Energy Informatics (2023) 6:32
https://doi.org/10.1186/s42162-023-00272-5

MEETING ABSTRACTS

Open Access

Abstracts of the 12th DACH+ Conference on Energy Informatics 2023

Vienna, Austria. 4 – 6 October 2023

Published online: 04 October 2023

P1

Poster abstract: a three-phase electricity grid model of a single family house

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Energy Informatics 2023, **6(Suppl 2)**:P1

Summary
Various models of the distribution grid are developed to assess the impact of imbalanced loads on the three phases or to conduct a state estimation with different kinds of measurement infrastructure installed in the grid. Sometimes very detailed models of small areas of the grid are also used to enhance load disaggregation techniques. In this paper, we present a detailed three-phase residential house model that can be integrated into low voltage distribution grid models. It enables both a detailed analysis of the impact of individual asymmetrical three-phase load and generation systems and the state estimation of the whole grid based on all kinds of measurement infrastructure. The model is based on a real house and validated with different load scenarios. We show that the model enables the identification of the impact of individual devices when integrating it into a distribution grid model. Other use cases include the evaluation of load disaggregation and state estimation algorithms for low voltage grids. The Python source code to duplicate and use our model is published as open-source.

Introduction
The load and the generation in the distribution grid either are assumed to be equal on the three phases, or sum up to an equal total in many simulations. However, small decentralized photovoltaic (PV) generation systems, electric vehicle (EV) chargers and widely popular household appliances such as electric kettles and hair dryers often introduce high currents on only one phase and therefore lead to unbalanced load of the three phases.
Because the historic grid networks were not designed with electric vehicle charging and distributed generation in mind, unregulated installation of such infrastructures can lead to problems. In sparsely instrumented distribution grids, these problems can not be identified, let alone localized. With a detailed distribution grid model and a corresponding power flow simulation it can be calculated [1] how much distributed generation can be installed in a grid area. However, as can be seen in the case study presented in this paper, a simulation of all three phases can be necessary.
In this present paper we sum up related works concerned with the modeling of load and generation in three-phase distribution grids and use cases for a three-phase house model. Then we outline the process of creating a three-phase electricity grid model of a single family house with using the electrical plans of a house as a starting point. Afterwards, the validation of the generated model is conducted by comparing the simulated voltage drop coming from resistive loads with real world experiments. The model can help with detailed power flow analysis in the distribution grid by allowing for a more granular view on the three-phase electricity distribution grid. The model as well as an exemplary use case are distributed as open-source Python code [2].

Contribution
The detailed model of the low voltage grid in the house allows for granular, three-phase power flow calculations. Because our model is based on a real house, it is validated and provided as an open source model, it can be used for further research. To the best of our knowledge, this is the first open model of a three-phase residential house for Pandapower and one of only few examples of three-phase power flow simulation with Pandapower. Furthermore, the outlined validation process of our model in combination with the source code of the model itself can serve as a template for the creation of a customized model for other research efforts.
With the case study presented in this paper, we show that modeling the loads and generation systems in three-phase distribution grids accurately can be of interest in certain scenarios. Future work on realistic scenarios can provide valuable insights into the distribution grid state.

Related work
The distribution grid model used in [3] consists of over 5000 end users, two substations and multiple cycles. This is done for only one phase, as it is assumed that the PV inverters and the loads are perfectly balanced between the phases. Similarly, the power flow is assumed to be balanced in [4] as they simulate the impact of PV in low-voltage distribution grids in Sweden.

However, other papers are concerned with an imbalance of the three phases in the distribution grid caused for example by charging electric vehicles [5] or decentralized energy generation [6]. In [7] the optimal size of a battery to support a residential PV system was evaluated. They identified the generalization of a large number of households as a problem of multiple other papers. With a more detailed model of a residential house, a less general but more optimal solution for the house in question can be obtained.

The model

To create the model we look at the electrical cabling and floor plans of the house. We extract the type of the cabling used and estimate the lengths of the lines. Furthermore, we are able to determine the exact topology of the cabling from these plans. The house model is based on the real-world houses at the KIT Energy Lab 2.0. The house consists of two floors with a base of 9.57 m by 7.6 m and a total living area of 107.5 m^2. Two rooms, a kitchen, a restroom, and a storage room form the bottom floor and three more rooms are located upstairs. A staircase in the middle of the house connects the two floors.

