retrieved from BIM model [1] with the operational data (BEMS). The results contribute to the existing efforts to reduce the amount of manual work in building data analysis in order to cope with the growing complexity of systems and increased requirements for energy efficency and comfort.

Keywords: BIM; BEMS; IFC; ifcOwl; Building Monitoring; Semantic Reasoning

Motivation and related work

According to the Statistic Austria [4] only 13 percent of Austria's population have their main residence in the buildings constructed after 2001. Considering that the standards for energy efficiency were only significantly improved in the recent years, we see a great opportunity to address the CO2-emissions of an old building stock with the assistance of advanced BIM-based building energy management systems (BEMS). Numerous attempts have been made in using BIM for effective BEMS (see for example [5],[6]). We would like to specifically mention the Dasher Project from Autodesk [7], which focuses on creating a BIM-based platform for building owners in Autodesk Forge and the ADA-EE research project [8], which offers a methodology for automatic evaluation of monitoring data [10], [11] and facilitates better decision making in BEMS. BIM4BEMS builds on these previous findings to improve the detection of inefficiencies and faults in BEMS

Demo building

The chosen demo building for the project is located in Vienna, Austria. It was built in the 1980s and has four floors with a basement. The newer part of the building is marked with red in Figure 1 and is visible on the aerial view on the left. Each building part is served by a separate plant. An additional zone supplies a fresh air to the seminar room in the third floor. The incoming air is supplied through a central ventilation system and outlets in the suspended ceiling. Heating and cooling temperature can be set individually at each office space. The heating and cooling load is covered by fan coils that are located next to the windows. A digital model of the building was created in Revit and exported as IFC 2x3.

[1]supported by FFG, "Stadt der Zukunft", project number 854677; duration 2017-2019

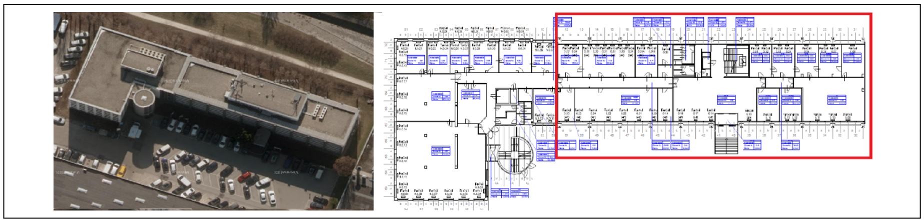

Figure 1: Aerial view of the building (left, ViennaGIS [9]) and a typical floor plan (right, Caverion Österreich GmbH)

Building Energy Management System

The demo building's automation system has more than two thousand data points for the complete building (control panels, sensors, actuators, virtual datapoints from control system, etc.) Lack of documentation and changes in facility management, as well as adaptations in building geometry make the optimal control of the building challenging and time consuming. In order to gain insights into indoor comfort, twenty wireless loggers of type HOBO ZW-007 were installed on the second floor of the building to monitor room temperatures and relative humidity. Two of the loggers are also equipped with CO2 sensors.

System architecture

The system architecture was designed to be modular with interfaces between core system modules, data storages, and external data sources, (Figure 2). Model Management, Visualization and Reporting and Data Analytics are core system modules (beige in Figure 2).

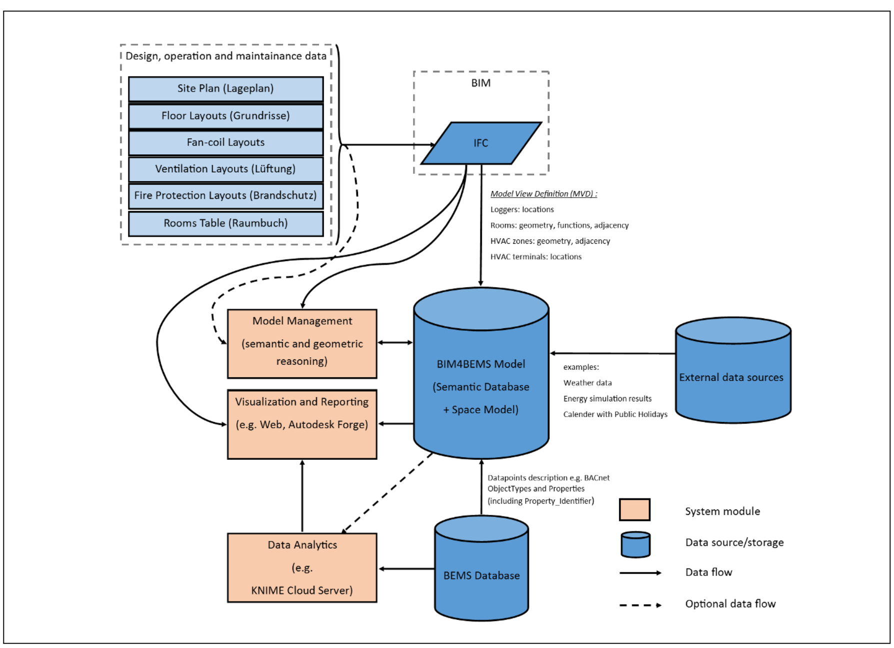

Figure 2: BIM4BEMS system architecture diagram

The BIM4BEMS model (center of Figure 2) is based on the alignment of Brick (v1.0.3), BOT and ifcOWL ontologies with some custom concepts added. The original IFC model is first converted into the ifcOWL representation. Through established alignments among ifcOWL, Brick and BOT the model is further enriched.

Space adjacency relationships, which are not included in the IFC data, are added by geometric reasoning. Furthermore, the IFC model of the building is transferred to the Forge platform and converted in situ into SVG format. The SVG model is then used natively by the Forge Viewer component for visualization. The element GUIDs of original IFC objects are preserved across these operations and are used to reference objects across components. The Visualization and Reporting module is used for the front-end visual analytics mentioned before. The Data Analytics module processes the monitoring data to enrich the visualization and reporting. As such it provides outlier detection, calculation of KPIs and further functions described in the following sections.

Use Cases

Three use cases developed for the project [2] were implemented in the present contribution: "Visualization of datapoint values in a spatial context"; "Visualization of alarms in a spatial context" and "Visualization of logging data in a spatial context. In the first and last use cases, a set of sensors is retrieved from an IFC model together with their unique IDs. Consequently, a set of datapoints is retrieved from BEMS and both are combined in the Autodesk Forge environment. The temperature differences of sensor data in adjacent rooms that exceed a predefined threshold coloured on the chosen level of aggregation (e.g. zone or floor). In the second use case, a specific set of datapoints with alarms from the control system is retrieved. Once an alarm occurs, a context is visualized with values from the loggers, that are located in the rooms of the relevant building zone and a suitable time period.

Visualization of the logging data in the spatial context

An Angular application was developed to allow the user to explore the monitoring data in the spatial context (Figure 3).

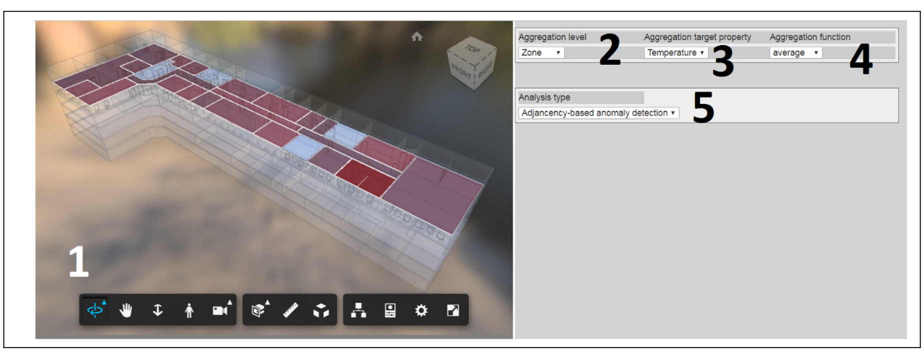

Figure 3: Model structure in the Autodesk Forge

It consists of a model visualization window with controls (1) and the following drop-down menus: Aggregation level (2); Aggregation target property (3); Aggregation function (4) and Analysis type (5). A user can set a number of parameters that influence the visualization. Selecting the sensor type (*Aggregation target property*) specifies which sensors are displayed on the model visualization view - in this case it is temperature, humidity or CO2 sensors. By selecting the *Aggregation level*, the data are aggregated on the level of an office space, a building floor, building zone or the whole building. Finally, selecting the *Aggregation function* specifies how the

PhD WORSHOP ABSTRACT PW1

Locality-Aware Overlay Network for VPPs Derived From the Grid Topology

Marius Stübs

Correspondence:
stuebs@informatik.uni-hamburg.de
University of Hamburg
Full list of author information is available at the end of the article

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Abstract

The idea of distributed Virtual Power Plants (VPPs) is to integrate thousands of independently operated intelligent energy devices (IEDs) into one organisational unit. Utilising an overlay network, the IEDs can communicate directly to an explicitly defined subset of neighboring nodes. We investigate how to design overlay networks, to acknowledge both the mostly tree-like topology of the power grid, as well as the interdependency between power flow and the control infrastructure. Therefore, we evaluate the use of locality-aware distributed hash table (DHT) routing for Smart Grids and present a node id scheme which allows combining the advantages of small-world topologies with strong respect to the locality of the electrical grid.

Keywords: Graph Theory; Locality-Aware ID Mapping; Smart Grid Security; Small-World Topology; Software Defined Networking

1 Introduction

Virtual Power Plants (VPPs) are an important concept when designing an architecture for future Smart Grids. When hundreds of thousands of independently operated small power plants or intelligent energy devices (IEDs) enter the electricity distribution grids, the question of efficient and secure distributed control arises. One possible way to handle all these IEDs is to organise them into VPPs. A solid concept for scalability and resilience to denial-of-service attacks is an important requirement when designing sustainable VPP architectures as self-organising entities, where IEDs can dynamically join and leave.

We define that an overlay network has a high degree of **locality**, if the geographical or grid-topological proximity of its nodes is mapped into the logical proximity within the overlay network. Locality is important for at least two reasons. First, it can be used to encapsulate failure state and find local solutions to local deviations, and also to prevent failure from cascading. Second, the knowledge of locality is very important for monitoring grid state and the capability of intervention.

The use of globally unique IDs or coordinates has proven to ease routing inside communication networks. Small-world networking protocols exist, that allow fast and efficient routing between nodes all over the network. Recent advances towards locality-aware grid topologies are elaborated in the Related Work Section.

Fig. 1 shows the steps required to organize a communication overlay network topology for a decentralized VPP. In this paper, we present our efforts towards implementing and evaluating a distributed scheme that assigns locality-aware IDs to a Smart Grid's participating IEDs.

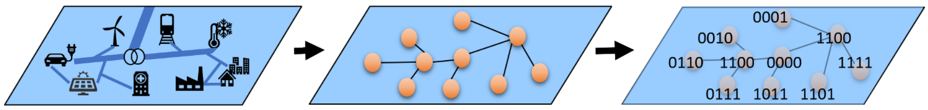

Figure 1 Three layers representing different abstractions of the grid topology in a distribution grid.

1.1 Research Questions

Virtual Power Plants can be implemented as distributed systems of independently acting agents, that provide a united service of power supply to the outside while agreeing on a possibly complex yet efficient schedule to the inside. To investigate an algorithm that allows to dynamically assign location information, in the form of a node ID, to each agent, we postulate the following research questions (RQ):

RQ 1: How can a global ID space be unfolded from local-only information using autonomous agents?