All outlets, lights and heating systems are part of the model. The lengths of the lines are estimated based on the floor plans and the line inductances are derived from the data sets provided by the wiring manufacturer. With this data, new standard cabling types are created as Pandapower standard types. The cables between the sockets and the distribution panels are of type NYM-J 3×2.5 mm^2 with a line resistance of $R = 7.41\Omega/km$. From here on to the house connection, all three phases are in the same cable, a NYM-J 5×6 mm^2 with a line resistance of $R = 3.08\Omega/km$. Smart home controllers, for example the floor heating controllers, are conencted using NYM-J 3×1.5 mm^2 lines with a resistance of $R = 12.1\Omega/km$.

The resulting model is shown in Fig. 1. Between the root node (connection to the public grid) and the distribution panels, one line represents all three phases. The distribution panels are represented by larger round black nodes. Each of these contains a Janitza UMG 604-Pro Power Analyzer. The three strains coming from each of these distribution panels represent the three phases. The red, green and blue nodes represent power outlets or appliances connected to only one phase.

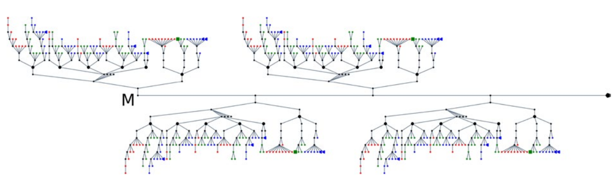

Fig. 1 (abstract P1) Distribution grid with four houses. Blue nodes represent phase S with the loads connected to the enlarged triangles. Green nodes represent phase R with the PV systems connected to the enlarged squares

Model validation

Validation of the house model is done by comparing the power flow simulations of the model with real world measurements. The parameters we are not able to extract from the wiring and floor plans are the lengths of the lines, which we therefore estimate during the development of the model. To validate the length of the lines, we place different resistive loads at different outlets within the house and measure the voltage drop across the individual lines. The voltage drop of a line depends on the resistance, which depends on the line length and the type of cable. Parameters of the cable are taken from the manufacturer's data sheet. Therefore, we are able to calculate the line length in the house from the voltage drop observed with different loads. The power flow simulation is validated by comparing the voltage drop observed in the real world with the voltage drop obtained from executing the simulation.

While this validation process results in line lengths that are within 10 % of our estimates, we are unable to specify contact resistances and errors resulting from these.

Case study

In the following simulation, four identical houses contain PV systems that are connected to phase R. These PV systems generate 3 kW of real power each. Household appliances and an EV charger are connected to phase S. All loads combined sum up to a total of 7 kW per house. In total, the small distribution grid area modeled in this scenario generates a total of 12 kW on phase R and draws a total of 28 kW on phase S. On the right side of the distribution grid area in Fig. 1, an external grid component is connected in the simulation that represents a power source for phase S and power sink for phase R. In the real world, this could be a transformer connecting the low voltage area to a medium voltage grid.

At the measurement point marked as "M" in Fig. 1, the simulation outputs a voltage drop of 10.6 V on Phase S and a voltage rise of 3.8 V on Phase R. However, modeling both loads on the same phase results in a voltage drop of just 6.5 V at the measurement point. These results show that modeling asymmetric loads is important for grid state analysis and installation of new grid infrastructure.

Conclusion

The case study we conduct in this paper makes it clear that a three-phase electricity distribution grid model is necessary for accurately simulating the impact of various appliances, decentralized generation and EV charging infrastructure. With the knowledge gained from such simulations, placement of grid-supporting infrastructure can be optimized to provide the greatest benefit. To conclude, the three-phase house model has numerous use cases. These include the realistic assessment of the impact of imbalanced load and generation, the development of new algorithms and research regarding the observability of the distribution grid with decentralized measurement devices, and the evaluation of load monitoring techniques without the preparatory work of creating a custom house model.