RQ 2: What are the most suitable overlay network topology and routing scheme?

RQ 3: How can conflicts be resolved when such a distributed algorithm is initiated at several locations simultaneously or overlay networks have to be merged?

RQ 4: How can the algorithm mitigate single malicious nodes that inject false data about the topology?

2 Related work

Structured peer-to-peer overlay network based on distributed hash table (DHT), such as Chord [1] and Kademlia [2] provide a scalable and robust routing service for large-scale distributed applications. The application of both DHT-based and tree-based overlay networks is not new for Smart Grids [3, 4]. The recent development of Canopus [5] provides a innovative self-organising protocol, that could highly benefit from our proposed locality approach.

The topic of byzantine robustness in Network layer protocols has already been elaborated by Perlman in 1988 [6]. Regarding the robustness of locality mapping algorithms against byzantine errors, Nesterenko et al. investigate requirements and non-cryptographic methods for neighborhood discovery and topology discovery in the presence of byzantine faults [7]. A recent applied concept of Byzantine Resilient Canopus [8] shows that this topic still has interesting open research challenges.

3 Algorithm Outline

We propose an algorithm for nodes to form a decentralised Virtual Power Plant. The algorithm differentiates between the underlying electrical **grid topology** and the network **overlay topology**.

3.1 Conversion to Tree

First step of the algorithm is to construct a minimal spanning tree from the grid topology. Circular connections are removed, some nodes have to be reduced and possible virtual nodes have to be added at grid conjunctions.

3.2 Globally Unique Locality ID

Each node gets assigned a number with e.g. 16 bytes that represents as its location ID in the Virtual Power Plant. Distance between nodes can be calculated using a weighted Hamming distance. In distribution grids, traditionally four hierarchy levels are used, but in the future, these might as well be extended to include nano grids, such as home energy management systems (HEMS), naval on-bord grids, islanded industrial complex grids and other circular micro grids.

3.3 Tree Merge

Since the algorithm can start at different positions in the grid simultaneously, it is possible to run into duplicate IDs. To achieve global uniqueness of IDs, it might be necessary to re-name nodes in this case.

As soon as two nodes from different VPPs make contact, it is recommended to merge them. Since both VPPs can contribute with topology information about separate domains, the resulting VPP will be based on a much more accurate representation of the grid state.

3.4 Dynamic Routing Strategy

The communication path between each two nodes can be computed both globally and locally. Using local neighbor lists, each node stores the addresses of a subset of neighboring nodes for routing. As a routing scheme we implement both Kademlia DHT and Chord DHT to compare their efficiency in the provided setup. It requires the acquisition and processing of reliable locality information, that means to know which nodes participate in a VPP and where they are located. We argue, that in a future Smart Grid, multiple IEDs might disconnect from a part of the grid and reconnect to another part of the grid simultaneously. Thus, a scheme of globally unique, locality-aware identifiers for participant nodes in distributed VPPs is ongoing research.

3.5 Gossipy Information Validation

The algorithm needs to be as simple as possible, to avoid accidental mistakes in the implementation or for edge cases to appear. Nonetheless it is necessary to guard it from false data injection attacks and make sure that it is byzantine fault tolerant. Each participating node has to be certified by an outside trusted third party. This certification should include identity information, like maximum power output, and authorization, e.g. when representing a substation. Such a certification scheme can build up the necessary trust between nodes. National power and grid agencies already have started to certify participants for future Smart Grids [9].

4 Discussion and Outlook

To evaluate the proposed algorithm, we setup three distinct experiments. To satisfy the validation testing approach, the algorithm will simulated with Omnet++ [10] and then emulated using OpenDISCO [11] in a distributed real-time environment as a controller-hardware-in-the-loop (CHIL) setting. The topologies will be selected from a set of test grids, such as the IEEE European Distribution Grid.

Experiment 1 – Consistency
Selected grid topology will be analyzed regarding their properties, such as density and average path length. The algorithm is initiated at a random node inside the topology. It is evaluated how many messages are needed before reaching a stable system state. The resulting spanning tree is compared to the original topology regarding the selected metrics.

Experiment 2 – Resolving Conflict
As in Experiment 1, two random topologies are generated and for each, the algorithm is initiated. After reaching the stable state, the topologies are connected. It is evaluated how many messages are needed to result in a consistent system state and how the result is different from the previous experiment.

Experiment 3 – Byzantine Resilience
A byzantine attacker is inserted into the investigated grid. The attacker's aim is to create duplicate IDs for other nodes as well as trying to split the network such that the attacker is the only link between two sub networks. We investigate what kinds of topologies are stronger affected by the attacker and what criteria for grid topologies we can derive from that.

5 Conclusion

In this abstract, we motivate deriving locality-based identifiers for the use within VPPs. We propose an algorithm for constructing an overlay network and to evaluate it regarding DOS resistance and messaging efficiency. We propose to postulate an attacker model where single malicious nodes aim to split the resulting topology such that the attacker positions itself as a single-point-of-failure. We further propose to simulate the algorithm to show whether the scheme is robust against the selected attacker model. The resulting overlay network's efficiency will be validated in a distributed real-time environment.

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PhD WORSHOP ABSTRACT PW2

Decentralized Trust Management for Privacy-preserving Authentication in the Smart Grid

Clemens Brunner

Correspondence:
clemens.brunner@en-trust.at
Center for Secure Energy Informatics, Salzburg University of Applied Sciences, Urstein Süd 1, Puch bei Hallein, Austria
Full list of author information is available at the end of the article

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Abstract

The rising number of different actors in the smart grid, e.g., electric vehicles, privately or community owned power plants or charging stations and the trend of decentralization opens new challenges for authentication. Authenticated information need to be exchanged and validated beyond company and national borders. Centrally controlled trust management systems and authentication providers can no longer fulfill the requirements of decentralized applications. In this extended abstract a PhD project which studies methods for decentralized authentication without single trusted third parties between all actors in the smart grid is presented. The aim of this project is to propose new solutions for a user-friendly and a decentralized system to authenticate all actors in the smart grid in a privacy-friendly way.

Keywords: Decentralized Trust Management; Blockchain; Distributed Ledger Technology; Authentication; Privacy-preserving; Smart Grid

1 Introduction

The modernization of the electricity grid is often called the *smart grid*. A smart grid establishes an additional layer for information and communication technologies for the interaction between all actors. Many improvements are attributed to this technology, e.g., increased consumer participation, minimizing climate impact or making it easier to use renewable energy sources. The smart grid transforms a centralized producer controlled network to a decentralized consumer controlled interactive network [1]. In order to enable consumer interactions, all actors within the smart grid need to communicate with each other, i.e., smart devices which adjust their power consumption based on the grid stability.

Expanding the functionality of the current electrical power grid introduces new cyber security challenges. Any type of communication in the smart grid is considered critical because information can influence the stable operation of the underlying electricity network. To enable a secure communication, all messages need to be authenticated. In order to enable authenticated messages an identity management system for all actors in the smart grid needs to be established. Some services may need additional information to authorize authenticated users and to enable additional services.

For clarification we define authentication and authorization (AA) below.

Authentication is the process of identifying an actor by (i) something the actor knows (e.g., a password), (ii) something an actor possesses (e.g., secret key, certificate) or (iii) something unique to an actor (e.g., biometrics) [2].

Authorization is the concept of specifying what an authenticated actor is allowed to do.

A straightforward solution for AA is to require a separate user registration for each service, hence each service needs to manage an own database for user credentials. This also means that each actor needs to register and manage credentials for all different services within the smart grid. This solution is possible but will be impractical, because the actors are not able to reuse their credentials for different services.

Single-sign-on services, e.g., Open ID [3], [4] or Kerberos [5], allow users to reuse credentials within different services. Users need to register once at the single-sign-on provider and are able to reuse their credentials for different services which are supported by the specific single-sign-on provider. For AA of users a request to the single-sign-on provider, which acts as a Trusted Third Party (TTP), is necessary. This means that this provider gets access to privacy-sensitive information, e.g., which service authenticates which actor, hence who communicates with whom. This creates a privacy issue and additionally, the single-sign-on service is a single point of failure, which is a high security risk concerning availability [2].

Public key infrastructures (PKI) use certificates to bind an identity to a public key. Authentication can be performed by using a digital signature created with the certificates' corresponding private key. These key pairs form the basis to enable future cryptographic operations, e.g., end-to-end encrypted communication. The certificates can be extended to enable authorization. Hierarchically structured PKIs are based on certificate authorities (CA), which are responsible for (i) issuing certificates and for (ii) managing a revocation list [6]. Web of Trust (WoT) [7] [8] does not rely on CAs, each user can act as CA and confirms other users. To verify a certificate issued in a WoT based PKI, a user needs to establish one or more verification paths from a party marked as trusted to confirm the certificate. Disadvantages of WoT are the distribution of revocations lists [9] and the bootstrapping of trust.

Combining PKIs with distributed ledger technology (DLT) to create a platform for AA is possible and remove a TTP as platform operator. However there are still open challenges in order to create a Decentralized Trust Management System (DTMS) concerning the following topics: trust management, privacy, security and usability.

2 Research Questions

The main research question (RQ) for this PhD project is:

(How) can a decentralized trust management system practically realized for the smart grid and *which methods are suitable to provide privacy-preserving authentication within such a system?*

This research question can be separated into the following four categories: trust management, privacy, security and usability. These categories are already well researched. The combination and especially the avoidance of a TTP as platform operator, however, opens up a new research area for a DTMS, as put forward by [10].

In order to address the main research question, it is divided into the following sub-research questions.

RQ1: To what extent can the need for trust in a third party be reduced by a DTMS and is it possible to get along completely without a trustworthy party or do we still need them to bootstrap such a system?

RQ2: Which privacy-preserving techniques can be adopted for decentralized authentication methods and is it possible to fulfill unlinkability [11] over different authentication attempts from the same actor within a DTMS?

RQ3: How can the DTMS be secured against cyber attacks, e.g., sibyl attacks and how can compromised actors be detected and turned off?

RQ4: How can the DTMS be designed to be scalable and therefore usable for all actors within the smart grid and how can it be applied in a user-friendly way?

3 Related Work

The current state of decentralized trust management systems, i.e, PKI solutions is summarized in [10]. Blockchain-based PKI management frameworks are presented, e.g., in [6, 12, 13, 14] however they did not solve the problem of trust bootstrapping nor they enable privacy-preserving authentication methods which fulfill unlinkability. In [15], a blockchain based system to issue and validate documents is presented. A PKI, which borrows concepts of WoT is established to verify issuers. A blockchain based system to issue and validate green energy certificates is presented in [16]. These concepts can be further improved and extended with privacy-preserving authentication methods.

Protunes [17] is a privacy-preserving authentication protocol for dynamic electric vehicle charging. They assume that a PKI is already established and that all cars have a pseudonym managed by a central trusted party. The main focus of this work is on fast authentication for charging purposes.

uPort[1] and Sovrin[18] are platforms to create a self-sovereign identity and enable privacy-preserving authentication based on DTL, however, privacy-sensitive metadata about the interaction between verifiers and users are publicly visible.

In [19], privacy issues of smart e-mobility are discussed. They claim that this will be a cornerstone application of the future in smart grids. They evaluate existing solutions and propose new privacy-aware design patterns for the e-mobility use case.