Funding

This research has been funded by the German Federal Ministry for Economic Affairs and Climate Action (TrafoKommune project, funding reference: 03EN3008F)

Availability of data and materials

[2]: https://github.com/KIT-IAI/ThreePhaseHouseGrid

Author's contributions

Conceptualization and methodology: SG and KF; Model development: SG; validation: SG; writing-original draft: SG; writing-review and editing: SG, KF and VH; supervision: KF and VH; funding acquisition: KF and VH. All authors read and approved the final manuscript.

Conflict of interest

The authors declare that they have no competing interests.

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P2

Poster abstract: district energy management simulation framework with rolling horizon approach

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Energy Informatics 2023, **6(Suppl 2)**:P2

The decarbonization of the energy sector brings new challenges and opportunities, especially operational-wise. Due to the nature of renewable energies to be on one side volatile but on the other side can be installed decentrally, the demand of energy management systems for districts with local energy production and consumption is rising, especially for heat and electricity. Most research focuses on either one algorithm to optimize the operation of such a multi-energy system or implements a simulation but omits a more realistic operation where prognosis data change over the course of time in a rolling horizon fashion. To aid the investigation of the operation of such district multi-energy systems, we propose Quarter Energy Management System (QEMS), a district energy management system with co-simulation capabilities. Our system is able to simulate different multi-energy systems and has a modular, microservice-based, approach to incorporate different simulators for energy devices and optimization algorithms.
Keywords: DEMS; Energy neighborhood; Local energy; Co-simulation; Model predictive control; MPC; Rolling horizon; Receding horizon

Introduction

To fight climate change, the transition to Renewable Energy Resources (RER) is needed. Using RER like Photovoltaic (PV) systems offers opportunities due to the distributed generation, but also brings challenges due to the volatility of RER [1]. Coupled with the heat transition, possibilities to handle the volatility arise by using Power to Heat (P2H), especially for district-sized systems.

For sector coupling, multi-energy management systems are typically used [2]. To investigate the performance of such a system, (co-) simulation frameworks were already implemented in the literature [3, 4, 5, 6, 7]. But all of the mentioned (co-)simulators fail to model the uncertainty of forecast, especially the irradiation forecasts which are important to model RERs like PV-plants, which are often part of rolling-horizon approaches [2, 8, 9] which lack the comparability of simulation frameworks.

We propose Quarter Energy Management System (QEMS), a co-simulation architecture for district multi-energy systems that incorporates a rolling horizon approach. It is based on a microservice architecture, which enables a replacement of different service parts, e.g., energy device simulators, Hardware-in-the- Loop (HIL) connectors or optimisation strategies. The simulators are connected via mosaik [10], which provides a powerful but easy-to-use interface for co-simulations.

The rolling horizon approach enables a more realistic simulation of an energy system in conjunction with an optimisation control strategy. The strategies are transformed into rolling horizon approaches that can be compared to other rolling horizon approaches like Model Predictive Control (MPC). As a proof-of-concept, we show that our approach turns Model Template for Residential Energy Supply Systems (MTRESS) [11], that contains a Mixed Integer Linear Programming (MILP) model and solver connection for multi-energy systems, into an MPC-style algorithm.

We describe our microservice and co-simulation architecture in Architecture. Then, in the Evaluation section results for our co-simulation system are discussed, after which Conclusions & Future Work summarises this work with a perspective on future improvements.

Architecture

We propose a microservice-based co-simulation architecture for QEMS. This enables the flexibility to swap out services depending on the systems requirements, e.g. new energy device adapters, prognosis providers or optimization algorithms.

A basic overview of this architecture can be seen in Fig. 1. It consists of infrastructure services, document- and time-series-databases and a central message broker between all connected microservices. Every device simulator is connected via a device-specific service, via which current state data and state control commands can be issued. Additionally, prognoses for the current energy demand, environment and energy production are provided via separate services.