4 Conclusion and Outlook

In this extended abstract, the initial idea of a PhD project was presented. The main objective of the PhD project is to create a decentralized trust management system including privacy-preserving authentication for all actors in a smart grid which is practically useable. A detailed description of the research question and the related subquestions is given. Related work concerning (decentralized) trust management systems is presented. This project contributes to the state of the art by creating a decentralized trust management system and by adapting privacy-preserving authentication without the need of a central TTP.

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[1] https://www.uport.me/

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Competing interests
The author declares that he has no competing interests.

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aggregated measurements will be combined. For example, if a user selects a floor aggregation level, all available sensors of the selected types will be collected for each floor, and then a selected function will be performed for all the readings at the particular time and at the particular floor. This generates a new aggregated time series for every entity of the selected aggregation level (floor in this case). Furthermore, the time series are used to compute KPIs, that are overlaid on the 3D visualization to identify problems or anomalies more easily. KPI visualized in Figure 3 shades rooms based on the difference of average temperature compared to adjacent rooms, i.e. blue rooms are significantly colder than adjacent rooms, and redder rooms are significantly hotter than adjacent rooms, on average. This specific KPI can be used to identify losses due to widely different temperature conditions of adjacent rooms. Every analysis can be parametrized in different ways by specifying thresholds, date ranges etc.

Conclusion

In BIM4BEMS an attempt was made to establish missing relationships with the help of alignment among ifcOWL, Brick and BOT and to enrich the model with the help of geometric reasoning. As part of the validations process, the prototype was tested by Caverion engineers and technicians online, and the documented feedback is going to be used for the further improvement of the tool. Another possibility would be to test the developed methodology and prototype by importing another building model and documenting the process.

Author details
[1]Austrian Institute of Technology. [2]Design Computing Group, TU Wien. [3]Automation Systems Group TU Wien. [4]Caverion.

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PhD WORKSHOP ABSTRACT PW3

Towards Advanced Resiliency-Oriented Multi-Microgrid Scheduling

Michael H. Spiegel

Correspondence:
michael.spiegel@ait.ac.at
AIT Austrian Institute of Technology
Full list of author information is available at the end of the article

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Abstract

Microgrids, which are tightly controlled electrical networks supporting both, grid connected and islanded operation, are often installed to increase power supply resiliency and to optimally integrate various Renewable Energy Sources (RES). Improvements including cost reductions are made by jointly operating several microgrids in multi-microgrid setups. Due to the possibly large extent of multi-microgrids, fault mitigation such as dynamic grid-reconfiguration and scalability of optimal day-ahead operation gain in importance. Both issues are not fully reflected in today's literature. This abstract specifically addresses the problem of multi-microgrid asset scheduling considering an extended set of failure modes and fault mitigation techniques. A methodology in assessing and advancing asset scheduling approaches is presented. It is expected that results will lead to an increased resiliency of distribution system and multi-microgrid operation.

Keywords: Microgrid; Multi-Microgrid; Smart Grid Resiliency; Asset Scheduling

Introduction

Microgrids, which can be both operated as islanded and grid-connected electrical networks were introduced several decades ago. Main driving forces in realizing microgrids include the call for increased reliability, which cannot be fulfilled by the main grid, efficiency gains by local energy production, as well as economic benefits by a tight integration of renewable energy sources and reduced purchase prices [1]. Since their introduction, many issues such as the reliable and economic operation have been studied in the context of microgrids [2].

The concept of operating and islanding several independent microgrids in a coordinated distribution network, which is herein called multi-microgrid, was introduced few years ago and has since attracted attention [3, 4, 5]. Incentives to implement coordination mechanisms linking microgrids may include economic benefits in normal operation and enhanced resiliency by powering microgrid-external loads, or sharing backup capacity in case of faults in the super-ordinate grid.

Due to the increased extent of a multi-microgrid and the reduction of local reserve capacity, the number of failures which affect the local operation of a microgrid drastically increases. The extended abstract motivates further research on resilient control strategies, pinpoints pending research needs and outlines a methodology for developing resilient control algorithms.

Call for Resiliency and Research Needs

One of the main driving forces in implementing microgrid and multi-microgrid setups is the ability to sustain failures, such as main grid outages, and line faults.

Therefore, thoughtful design of various interlinked aspects ranging from low-level protection and islanding schemes to optimal asset scheduling is needed [2]. In particular, the abstract raises the following question: How can a multi-microgrid that includes a high share of volatile RES be optimally operated, such that a large set of failures can be withstood without triggering a critical multi-microgrid fault?

Literature often uses the term resiliency to describe the ability of a system to sustain and recover from certain impacts without entirely loosing functionality. In contrast to robustness, which does not fully reflect service restoration, resiliency is herein defined as "the ability to reduce the magnitude and/or duration of disruptive events" [6]. As a consequence, resiliency-oriented multi-microgrid scheduling is understood as short-term resource planning, which is not restricted to avoiding outages entirely, but which also considers rapid recoverability in case of power shortages.

Several authors contributed approaches to manage the complexity of optimally scheduling assets under uncertainty such that certain failures can be withstood [2]. A stable islanded operation of a single microgrid in case of main grid failures is ensued by [7], which specifically takes primary control requirements into account but only reflects volatile RES via static security margins. A robust optimization method for finding a single-microgrid schedule that guarantees the supply of critical loads in the presence of volatile loads and generation was presented in [8].

Multi-microgrid setups are specifically targeted in [9], which presents a risk-based formulation of optimal energy exchange scheduling. In contrast to other publications, such as [10], which focuses on coupled networks without fully-fledged islanding capabilities, the paper does not only consider main grid faults, but also takes the possibility of line tripping failures into account. Nevertheless, failure modes beyond main grid faults, such as communication and generation failures and their mitigation techniques, such as grid reconfiguration options, are rarely considered in current resiliency-oriented (multi-)microgrid scheduling problems.

To guarantee a satisfying level of resiliency and robustness while maintaining a cost-effective operation, advanced asset scheduling in extensive microgrid and multi-microgrid installations needs to consider a large extent of failure modes and implemented fault mitigation techniques. In addition, a resilient schedule needs to consider inherent uncertainties related to volatile loads, fluctuating RES production and forecasting errors. Emphasis needs to be put on the accuracy of probabilistic input assumptions and models which may easily lead to a degraded operation or an increased risk of faults.

Development and Validation Methodology

To build the basis for novel resilient multi-microgrid scheduling algorithms, first, a systematic approach for assessing and comparing the performance of these algorithms will be developed. In particular, a simulation-based testbed, which allows to assess resilient (multi-)microgrid scheduling algorithms is created and applied to various approaches found in the literature. Based on the findings, out of several candidates, the framework of developing an advanced multi-microgrid scheduling algorithm is selected. Subsequently, a novel method, which closes the observed gaps is developed and evaluated.

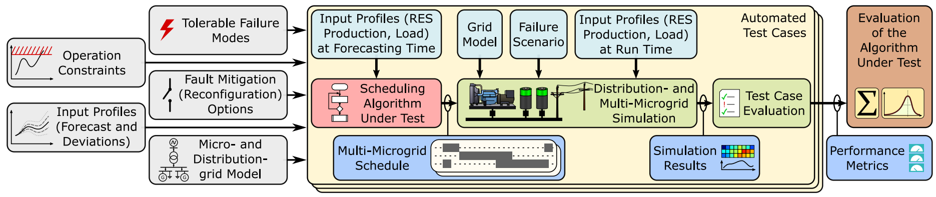

Figure 1 Advanced Resiliency-Oriented Control Algorithm Testbed

Control System Testbed

The basic structure of the envisioned testbed is illustrated in Figure 1, which shows the major components of the test cases, as well as significant inputs and results. The testbed allows to apply various test cases to the scheduling algorithm under test and to evaluate the scheduling outputs based on a detailed grid model.

Since outages and forecasting errors cannot be known deterministically, the scheduling algorithm operates on generated forecasts and stochastic information only. The grid simulation then computes selected performance metrics based on the failure scenario, the actual environmental conditions bundled in the test case, and the optimized schedule from the algorithm. Due to the two step approach, phenomena such as the impact of low-level control functions and various outages can be assessed, although they may not be covered by the scheduling algorithm itself.

Application of Conventional Scheduling

Selected algorithms from literature will be implemented in the multi-microgrid test environment. For each setup, it is first assumed that each independent microgrid is operated with the same scheduling algorithm and no cooperation is performed. Thereby, the performance in failure scenarios, which were not tackled by the related work is focused on.

Secondly, scalability is studied by assuming a central controller that schedules all multi-microgrid assets. Consequently, also non-distributed algorithms can be tested on a multi-microgrid scale. In the expected case that scaling reveals some limits of the existing methodologies, these limits shall be studied and documented such that further developments are guided.

Design and Evaluation of Advanced Scheduling

Based on previous findings, the mathematical framework such as robust optimization or sequential stochastic decision problems, which should be used to attack the problem is chosen. In particular, work such as [11] and [9] may be used as a basis for further refinements. Due to the inherent complexity of (multi-)microgrid scheduling, it is expected that existing methods such as stochastic linear mixed-integer programming approaches will face performance issues when scaling tolerable failure modes and usable redundancy in terms of grid-reconfiguration options.

To manage the computational complexity and to aid engineering practice, it is planned to develop a modular approach which iteratively constrains the scheduling problem until all failure cases can be tolerated. One possible lever to unitize the problem is presented in [12]. The work uses a grid simulation to verify and refine optimal grid partitioning solutions. Similarly, failed schedules may be used to constrain to operating points in which fault mitigation options can still be applied. Heuristics may guide the selection of proper failure cases to quickly generate relevant scheduling constraints.

Conclusion and Outlook

Microgrids and multi-microgrids present an opportunity to tightly integrate RES and to increase the resiliency of electricity networks by providing islanding capabilities and advanced reconfiguration options. To guarantee a stable, resilient and economic operation, energy management and asset scheduling approaches, in particular, need to consider an increased number of failures and fault mitigation techniques. A comprehensive quantitative and qualitative comparison—one aim of the described methodology—is required to select the best suited scheduling approach for practical implementation and to assess further development options.

A multi-microgrid scheduling testbed is created which assesses various performance aspects of the algorithms under test and allows to compare them based on common boundary conditions. Results from the evaluation can be used to select the framework for developing resiliency-aware scheduling algorithms which push the limits of considered failures and deployed fault mitigation options. The abstract briefly sketches options in addressing resiliency aspects in multi-microgrid scheduling. It is expected that the focus on fault mitigation in scheduling will contribute to an increased resiliency in multi-microgrid operation while maintaining economically feasible solutions.

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Author's contributions
The entire contribution except referenced work was done by the single main author.

Competing interests
The author declares that he has no competing interests.

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PhD WORKSHOP ABSTRACT PW4

Adaptive Overlay Network Topologies of Smart Grid Services with Dynamic Constraint Hierachies

Frauke Oest

Correspondence:
frauke.oest@offis.de
OFFIS - Institute for Information Technology, Escherweg 2, 26121 Oldenburg, Germany
Full list of author information is available at the end of the article

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Abstract

The future communication infrastructure in distribution grids might lack, for economic reasons, bandwidth for running all possible smart grid services. This can create communication congestions which can lead to delayed critical messages in the power system possibly affect the power system stability. Prioritizing smart grid services may maintain the core functionality of the power system in high traffic situations by neglecting low-prioritized services. The number of neglected services can vary depending on the system situation. The prioritization of services considering QoS, such as latency, can be transformed into a dynamic constraint satisfaction problem. Constraint satisfiability may be positively influenced by virtualized services that are flexibly moved to servers in order to relieve or avoid the congested communication areas. This PhD-project focuses on the combination of the dynamic constraint hierarchies and virtualization of smart grid services to contribute to the operation of distribution grids.

Keywords: Overlay Networks; Virtualization; Constraint Hierarchies; ICT; Smart Grid

Introduction

With the continuous integration of renewable energies into distribution grids, power flows has become less predictable. Therefore, a demand for smart control and monitoring of technical actors and thus for information and communication technology (ICT) in distribution grids exists, which transforms distribution grids into a smart grids. The use of intelligent devices for measurement and control affects the ICT system state, e.g. by higher sampling rates of measuring devices in critical situations, which can lead to congestions in the ICT system. In contrast, an impaired ICT system could result in critical messages not arriving in time. Therefore, requirements for communication services in the energy domain are defined in so-called *quality of service* (QoS) requirements, e.g. maximum latency, minimum bandwidth, and maximum packet loss; which define constraints of the ICT system.

For a fast and low-cost ICT setup even in the last mile, the guaranteed bandwidth required for real-time communication might not be sufficiently available everywhere to avoid congestion at any time, or it needs to be heavily over-provisioned, resulting in higher costs. This seems counterintuitive by the upcoming QoS requirements of the expected increasing quantity of communication services used to monitor and control the power system. A solution in limited ICT systems could be to prioritize services according to their importance in the power system, accepting QoS constraint violation of low-prioritized services. The criticality of services in the smart grid can also change during operation, e.g. if over- or undervoltage occur, voltage control should be prioritized over state estimation.

In order to keep the neglected services as low as possible, new flexibilities in the ICT system are needed. A new approach deals with the virtualization of *smart grid services* (SGS) (e.g. state estimation, voltage control, or line monitoring), i.e. the decoupling of service and hardware. This allows SGSs to be moved or distributed flexibly and need-driven to different general-purpose hardware. This flexiblity can be used to mitigate congested ICT situations by moving SGS to a different area, or distribute one SGS to multiple servers in order to reduce the traffic.

The goal of this PhD-project is to develop a methodology for normal operation in distribution grids that uses SGS virtualization to adapt overlay network topologies, and to consider dynamic constraint hierachies which respect changing SGS priorities. This involves research under which constraints SGS can be virtualized and how to represent smart grid situations as dynamic constraint hierarchies. Furthermore, it is necessary to analyze how SGS virtualization affect the quality of the task of a smart grid service.

1 Related Work

This research combines different methods and techniques. In the following, related work on the core aspects network function virtualization, overlay network optimization, and constraint satisfaction are presented.

1.1 Network Function Virtualization

Network function virtualization forms the conceptual basis for SGS virtualization and can be used in this project for the underlying ICT. The decoupling of hardware and network functions offers both advantages as well as challenges, which could also apply to SGS virtualization. As advantages, Mijumbi et al. [1] lists a more flexible virtual network function (VNF) deployment on general-purpose hardware and an increased dynamic scalability through virtualized resources or reinstantiation of a VNF. However, according to Han et al. [2], it is challenging how to place servers for NFV efficiently and how VNF can be dynamically instantiated as required. They also mention virtualization issues due to abnormal latency variations and throughput instability. The problem of optimal allocation of NFV is addressed by Wen et al.[3]. The objective here is to provide a performance guarantee in various NFV scenarios taking into account the elastic end-to-end throughput requirements of the service function chaints (SFC) while considering the underlying ICT network.

Niedermeier et al. [4] propose to use NFV in advanced metering infrastructures to transmit energy-related information reliably and cost-effectively. Closely related to NFV is the approach of *software defined networking* (SDN), which decouples data flow from the management. A collection of case studies for the use of SDN in smart grids is summarized in Rehmani [5]. In addition, Nayak et al. [6] show that SDN is also suitable for time-sensitive networks (TSN). These TSN guarantee deterministic end-to-end real-time communication by scheduling packets at end systems, thus avoiding congestion on the network core. Therfore, TSN supports the smart grid in data transmission with real-time requirements.

1.2 Overlay Network Optimization

Virtualization of SGSs can be seen as an adaptation of overlay network topologies, such as *service overlay networks* (SONs). SONs are managed by SON operators on top of the physical ICT structure by negotiating a service level agreement on bandwidth and QoS with the underlying internet service provider. The operation of SONs involves certain challanges, such as the optimal assignment of users to overlay nodes and prioritization of users and their services. Those challanges are adressed by Elias [7]. SONs can also dynamically adjust the overlay topology as communication requirements change. Fan et al. [8] studied dynamic adaptations taking into account the cost of a change considering the decision if a topology change should be made.

1.3 Constraint Satisfaction Problems

When considering many SGS at the same time and the associated QoS constraints, a system state can be reached in which not all constraints are satisfiable. An overview of those over-constrained systems and how to approach them can be found in the survey of Jampel [9]. Here, different variations for solving partial constraint satisfaction problems (PCSP) are presented, e.g. constraint hierachies, in which some constraints are higher prioritized to satisfy. Schiendorf et al. [10] presented another approach to solving CSPs with many constraints or where the constraint hierarchies cannot be configured easily. Instead of hierarchies, constraints are topologically sorted according to the "is more important than"-relation between constraints.

2 Methodology

The use of SGS virtualization to adapt overlay topologies and the use of dynamic constraint hierachies for normal operation in distribution grids involves various challenges. These will be addressed here and the planned research approach will be described in three major steps.

In the first step, a static analysis on virtualization constraints and the power system will be conducted. Here, considered SGS and their associated information technology and operational technology (IT / OT) devices will be determined. Furthermore, dependencies between SGS and additional virtualization restrictions, e.g. deriving from the power system, will be identified here. This also includes if a node should have virtualization ability. Furthermore, it is necessary to identify which power system situation leads to an adjustment of constraint hierachies and how the constraint hierachies should be adjusted. The approach of Schiendorfer et al. [10] to construct constraint hierachies as constraint relationships will be pursued, since it may be suitable for dynamic and complex problems.

Next, a dynamic analysis will be performed with a combined ICT and power system simulation environment to explore interdependencies. Here, it should be studied what effects certain virtualization decisions have on the power system. Additionally, the transition phase of a virtualization process should be studied as data might be lost in the process through packet loss or loss of historical data that is needed for the SGS.

The evaluation step comprises the definition of meaningful scenarios. The proposed methodology will be evaluated in the simulation environment against grid size, integration of renewable energy ressources and performance of the overlay network topology adaption.

3 Conclusion and Outlook

The use of ICT in distribution grids is becoming increasingly important, but for cost reasons, an overprovisioned communication network might be unwanted in distribution grids. As a result, ICT congestion may occur and the QoS of SGS might be violated, which can cause potential disruptions in the power system. For the robust normal operation of the power system, intelligent and adaptive ICT management is needed.

The goal of this work is the development of an solution which, due to changing SGS priorities determined by the power grid's state, makes adjustments to the overlay topologies of the SGS in order to solve the SGS priorities as dynamic PSCP. The basis for the adaptation of overlay topologies is the virtualization concept for SGS, where SGS can be moved to other servers.

The next steps include a refinement of the methodology and a study to examine whether classical PSCP solving is suitable for the operational management of the power system.

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Author's contributions
The author has read and approved the final manuscript. The content of the manuscript was created by author FO, unless otherwise indicated.

Competing interests
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PhD WORKSHOP ABSTRACT PW5

Blackout Recovery. Resilient NFV-enabled ICT Infrastructure for the Smart Grid

Anna Volkova

Correspondence:
anna.volkova@uni-passau.de
University of Passau, Innstrasse 43, 94032 Passau, Germany
Full list of author information is available at the end of the article

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Abstract

The increased interconnectedness of power and communication systems has resulted in substantial interdependence between both systems. This phenomenon is becoming especially critical when it comes to the Smart Grid and its resilience against major disturbances, such as cyberattacks or natural disasters. These disturbances may lead to severe power system outages. In this case, lack of sustained power supply has a detrimental effect on the communication infrastructure operation and constrains fast network restoration.

At the same time, communication networks in the Smart Grid are represented by diverse technologies and standards, which require specific resilience measures. A technology-agnostic resilience design for such networks could increase maintainability and controllability of the whole ICT system and facilitate faster restoration. This paper describes an approach for resilient communication infrastructures for the Smart Grid, which enables rapid network recovery in case of massive power system outages.

Keywords: Network Restoration; Blackout; Network Function Virtualization; Resilience

Introduction

Resilience of an ICT system is the result of a huge number of technological and methodological techniques. It is defined as an ability of the network to provide and maintain an acceptable level of service in the face of various faults and challenges to normal operation [1] and considers a wide range of disciplines including survivability, disruption and fault tolerance. In the Smart Grid, the ICT system is represented by diverse network technologies, which use different protocols and media as well as have contrasting QoS requirements. This overall complexity makes resilient design of such a system complicated.

A lack of resilience leads to the inability of the Smart Grid to withstand challenges and results in massive service disruption of multiple subsystems and, at worst, blackouts. These challenges may have different origins: malicious attacks, natural disasters or cascading failures, as reviewed in [2]. The rapid restoration of the communication infrastructure in these cases is not possible in both cases: due to lack of the power supply and disruption of the hardware. Since the communication between nodes of the power system are heavily impaired, the process of power system restoration is significantly slowed down.

These examples show the importance of the fast and effective restoration of the communication network in order to enable and manage the power system recovery. Nevertheless, the restoration of the communication network implies a major energy demand from the hardware side. This is explained by the high amount of the middleboxes which represent specific network functions, such as switching, routing, load balancing and other.

Furthermore, the review of resilience methods shows that most of the well established mechanisms are not applicable to the blackout scenario. Mutual dependencies between power and ICT systems, topology disruption and related communication degradation introduce a unique task setting, which should be solved with help of the most up-to-date methodology. Building a resilient ICT infrastructure is an essential task to provide accelerated Smart Grid restoration.

This paper proposes the design of the ICT system for future power systems in order to provide resilience and guarantee an effective communication system restoration in case of a blackout. It represents the methodology employed to reach the described goal and is organized as follows. Section “Related Work”provides an overview of the state of art. Section “Methodology ”specifies the overall research objective and outlines the method, while Section “Conclusion and Future Work”concludes and reviews future work.

Related Work

The Smart Grid is exposed to multiple challenges coming from its different subsystems. For example, heterogeneity of the network technologies and protocols of the ICT system, discussed in [3], causes an increased amount of security vulnerabilities, critical for the operation of the whole system. Such security issues of the industrial control protocols are shown in [4].

The concept of resilience and related disciplines are discussed in multiple works during the last decade, but this paper mainly relates to definitions, used in [1] and [5]. To achieve resilience, multiple opportunities are opened by software-based networking. The benefits of SDN-enabled infrastructures are shown in [6]. For the Smart Grid resilience specifically, [7] observes multiple solutions and summarises current approaches with respect to the resilience disciplines, such as disruption tolerance and survivability.

Since the energy efficiency of resilient design is one of the main focuses, the energy efficient placement of VNF should be considered. The early approach on energy efficient VNE is presented in [8]. A comprehensive work on cost-aware virtual resources and VNF placement strategies is presented in [9]. VNE in particular is thoroughly reviewed in [10].

One of the main challenges of the current work is to model communication network restoration method with respect to mutual interdependencies between ICT and power system. An approach to model this bidirectional linkage of two infrastructures considering multiple sources of failures is proposed in [11]. The paper describes the way failure propagation can be expressed by state machine model in order to qualitatively assess interrelated failure states. The way interconnected systems can be modelled is crucial for this research, since it points the way how joined power and ICT systems should be simulated. A review of co-simulation setup and different testbeds is presented in [12].