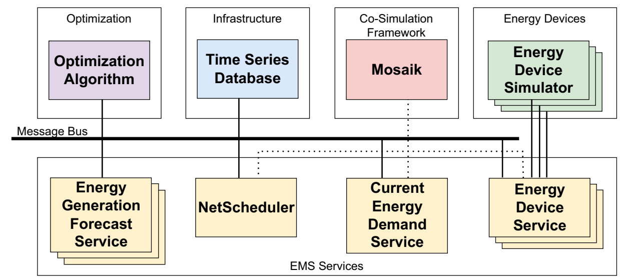

Fig. 1 (abstract P2) QEMS Architecture for Mosaik simulation

This information is fed into a central *NetScheduler* service, which manages the periodic recalculation of the schedule. It then distributes control message according to said schedule for each energy device via its specific service. This service calculates a new schedule via a connected Optimization Algorithm, in our case MTRESS. The rolling-horizon schedule is recalculated every 15 min, or if the deviation from the current schedule is too large, e.g. through unexpectedly high solar production.

While the system is capable of running in a live environment as an actual Energy Management System (EMS), the focus of this work is in the simulation. For the simulation, we chose to integrate the *mosaik* co-simulation framework [10]. It acts both as a central simulation-clock and a communication platform, via which the energy device messages are routed instead of the central message broker in the case of a simulation. This allows the reproducible simulation of scenarios for different setups and time-frames. To simulate the rolling horizon behaviour, different previously collected prognoses are chosen according to the current simulation time-step.

Evaluation

To evaluate the performance of the **Rolling Horizon** approach for energy system control, we compared it to an **Open-Loop** and a **Perfect Forecast** simulation. The Open-Loop result acts as the baseline comparison, which has to be improved upon, while the Perfect Forecast simulation run is the optimum achievable scheduling approach, which should be approximated by the Rolling Horizon algorithm. The results of this evaluation were obtained for a scenario consisting of a 300 kW peak PV system, a 500 kWh battery, a 460 kW thermal air-water heat pump, A5W35COP of 4.0 and a 86 kWh Hot Water Energy Storage (HWES). The data for these demands were modelled for a residential district with 140 apartments, utilizing standardized load profiles based on the weather in northern Germany for 2017, as per the work by Schmeling et al. (2022) [12].

While the open loop 24-hour controller results in an own-consumption of 73.35 %, QEMS reaches an improved own-consumption of 90.53 %. Nevertheless, the MTRESS-based controller still has some limitations, like heat-spikes in the heat pump schedules, which may be infeasible in the real world or impact the health of the device.

Conclusions & future work

In this work, we presented QEMS, a mosaik-based co-simulation for residential multi-energy systems, mainly designed for districts. The simulation focuses on time-based predictions where different timesteps have different prognosis data, to better simulate a real-life operation and easily replaceable simulators. We showed that the co-simulation can be used to track the performance of an optimisation algorithm in a rolling horizon environment.

As a proof-of-concept, we showed that our approach turns MTRESS [11] into a rolling horizon approach. One limitation is that we assume that all devices are connected to each other, which may be needed for further analysis and representation of larger districts. Also, due to the used algorithm, we aggregate all devices of one type into one and distribute the schedule in a greedy fashion, which may lead to worse schedules.

We develop the software further to enable other parties to use QEMS to simulate their optimisation algorithms or define other energy device simulators more easily. Afterwards, the framework will be published as open-source software. Also, adding numeric solar irradiation forecasts for the next 2–3 days in addition to our satellite forecast is planned. The forecasts may have different time resolutions, which must be considered when calculating a schedule.

Funding

We would like to thank all project partners for their contribution and effort in this project. This research was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and the Federal Ministry of Education and Research (BMBF) of Germany in the project ENaQ (project number 03SBE111).

Availability of data and materials

There are no sources of data or materials in this article available.

Author's contributions & Conflict of interest

Alexander Hill: Coding, literature, writing, data acquisition, Chrisitian Pieper: Coding, writing, data acquisition, Jan-Henrik Bruhn: Coding, literature, writing, data acquisition, Patrik Schönfeldt: MTRESS, writing, Fernando Andres Penaherrera Vaca: writing, review

The authors declare that they have no competing interests.