The application of the described approach is planned as a part of the Smart Grid blackout restoration service, which is described in [13].

Methodology

To answer the research objective, a flexible blackout-resilient ICT infrastructure is developed by using the principle of virtualized networking. This technique enables network enhancement by transferring hardware network functions into software. Hence, network devices such as routers, switches or firewalls, are replaced by virtualization-based analogues. As a result, the infrastructure consists of physical servers with several software network components installed. Virtualization allows the network infrastructure to respond rapidly to disturbances and changes [14]. Multiple communication media and technologies are addressed and connected by the provision of programmable interfaces.

Such a programmable communication network enables the development of a custom network restoration schema for severe disturbances, which employs the concept of a network overlay. Since network functions are decoupled from the hardware and therefore accessible on demand, they can be distributed and dynamically relocated according to the needs of topology of the overlay. If energy resources of the underlying hardware are running out, the whole network setup can be migrated to another available hardware with sufficient capabilities or split and reconfigured on a set of devices.

The technological pool which allows to build the described network infrastructure includes NFV and SDN. NFV establishes several processes, which enable construction of an overlay network. The first process is an instantiation of VNFI in order to execute VNF. Each VNF has a specific type and function, what has an impact on the resource demand. Another process of NFV, that is beneficial for the design of the restoration service, is VNF migration – transferring the memory associated with VNFI from one node to another within the available physical network.

These processes are used within the reconfiguration algorithm, which includes several phases. At the starting point, the hardware available after the blackout and ICT resources are detected. If these resources are sufficient to build an overlay network, VNFs are allocated and embedded according to the needs of the overlay and the QoS requirements. If available functions are not sufficient to build an overlay, new VNFs should be instantiated with respect to the required energy resources. At the validation phase, an overall connectivity is tested and the current topology is updated. The algorithm continues until all the available resources are detected and integrated into topology. The placement of the virtual resources in the presence of uncertainties in the power supply and therefore availability of the hardware introduces an additional challenge. Finding models and heuristics for energy-aware resource allocation will be discussed in the context of VNE.

Conclusion and Future Work

The aim of this work is to develop a methodology for the accelerated ICT system restoration to support Smart Grid resilience. The Smart Grid blackout is a challenging scenario, which involves a high range of theoretical and practical aspects. The conducted research shows that generic resilience measures, applied to unreliable networks, are not sufficient when it comes to low energy supply use case. At the same time, it shows that the use of virtualized communication network infrastructures is a promising approach to build flexible energy-aware network overlays, aimed to reach sufficient communication quality in case of the large power system outage.

Next steps include the further architecture and model design that are suitable for the intended approach and selection and justification of applicable co-simulation techniques. The framework for the co-simulation, which is able to maintain experiments for a big number of nodes, as well as definition of the simulation scenarios are planned as a next research goal.

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Availability of data and materials
Point to sources of data and materials in this article. If there are none, state so. Do not remove this section.

Competing interests
The authors declare that they have no competing interests.

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PhD WORKSHOP ABSTRACT PW6

Interdependent ICT and Power System State Classification for ICT-reliant Energy Systems

Anand Narayan

Correspondence:
anand.narayan@offis.de
Carl von Ossietzky University of Oldenburg, Ammerländer Heerstraße 114-118, 26121 Oldenburg, Germany
Full list of author information is available at the end of the article

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Abstract

The ongoing decarbonization of power systems depends heavily on Information and Communication Technologies (ICT) giving rise to smart grids. ICT enables better monitoring and operation of the grid, but also introduces new challenges. Current methods of system operation assumes the interconnected ICT system to be fully functional. However, past incidents have shown that ICT events can also cause the interconnected power system to fail. This paper presents the idea of joint state classification model capable of analyzing the interdependancy between power and ICT systems. It can be used to analyze the impact of harmful events from both systems in terms of combined system states.

Keywords: ICT system operational states; Power System-ICT interdependancy; Joint state classification model

Introduction

The decarbonization of power systems (PS) implies increased penetration of Distributed Energy Resources (DERs), which are characterized by high uncertainties due to their dependence on weather. Information and Communication technologies (ICT) are a vital part of future power systems as it enables enhanced monitoring, decision making, optimization and control required for the safe and reliable operation of the grid. The ICT networks are continuously developing and are becoming deeply integrated with the PS; giving rise to smart grids or Cyber-Physical Energy Systems (CPES) [1].

CPES are characterized by a strong dependency of PS on ICT. Several ICT-enabled services (e.g. Wide Area Voltage Control system and State Estimation) are essential for the normal operational of the PS. These services have certain requirements on the ICT system and a degradation in the ICT system may cause them to operate inaccurately; thereby affecting the PS. However, ICT system also depends on the PS for power supply and data. The strong interdependencies between the systems also brings-in several new threats and vulnerabilities. Recent events have shown that a failure in ICT system can cause (e.g. cascading failure) or aggravate (e.g. escalating failure) failures in PS. The 2003 North American blackout was caused by a state estimator software failure [2]. As shown by the 2015 Ukraine blackout, ICT systems are vulnerable to cyber-attacks as well. In Austria, the congestion in ICT infrastructure caused by a software bug almost caused a blackout [3]. Evidently, ICT has become more than just a support system for PS making it necessary to model and analyze their interdependencies. Specifically, the impact of ICT events on PS and vice-versa are not fully understood due to lack of sufficient tools and methods to analyze them [1].

Operational state classification is a widely used tool by power system operators to assess its status [4]. It considers various disturbances and categorizes the system degradation in one of five well-defined states. Each state gives several vital information about the PS such as voltage and frequency threshold violation. Based on this, suitable control actions can be applied to bring the system back to normal state.

This presented project aims to develop a joint state classification model considering the interdependancy between PS and ICT. The model builds on the traditional PS state classification by adding ICT states. Consideration of both PS and ICT states in the model accounts for their interdependencies i.e. how a state degradation of one system affects the other. The development of ICT operational states for CPES is a vital aspect of this project. The model should be able to evaluate the impact of power and ICT system events in terms of combined system state degradation. Give the probability of the events, the model can also be used to evaluate risks as well as suitable countermeasures.

State-of-the-Art

One of the first joint state classification models is with PS and ICT having two states each (4 states in total) [5]. The combined system is normal when both PS and ICT are normal. The combined abnormal state is worse than individual abnormal states. This model is conceptual but can show the main challenges due to interdependencies in CPES. A joint model with both PS and ICT having four to five states each is presented in [6]. It differentiates failures and malfunctions in both hardware and software. This model is extended in [2] focusing on operator situational awareness. However, the lack of component failure rates makes this approach difficult to use. In [5], a joint state model for supporting system operators is presented. The PS and ICT have three states each (9 states in total). The excited state implies that the system may soon be in a critical situation, e.g. N-1 criterion is harmed. This meta-model is build for post-incident analysis of ICT-induced blackouts but not for planning and operation. Moreover, different models are used to analyze different scenarios. In [1], a detailed survey of interdependencies in power and ICT systems is presented. It conclude that the topic of interdependency analysis in CPES is relatively new as there is a lack of sufficiently comprehensive models and methods.

A drawback of existing joint state models is that they use highly abstracted system states providing little information about the actual system behaviour. The states are also specific to the models and are not standardized outside their respective contexts. The existing models only focus on structural (or physical) interdependencies. However, due to the growing intertwinement between PS and ICT, functional interdependencies should also be considered i.e. how the systems influence each other during operation. Moreover, these models do not consider the severity of the events and design aspects of the system, e.g. redundant link failures are less severe than non-redundant link failures. The proposed joint model incorporates aspects from system operation to consider functional interdependencies. The model uses traditional power system operational states where the states well-defined in a global context. The ICT state model is developed based on its performance. The model also incorporates system design aspects such as redundancy in the network and presence of back-up data. Additionally, it considers outages from both power and ICT system so as to analyze multi-domain failures.

Joint State Classification Model - Concept and Methodology

The concept of joint model is shown in Figure 1. The vertical axis represents the traditional PS operational states. The horizontal axis denotes the ICT system states. Examples for system degradation paths for different outages are shown. *Path A* shows a classical blackout caused by electrical equipment failure. Path B shows a PS failure which cascades by affecting ICT; thus causing a blackout (e.g. power outage causing loss of power to interconnected ICT equipments). *Path C* shows an ICT failure which affects the PS (e.g. 2003 North American blackout). The model can also provide information (*Path D*) about failures (e.g. which components and services have failed) which can potentially be used to restore both system in a complementary manner.

The project involves the development of two artifacts along with their testing and validation. To develop the ICT operational state model, the scope and the purpose of the ICT system are first defined. This is followed by an literature survey of past PS blackouts influenced by ICT. The aim here is to identify the harmful events (or disturbances) in the ICT system that can affect its performance and cause state degradation. Suitable methods to detect these harmful events will then be investigated. As a initial idea, the concept of ICT-health monitoring, which involves monitoring the health parameters of ICT components to detect abnormal behaviours, will be investigated. From this, the operational states of the ICT system will be derived with the harmful events as state transitions. The initial formalization of ICT states will be done using state automatons due to their ability to capture states as well as state transitions. This will result in the formalized ICT operational state model (Artifact 1). Additionally, the joint model requires a PS state model. A survey on the existing formalization of the traditional PS operational states would be conducted. State automaton based approaches would be preferred due to their compatibility with the developed ICT operational state model. Both the operational state models are then combined to form the joint state model (Artifact 2). The challenge here is to determine different structural and functional interdependencies and incorporate them into the model. Validation of the developed joint state model is the final step. Since failures involving multiple domains are relatively new in CPES, the challenge here lies in the development of suitable test scenarios. The goal is to come-up with failure events that can cause a state degradation in the individual systems and the joint model should be able to determine the aggregated impact on the combined system state. The validation of the model would require a co-simulation platform with integrated power and ICT systems.

Conclusion and Outlook

The presented project aims to develop a joint operational state classification model capable of investigating the interdependencies between power and ICT systems in CPES. The model can be used to evaluate the impact of individual system failures

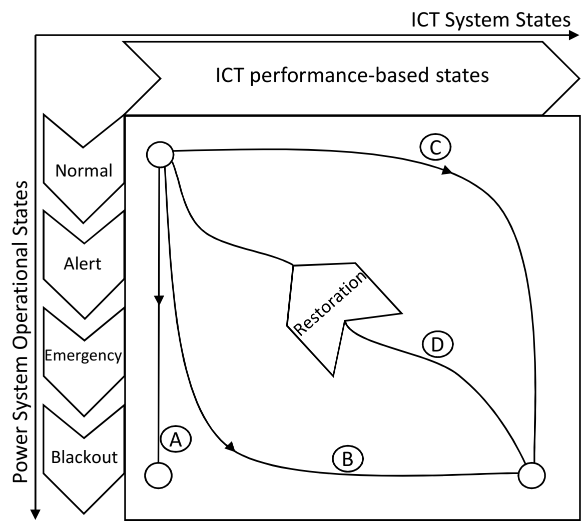

Figure 1 Concept of Joint State Classification model.

on each other as well as the combined system. It can also be used to determine the current operational state of the system and analyze the propagation of failures in order to take suitable countermeasures. The identification of ICT faults from previous blackouts and the development of the ICT states for CPES is an ongoing task. Then the formalization of the ICT states will be done. This would be followed by the investigation into power system states and finally, the development and validation of the joint state classification model.

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Author's contributions
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PhD WORKSHOP ABSTRACT PW7

Distributed Blackstart in an impaired ICT-reliant Renewable Energy System

Sanja Stark

Correspondence:
sanja.stark@offis.de
Carl von Ossietzky University of Oldenburg, Ammerländer Heerstraße 114-118, 26121 Oldenburg, Germany
Full list of author information is available at the end of the article

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Abstract

The growing prominence of renewable energy sources, which were not considered in existing power system restoration methods, is introducing both flexibilities as well as challenges for the Smart Grid restoration. Advanced monitoring and control functions on distribution level are needed to conduct a safe system restoration. However, in case of power system blackouts, the communication system responsible for these functions can also be severely impaired. The presented project aims at developing an agent-based restoration algorithm for the distribution grid, which uses available renewable resources to restore the communication system and thereby enables sufficient observation and control to restore the overall power system. Starting from blackstart-capable units, the agents communicate with each other to form island grids, which are then expanded and merged with each other.

Keywords: Blackstart; Distribution System Restoration; Multi-Agent-System; Multi-Objective Optimization; Co-Simulation

Motivation

The Power system is an important safety-critical system. Security and reliability of power supply is essential. When a failure occurs that leads to a (full or partial) blackout of the power system, the duration of power supply interruption should be kept as low as possible. Power system restoration today starts from transmission level. A generator with blackstart capability is used to energize a line, thereby providing power to more generators. Blackstart capability encompasses two important functions [1]. The first is the ability of a unit to go from a shutdown condition to an operating condition without external power supply. The second one describes the ability of a unit to stabilize voltage and frequency in an island grid on its own by balancing active and reactive power during load pickup. When there is enough power available, loads on distribution level are re-connected. The process is manually coordinated by the system operators of the parts of the grid where the blackout has occurred. Distributed Energy Resources (DERs), such as solar and wind plants, are typically shut off, so the possible uncertain feed-in can be ignored [2]. This needs to be adapted in the future due to the increasing number of DERs in distribution grids which will make up a large part of the total energy production. This makes it necessary to integrate the DER as an active part in the restoration process. In order to deal with the grid's complexity, advanced Information and Communication Technology (ICT) devices in the distribution grid is required to enable automatic monitoring and control thereby supporting the operators to ensure grid stability.

Due to the interdependencies of ICT and power system, a blackout in the power system would also lead to impairments in the ICT system in the blackout areas. This leaves certain parts of the grid uncontrollable and thereby complicate the system restoration [3]. DERs can assist in the restoration by forming local island grids. These island grids would limit the effects of a blackout for the customers and can also restore important ICT devices, which are necessary to coordinate the overall system restoration. This approach places certain requirements on the distribution grid, for example sufficient monitoring and control devices (in the following aggregated with the term Intelligent Electronic Device - IED) for all relevant grid elements and the existence of blackstart-capable units.

A restoration process on distribution level imposes two main challenges. The first is identifying the optimal restoration procedure. This is a computationally complex problem for several reasons [4]: 1) it is highly combinatorial, 2) it is non-linear, 3) it is non-differentiable, 4) it is constrained and 5) it is multi-objective. The second challenge is receiving all necessary information – flexibilities of the DER, the state of the system and the amount of loads – considering the impaired ICT system. Multi-Agent-Systems (MAS) have proven to be an efficient strategy for solving similar problems. A MAS offers a good basis for resilient control and protection schemes due to its ability to dynamically adapt to changing communication infrastructure and its flexibility with regards to communication needs. This makes it applicable in an impaired communication scenario [5].

The goal of the project is to develop a MAS-based algorithm for the distributed system restoration of a distribution grid with a high penetration of DER, accounting for ICT impairment.

State of the Art

MAS have become a popular approach for distributed control functions in the future Smart Grids due to their scalability, robustness, flexibility and learning behaviour [6]. This includes applications like coordination of DERs, electric vehicle management, electricity market and also fault detection, protection and self-healing. The availability of agents in the grid in normal operation gives the option of using their computational power and control abilities during restoration without additional installations. Therefore, distributed power system restoration with the help of a MAS has been the subject of several research projects, resulting in different self-healing approaches [7, 8]. However, many of these approaches do not consider the possibility of an impaired communication system at all or only as binary states (available/not available) (for example see [9]). In reality though, the degradation of the communication system could also include intermediate states which should be considered in the design of the MAS [10].

This project aims to close that gap by designing a MAS-based restoration algorithm that is able to work with reduced observability and controllability of the power system as well as potential Quality of Service (QoS) limitations resulting in message delay or loss.

An alternative approach is to reduce the dependence on the ICT system by using communication-less control of DER. Here local measurements of voltage and frequency are used to adjust the power feed-in from DERs to the current grid state.

This is, for example, used in the German project LINDA [11]. Communication-less control could be used as a fallback-option, in case the impairment of the ICT system has reached a point that makes it impossible for the agents to communicate at all.

Methodology

In the course of this project, two main artefacts will be developed. The first one is the conceptual design of a distribution system restoration algorithm executed by a MAS. The algorithm should be able to work within an impaired ICT system and solve the defined multi-objective optimization problem in order to form island grids on distribution level. The second artefact is the implementation of this algorithm into a simulation environment, co-simulating the MAS, the power system and the ICT system. This will be used for extensive experiments and evaluation.

As a first step, the scenario has been specified for which the restoration algorithm will be developed. This includes the previously mentioned requirements, such as blackstart-capable units and sufficient ICT penetration in the distribution grid. During the restoration of a power system, several dynamic effects need to be considered. Transient system behaviour could lead to protection triggering and thereby inducing another blackout. The focus of this project is on designing the agent-based algorithm that solves the optimization problem and not on simulating the dynamic effects of a power system during restoration. Therefore, these effects are not considered and the system is assumed to be in steady-state. To depict the effect of the impaired communication system on the power system, the interdependency of both systems was specified. This was done by defining states that reflect the quality of the communication link from the agent to its IED. Depending on the state, the agent has a different level of control over the connected element.

Following this conceptualization, the design, implementation and evaluation of the artefacts will be conducted. For the formalization of the optimization problem a literature review has been carried out. The results will be extended by integrating uncertainties caused by the integration of uncertainty caused by the impaired ICT system into the problem formulation. Considering that power system restoration is a time critical process, finding a valid solution in short time is more important than finding the optimal solution. This makes heuristics a good choice. For this project, the COHDA (Combinatorial Optimization Heuristic for Distributed Agents) algorithm has been chosen [12] but can be exchanged for any other distributed heuristic.

The implementation will be done using the co-simulation framework mosaik[1] to combine the simulation of power system, ICT system and MAS. The power system model will be designed based on the SimBench[2] models. For the ICT system, suitable models will be investigated. Goal of the simulation will be to evaluate the algorithm regarding various non-functional requirements, including performance, robustness, efficiency, stability and scalability. In order to do this, simulation setups will be defined based on Design of Experiments. This includes determining what types of failures can lead to a blackout state, thereby resulting in different initial scenarios. Relevant parameters will be defined and varied in order to evaluate their effect on the restoration process. Finally, statistical tests will be used to evaluate the significance of the results.

[1] https://mosaik.offis.de
[2] https://simbench.de

Conclusion and Outlook

The aim of this project is to investigate, how a blackstart procedure in a distribution grid with a high penetration of DER and an impaired ICT system can be performed with the help of a MAS. In order to do this, an algorithm will be developed and implemented within a co-simulation environment for testing and evaluation. The algorithm will be refined and improved stepwise, taking the results of the previous evaluation into account. The project is currently in the first cycle of implementation. After defining a concrete scenario and a list of assumptions in order to specify the task and formulate requirements, a first version for the algorithm and the MAS architecture have been designed.

The next steps would be to finish the implementation, conduct the evaluation and then refine the algorithm accordingly. One major challenge will be the integration of uncertainty into the optimization problem and defining an appropriate evaluation setup.

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Author's contributions
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Competing interests
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PhD WORKSHOP ABSTRACT PW8

Local Energy Community Systems and the Impact on Prosumers and the Smart Grid

Oliver Langthaler

Correspondence:
oliver.langthaler@fh-salzburg.ac.at
Center for Secure Energy Informatics, Salzburg University of Applied Sciences, Urstein Süed 1, 5412 Puch/Salzburg, Austria
Full list of author information is available at the end of the article

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Abstract

The steadily growing share of renewable energy production combined with other disruptive technologies such as electric vehicles poses new challenges on an electrical and a regulatory level. Power grids will need to be able to handle increasing amounts of demand as well as increases in volatility and decentralized production. Combined with the interests and requirements of electricity producers, consumers and prosumers, new solutions need to be found and explored in order to preempt possible clashes of interest, impairments of privacy or undue financial burdens on some social classes. New approaches regarding smarter systems, algorithms and devices will be required in order to maintain grid stability without requiring extensive upgrades. The proposed dissertation explores, how local energy communities can aid in mastering these challenges and which IT infrastructures and methods are needed to enable this contribution. Possibilities to model local energy communities with regard to socio-economic factors and technologies to harmonize production and consumption will be investigated in the process.

Keywords: Local Energy Communities; Smart Grid; Prosumer; Renewables; Direct Consumption

1 Introduction

In recent years, it has become increasingly clear that the electricity infrastructure needs to become smarter to accommodate the increasing demands that the growing popularity of paradigm-shifting technologies such as photovoltaics (PV), batteries and electric vehicles (EVs) pose. One promising development which may help to offset increased power consumption and volatility is the formation of local energy communities (LECs), envisioned by the EU as a means of fostering renewable energy production, spreading energy democracy and decreasing energy poverty rates. An LEC in this context is defined as a single building or a group of buildings serving a predominantly residential purpose and inhabited by multiple parties that utilize a community energy system. A community energy system in turn is, according to [1] and [2], defined as "electricity and/or heat production on a small, local scale that may be governed by or for local people or otherwise be capable of providing them with direct beneficial outcomes". The proposed work focuses primarily on the IT aspects of LECs and will include a case study based on a specific project.

Especially for new residential construction projects incorporating PV hardware, battery storage and EV charging, it is reasonable to set them up in a way that enables the establishment of an LEC. In the short term, maximizing the consumption of locally produced renewable energy may allow for the acquisition of subsidies intended to offset some of the additional costs for environmentally sustainable housing. In the long term, it helps to reduce electricity costs. Battery storage can augment this reduction by improving the rate of self-consumed energy. However, as it is still relatively costly and its cost effectiveness is associated with a relatively high degree of uncertainty (see e.g., [3]), direct consumption is likely to remain an important factor for the foreseeable future.

The rest of this document is structured as follows: Section 2 discusses the goals and motivation for the proposed work. In Section 3, the research questions that follow from the stated goals are presented. Section 4 outlines the methodology with which the the envisioned solution will be pursued. Finally, in Section 5, an outlook on the first steps is given.

2 Motivation

Driven by the developments discussed in Section 1, the goal of the proposed dissertation is to explore and develop the IT systems and infrastructure required to ensure that the new possibilities that LECs offer can be leveraged to optimize the impact on the residents and to harness energy production and storage within the LEC to improve their effect on the grid at the same time. Smarter consumption of self produced energy offers considerable potential benefits:

- It should lead to savings on the consumer side, as minimizing power draw and/or peak demand on the grid can be expected to equate to minimizing cost (especially in case of peak charge tariff models such as the ones discussed in [4]).
- It may allow for savings on the distribution system side by eliminating or reducing the need for grid upgrades.
- It may facilitate savings on the electricity producer side by mitigating the need to adjust power plant output based on renewable energy production and by reducing the need for power plant and storage upgrade or construction.
- If their volatility can be reduced, it will help to expedite the adoption of renewable energy sources such as PV or wind.

By investigating the contributions that LECs can make and by creating the ecosystem required to facilitate their successful adoption, the transition towards ecologically sustainable energy production will be supported. This includes the development of privacy-preserving IT systems and methods that are set up in a socially acceptable way by supporting accounting models capable of ensuring that no undue financial burdens arise, especially for low-income brackets.

3 Research Questions

The suggested work aims to explore, how LEC tariffs and infrastructure can be modeled to best serve the interests of their participants with special regard to socio-economic factors and, by leveraging overlapping interests, which contribution they can make towards mastering the challenges that the electricity grid is expected to encounter in the near future. More specifically, a technological basis is to be developed to that end. From this, a series of research questions can be derived:

RQ1: What are the technological and regulatory requirements to enable the stated goals?

RQ2: How can production and typical (current and future) household loads be coordinated and shifted across the LEC in a way that maximizes the consumption of self-produced energy while requiring minimal to no user interaction?

RQ3: What IT infrastructure is required for an LEC to function effectively?

RQ4: How does the infrastructure need to be designed in order to preserve privacy, ensure security and require minimal trust between the various parties?

RQ5: How can socio-economic interests be incorporated? There may, for example, be a governmental interest to incentivize the formation of LECs that consist of a certain mixture of demographics or which primarily benefit growing families. Can a steering effect be achieved to make this possible?

RQ6: What rates of self-consumption are achievable using these methods? Under which circumstances is battery storage necessary and/or economically viable?

RQ7: How can the technical viability of the developed solution be validated?

In essence, it is proposed to provide a holistic view on the raised issue which is intended to ensure that all relevant aspects of LECs are considered during the development of the necessary technical solution(s).

4 Methodology

In order to find answers to the research questions listed in Section 3, first, a more comprehensive overview of the state of the art is to be gained and grouped into thematic areas such as architectures for energy communities, privacy/security/trust and social/economic topics. The existing work is then to be evaluated regarding its viability for a series of defined LEC use cases. Subsequently, areas that are not or insufficiently covered by existing research can be identified and focused upon.

An opportunity through which some answers to the formulated questions may be gained, is the construction project "Urban PV", hereafter referred to as UPV. This project, in which the Center for Secure Energy Informatics is participating as a research partner, is currently under construction with completion scheduled for late 2020. It encompasses several residential buildings equipped with PV production facilities as well as multiple different kinds of battery storage and public EV charging stations. Its electrical infrastructure is specifically set up in a way that allows the produced energy to be stored and consumed across the residential complex, so it is ideally suited to be used as a data source as well as a possible testbed for some of the solutions developed during the proposed thesis. As a first step, all available data is to be gathered regarding energy flows within the complex. To that end, an advanced metering infrastructure is already in development.

Based on the current state of knowledge, a first overview can be given as to how the research questions raised in Section 3 may be tackled:

- Close involvement in the construction project UPV will provide practical insights that aid in answering RQ1, RQ3 and RQ6.
- Continuation of the work presented in [5] is expected to yield a result for RQ2.
- Incorporation of related work regarding privacy and security (such as [6]) should provide a basis for developing a practicable solution that fulfills RQ4.

- For RQ5, contrasting the measurement results from UPV regarding load shifting potentials via the installed batteries with network tariff models such as the ones discussed in [4] should yield meaningful results. Additionally, a case study based on UPV, in which all the collected data (PV production, Battery status, consumption of each individual household) is combined may be performed to develop and test different internal accounting models.
- A prototype system for LECs will serve to demonstrate the feasibility of the developed solutions for RQs 2-6, thereby representing an approach towards answering RQ7.

5 Conclusion and Outlook

In conclusion, the proposed work contributes to the state of the art by providing an overarching view on the raised issue of maximizing the consumption of self-produced energy within an LEC and seeks to develop concrete protocols and systems to address these issues.

The first step, for which an appropriate system is currently already in development, is the collection of data from UPV. This data will then be supplemented to include as much social information as possible on the residents as well as the electrical devices they use. Furthermore, data about PV production and battery usage will be collected. Combined with existing data sets such as the one used in [4], this data will then be used as a basis for the main body of the proposed work.

Further activities involve an early evaluation of the gathered data and, if necessary, the implementation of corrective adjustments to the measurement infrastructure. This will be followed by the development of a simulation to test different accounting models and a refinement of communication and consensus protocols to enable these models, facilitating an assessment of their impact. Furthermore, the effectiveness of different battery usage strategies as well as basic what-if scenarios, such as increasing hot water storage capacity or replacing district heating with heat pump heating, can be investigated at this point.

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Competing interests
The author declares that he has no competing interests.

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PhD WORKSHOP ABSTRACT PW9

Management of Virtualized Smart Grid Services in a Degraded ICT System

Carsten Krüger

Correspondence:
Carsten.Krueger@offis.de
OFFIS e.V., Escherweg 2, 26121 Oldenburg, Germany
Full list of author information is available at the end of the article

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Abstract

The utilization of Information and Communication Technologies (ICT) becomes a vital part since the need of more observability in distribution grids for safe and reliable operation. Emergency services of smart grids in particular, are sensitive to incidents caused by threats in parts of the ICT system. To keep the the system in a reliable and resilient state, new management methods for smart grid services are needed. This paper presents a methodology to manage smart grid services under real-time requirements in a degraded ICT system. The problem is formalized as a Constraint Satisfaction Problem (CSP) and solution approaches are proposed. Essential research questions are identified to accompany the methodology and structure the underlying project.

Keywords: Management; Smart Grid; Resiliency; Virtualization

Introduction

The change from fossil fuels to a more sustainable power supply using Renewable Energy Sources (RES) brings-in more flexibility as well as uncertainty in smart grids. The utilization of Information and Communication Technologies (ICT) in view of the distributed energy production is becoming more important for the safe and reliable operation. For the present transmission grid, the ICT system is reliable or redundant through dedicated lines and nodes. The same approach would be costly in distribution grids due to huge number of actors and relevant data exchange. Various smart grid services such as state estimation and wide area voltage control, depend heavily on a reliable ICT infrastructure for real-time monitoring and control through Supervisory Control and Data Acquisition (SCADA) systems. Nevertheless, there are recent examples such as the Ukraine blackout that show the vulnerability of ICT systems and its impact. Environmental conditions, cyber-attacks, software bugs and operational errors are some examples of threats that lead to incidents such as link failures, malfunction or equipment breakdown. Due to the unpredictable nature and diversity of threats, it is difficult to plan a system that is completely reliable. Such incidents can cause a degradation of the ICT system.

New technologies must be introduced so as to mitigate the impact of incidents in the smart grid or restore the system from a degraded state. One such technology is Software Defined Networking (SDN), which facilitates network management to improve network monitoring and the performance by enabling programmable configurations [1]. On the other hand, Network Function Virtualization (NFV) decouples software from hardware to run network functions such as routing, switching and network security on standard hardware [2]. Along with SDN, NFV offers more flexibility to

manage the network in the case of degraded ICT systems.
The management of smart grid services in case of degraded ICT infrastructures is not fully considered in the current research. Management refers to the orchestration and execution of actions such as start (wake up), stop (deactivation) and reallocation (migration) of smart grid services or redistribution of resources. As a starting point the following parts consider first the reallocation of services. More precisely, in the case of incidents to certain parts of the ICT infrastructure, the affected services should be e.g. reallocated to other available hardware resources (e.g. CPU, memory and storage) considering network requirements (e.g. latency and bandwidth) and power system requirements (e.g. data acquisition, connection to field devices). However, the management requires different methods such as ICT monitoring and resource allocation. Observation of the ICT infrastructure by using SDN or network management from telecommunication systems can be utilized in smart grids to detect arising threats or degradation in the system. To manage resource allocation it requires monitored information about Quality of Service (QoS) properties from Information Technology (IT) and Operational Technology (OT) devices. Reallocation of services in the case of detected incidents causing a degradation in the ICT system requires a decision making to identify a possible reallocation based on QoS properties, network usage and current resource utilization. The goal of this abstract is to provide a methodology for managing smart grid services in a degraded ICT system.

Related Work

This section addresses the state of the art of four relevant research areas, which are connected to the investigated concept of managing smart grid services and provide a overview of technologies as well as methods that can be applied.
The reliability of ICT infrastructure is investigated by the survey from Tondel et al. [3] which proposes interdependency analysis between power and ICT systems via hazard identification methods and dynamic analysis methods. Even if hazards, threats and intrusions can be detected using anomaly detection or IDS, it is important to analyze their effect on smart grid services. Typical methods such as fault tree analysis, block diagram, attack trees and bayesian network are proposed for time-independent analysis whereas markov processes, petri nets and agent based methods are proposed for time-dependent analysis.
To identify threats and malfunction, ICT monitoring is an important mechanism. SDN is one of the new technologies which is able to monitor and manage the ICT network. Rehmani et al. [4] presents a comprehensive survey of the current research in SDN in smart grids along with different taxonomies in this topic. Some areas such as smart grid resilience and self-healing consider the flexibility of SDN to react on sudden failures and attacks by recovering and maintaining the critical services.
The management of smart grid services require concepts such as virtualization and resource allocation. Beside SDN, technologies such as NFV and cloud computing are relevant. Mitjumbi et al. [2] present various opportunities as well as challenges in NFV and Sonkar et al. [5] proposes resource allocation and VM scheduling techniques to increase the overall utilization of server resources using cloud computing.
To transform constraints into a mathematical model that facilitates the solution of

multi objective functions, CSP is an established model. Sheindorfer et al. [6] provide a general definition for CSP and introduces constraint relationships for soft constraints to handle CSPs with a high number of constraints by transforming constraint relationships into a k-weight CSP.
Rule-based expert systems are able to handle knowledge based information, such as constraints and monitored status information by transforming them to a set of rules and facts. Grosan et al. [7] proposes a general overview of rule-based expert systems and explained different types of expert system such as to satisfy certain constraints. Beside the concept there are certain implementation of rule based expert system such as Drools from JBoss.

Methodology

The research problem is identified and motivated by the missing state of the art for managing smart grid services in a degraded ICT system. The methodology starts with a CSP formalization and follows with a design, development and evaluation description.

CSP Definition

The set of variables $X = \{x_1, x_2, \ldots, x_n\}$ is defined as the minimal required services needed for a reliable operation in smart grids with $n \in N$. Each service $x_i \in X$ has two network QoS requirements, qos_l = latency and qos_b = bandwidth and three hardware QoS requirements, qos_c = CPU usage, qos_m = memory and qos_s = storage. Additionally, a set of nodes $N = \{n_1, n_2, \ldots, n_r\}$ represents the required OT-devices for each service $x_i \in X$ with $r \in N$.
The corresponding domains $D = \{D_1, D_2, \ldots, D_n\}$ represents, for each service $x_i \in X$, a set of overlays $D_i = \{O_1, O_2, \ldots, O_m$ with $m \in N$. An overlay $O_i \in D$ is defined as graph $O_i(V, E)$ with $V = \{v_1, v_2, \ldots, v_k\}$ as a set of nodes and $E = \{e_1, e_2, \ldots, e_l\}$ as a set of edges between nodes, where $k, l \in N$. The overlays are topological descriptions of the ICT infrastructure and each overlay include a server (a server represent any devices which provides enough resources to run smart grid services), a set of connected OT-device, a set of router as well as the corresponding edges in between. SDN is able to configure such topological descriptions and it is assumed that only valid (i.e. in terms of feasibility in the physical network) overlays are proposed. Each set of nodes V contains a server with hardware resources (res_c = CPU capacity, res_m = available memory and res_s = available storage), a number of router for package routing (overload is not considered here) and number of connected OT-devices such as IEDs and RTUs providing an interface for field sensors and direct control on devices such as transformer (e.g tap changer) or inverter. Each corresponding edge $e_i \in E$ has a parameter res_l = latency and res_b = bandwidth to represent the network properties between two nodes. Additionally is a finite set of constraints $C = \{C_1, C_2, C_3\}$ defined, which limits the number of services on a server by the network QoS requirements, the hardware resource requirements and the dependencies between field devices and services.

Design, Development and Evaluation

The first step is to monitor the ICT infrastructure and identify failures and malfunctions of smart grid services to determine the degradation of the smart grid.

For this purpose, the status is monitored by SDN or network management tools based on a simulation that mimics well known smart grid services such as state estimation, unit commitment and wide area voltage control. To degrade the ICT system various scenarios with malfunctions are executed on a communication simulator. A new concept will be developed based on SDN, NFV and cloud computing concepts, to allocate resources, restart services on different devices and reorganize communication flows in smart grids. The objective to formalize the problem as CSP is done in the previous section. The last objective is the evaluation of various metrics such as solution quality, performance, robustness, and reliability. To evaluate the metrics, a co-simulation or real-time simulation with different simulators will be developed including communication and power system simulations, service virtualization, network management system as well as algorithm to orchestrate the virtualization.

Conclusion & Outlook

The current changes in smart grids from fossil fuels to RES, mandates a methodology to manage smart grid services in degraded ICT infrastructures. A formalization of this problem as a CSP is presented, which is currently under refinement. One future task is to adapt the CSP, so that minimal necessary reconfiguration of the services are necessary. To address the formalized problem the future work will consider a rule-based expert system as solver, which is a simplest form of artificial intelligent. The available knowledge from the constraints are mapped to a rule set, whereas the measured status information used as input facts to the solver. In addition to CSP, the next step includes the identification of incidents in smart grid services. To evaluate the idea against solution quality, performance, robustness and reliability, a simulation will be developed with various ICT scenarios to show the first proof of concept.

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PhD WORKSHOP ABSTRACT PW10

Analysis of market-based re-dispatch for the German bidding zone

Ramiz Qussous

Correspondence:
ramiz.qussous@inatech.uni-freiburg.de
INATECH, Albert Ludwig University of Freiburg, Emmy noether Straße, 79112 Freiburg im Breisgau, Germany
Full list of author information is available at the end of the article

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Abstract
In a zonal electricity system, overloaded transmission lines are relieved through non-market-based measures, such as re-dispatch, which is usually procured through obligatory participation procedures. Such methods are considered discriminatory and not directly complying with the European market goals. Various suggestions and proposals have been presented to introduce alternative organizational methods, market-based re-dispatch being the most prominent currently. This project aims to analyze market-based re-dispatch implementation on the German electrical markets, and potential gaming or abuse of such market design.

Keywords: Electricity Market Simulation; Market-based Re-dispatch; Agent based modelling; Power flows

Introduction

Although the European internal energy market liberalization started more than 20 years ago, and it is over in most EU member states, there are still some issues that remain unsolved, preventing the unique electricity market goals, leading to regional fragmentations [1][2]. It can be noticed that market liberalization resulted in national bidding zones in many countries [3], with exception to Norway, Sweden, Denmark, and Italy, where each consists of multiple bidding zones on the national level, and aside from Germany, Luxembourg, and Austria which were one bidding zone up until October 2018 [3][4].

According to the European commission regulation[5, §2], market participants within a single bidding zone are allowed to exchange energy without capacity allocation. This implies that power plants dispatching plans are determined according to a marginal pricing scheme. On the one hand, this indicates that a larger bidding zone, expanding over a wider geographical region, within which unlimited exchange between supply and demand can take place, would be better, since it allows more market participants to be active, increasing market liquidity [6]. On the other hand, market dispatch plans might be technically infeasible, if the spatial distribution of generation and demand, as well as transmission constraints, were not taken into consideration [3][7]. To ensure technical feasibility of a dispatch plan, and grid stability, some remedial measures might have to be carried out.

The implementation (preparation and activation) of different remedial actions is carried out by the transmission system operators (TSO) to ensure that operation within the TSO's control area stays within operational security limits. The TSO designs, prepares and activates the necessary measure by itself unless it was explicitly required that the measure should be managed in a coordinated way [8, §21]. The selection method of the appropriate activation measure is based on the effectiveness and economic efficiency of the selected method.

Currently, in central European countries, re-dispatch is organized and procured through regulatory obligations, where the different generators are obliged to participate in re-dispatch (with the exemption of small, renewable-based, and combined heat and power generators) [9][10]. Regulatory re-dispatch is considered to be a discriminatory measure to some extent, restricting the freedom of dispatch (free movement of goods, as defined by European Parliament Directive 2009/72/EC) of involved market parties [10]. An alternative to regulatory re-dispatch is the market-based re-dispatch (MBR), which is based on economic precedence, through a voluntary market. Market-based design, allows market participants to compete on a market separate from the wholesale electricity market, by sending bids that represent the prices at which they are willing to change their status to relieve the congestion [9]. Although MBR enables coherence with other market segments of the energy-only market, the design of such markets could also impose some operational challenges, such as, forecast variations, causing a change in required re-dispatch power/energy, avoiding procurement of unnecessary re-dispatch, risk of insufficient re-dispatch supply, or market abuse through anticipation and strategical bidding. The goal of this work is to develop an energy market model further to investigate re-dispatch procurement mechanisms and their effect on the market results. The key questions of interest in this work are:

- How would the introduction of a market-based re-dispatch platform affect prices in the German power market?
- Can decentralized, small-scale plants be used economically for grid bottleneck management?
- Will the implementation of market-based re-dispatch in Germany make the market prone to gaming, and market power exertion?

Related Work

Congestion management in general and re-dispatch particularly are gaining increased attention in research communities due to the increased costs and implementation of remedial actions. Currently, there is an increased interest in investigating the implementation of a market-based re-dispatch system. The authors of [11] compare different alternatives for congestion management, under which a cost-based and market-based re-dispatch are compared, and conclude with the recommendation that the current European energy markets should be further developed, before the implementation of such a system. ReFleX model was introduced in [12], where it presents the concept of a market-based re-dispatch platform on a distribution grids level, and focuses on investigating the potential of using distributed energy resources (DER) for congestion management.

The benefits of both cost- and market-based re-dispatch are compared and presented in multiple studies [10][11][13], although market-based re-dispatch provides a non-discriminatory platform where participants could compete with each other, it might be still considered an inefficient long-term solution. It was shown in [9][14] how a market-based re-dispatch design could be counter-effective and prone to gaming, even in a competitive market (where monopolies do not exist).

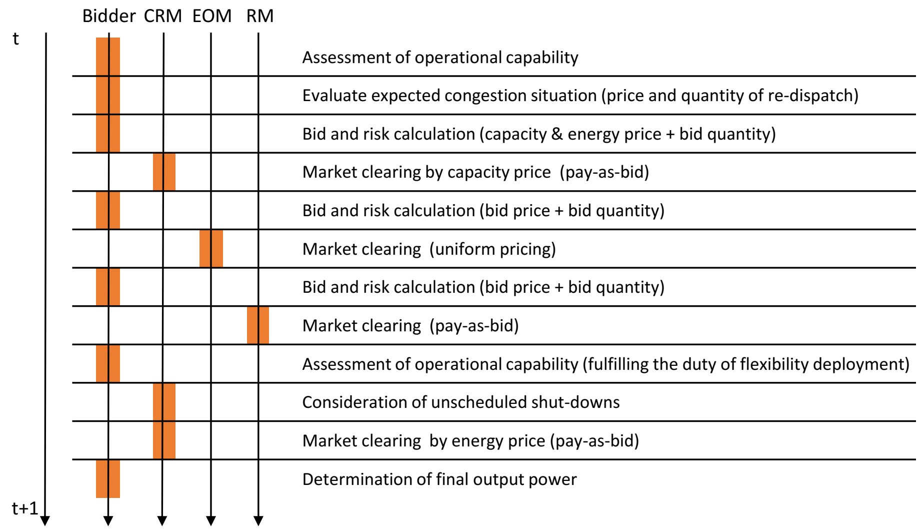

Figure 1 Sequence of actions in the simulation run showing succession of bidding on the different market platforms, control reserve market (CRM), energy-only market (EOM), redispatch market (RM). The left access represents the timeline, where t is a time step.

Methodology

Within the scope of this work, the market model introduced in [15] will be expanded and coupled with a network model. Different re-dispatch organization and procurement methods would be modeled. Cost-based re-dispatch (CBR) would depend on bids sent by the market participants in the energy-only market whereas Market-based re-dispatch (MBR) will provide the market participants the ability to join in a voluntary market platform where they could offer their flexibility.

Following a similar approach presented in [16], the network will be split to multiple non-overlapping geographical zones. For each zone, there would be a responsible TSO to relieve congestion. In a high coordination scenario, one system operator would be responsible to organize re-dispatch all the different zones, with the goal of minimizing the total system cost and assurance of technical feasibility of flows all over the network. A second configuration will allow each TSO to control only resources within its responsibility zones, to minimize own costs and assurance of technical feasibility of flows all over the network. In an uncoordinated configuration, each TSO will aim to reduce own costs and assure technical feasibility of flows within their networks. Power and energy traded within the German bidding zone will continue using the approaches introduced in [15]. The current bidding strategy should be re-adapted to take into consideration re-dispatch. In the case of positive re-dispatch, power plants could gain extra profit, and in the case of negative re-dispatch, the minimum operation limit should be considered. If the negative requested re-dispatch exceeds the minimum operation, the power plant will treat that as an unscheduled shutdown. In case of a MBR implementation, a new bidding strategy should be implemented, Fig. 1 shows a proposed sequence of action for power plants participating in the market. After bidding on both CRM and EOM the market participant could consider bidding on the re-dispatch market (RM). In a cooperative scenario, market participants will be bidding with their marginal prices directly. An extra bidding strategy option has to be implemented, to simulate effects such as gaming and market design abuse. An extreme case would be a non-cooperative anticipating market participants, joining in an inc-dec gaming (cf.[9][17]). These market participants will try to anticipate different network congestions, and bid on energy-only markets in a method to increase their profits from congestion management procurement under a competitive market design.

Conclusion and outlook

This project will contribute to evaluating different re-dispatch market designs and potential of market power exertion. Some preliminary results of the project will also contribute to answer research questions being studied in the scope of C/sells project. In comparison to currently existing literature and studies which depend majorly on solving sets of mixed integer linear problems, the model in this work will introduce a simulation model, which could offer a better understanding of the dynamics of the electrical market and implementation of market-based re-dispatch.

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Availability of data and materials
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Author's contributions
RQ analysed related work, identified open issues, and developed a research proposal related to her PhD project. The author read and approved the final manuscript.

Competing interests
The authors declare that they have no competing interests.

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