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P3

Poster abstract: modeling of resilient state estimation in cyber-physical energy systems

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Energy Informatics 2023, **6(Suppl 2)**:P3

Abstract

Cyber-Physical Energy Systems are susceptible to new disturbances due to the strong interaction between power systems and information and communication technologies (ICT). Energy management systems require state estimation (SE) service for several monitoring, management, and control services. Failure of state estimation leads to a loss of situational awareness, which affects the operation of the power system. Therefore, it is essential to maintain the performance of state estimation in the case of disturbances. Switching the SE mode between central and distributed with the aid of virtualization is a promising approach to mitigate the impact of disturbances. This paper presents a methodology for the configuration of SE service when switching to distributed mode with consideration of its ICT requirements. A description of the SE resource requirements in the ICT system is provided.

Keywords: State estimation; Distributed mode; Information and communication technology requirements; Allocation problem

Introduction

The operation of modern power systems (PS) is done using a set of grid services (e.g., state estimation, voltage control, frequency control), which enable monitoring and control of the grid. State estimation is a key service used to provide real-time monitoring of the PS [1]. The system state variables (i.e., voltage magnitude and phase angle) estimated by the SE service are used by other grid services, e.g., voltage control [2]. Due to its dependence on information and communication technologies [3], the performance of SE service can be impacted by ICT disturbances such as component failures or congestion. This can lead to incorrect control decisions. The 2003 North Eastern blackout shows the importance of SE service, in which a software failure in the centralized state estimator led to providing the system operator with inaccurate situational awareness [4]. Evidently, the performance of SE service has to be maintained in the face of disturbances.

The SE service can be processed in two execution modes: centralized and distributed. Typically, these two modes are predefined during the design phase and are restricted by hardware-software setups [5]. Centralized SE mode benefits from redundancy and interconnected measurements, and thus provides an accurate estimation of state variables in comparison to distributed SE mode [6]. However, ICT disturbances such as overload traffic [7] and single critical component failures (e.g., SE server) [8] can impact the performance of centralized SE service, and lead to incorrect control decisions. Switching the SE execution mode (between centralized and distributed) during operation is a promising approach to guarantee the performance of SE service. This novel approach along with its implementation in cyber-physical energy systems (CPES) using virtualization is described in our preliminary work [9]. That work considers that the allocation of SE service to distributed mode is predefined, i.e., the SE allocation requirements in the ICT system were not considered. However, the online decision on how to realize the distributed SE in case of switching from centralized mode requires considering the ICT requirements of the distributed SE.

Background

In this section, the foundation of the switching concept of SE service mode used in the work is summarized. This concept is the base of the following work in the paper. This concept is used to maintain the performance of SE service in the face of ICT disturbances by switching between centralized and distributed modes. This is done with the aid of virtualization. It includes three parts – virtualized SE service, SE operational states, and management [9]. The virtualized SE service represents the service which its execution mode can be flexibly switched. The operational states of SE service represent the performance assessment of the SE service which is used for taking the switching decision. The states of SE service are defined as Normal, Limited, and Failed. These states assess the impact of disturbances on the operation of SE service. A more detailed description of these operational states can be found in [10]. The management part has two aspects, a service controller and a local manager on each grid hardware. The local manager monitors the availability of virtualized SE service and the computational resources of hardware; and provides it to the service controller via the communication network. The service controller then aggregates the received information, and assesses the state of the virtualized SE service. In the case of disturbances affecting the SE service (e.g., software failures), the service controller decides on switching the execution mode using the available received information. This switching includes the reconfiguration of the SE service based on available resources. The local manager executes the received control actions sent by the service controller and starts running the new execution mode of the virtualized SE service. Further detailed information about the switching approach of SE mode can be found in [9].

Methodology

In order to perform the SE service in distributed mode, resource requirements in the ICT system for processing and delivering SE outputs need to be considered. Computational resources, delay to service controller, and inter-substation delay are considered. Computational resources allow the processing of distributed SE service in the corresponding servers. These resources are mainly - central processing unit (CPU), memory, and storage. The CPU demand (c_S) specifies the amount of processing cores required to execute and run the SE service on a server, and deliver the desired output (i.e., estimated state variables). Additionally, several other services, e.g., control actions, need the SE service results. As a consequence, the servers holding the distributed SE service should have enough memory available to be able to save the SE results and use them by other services. This is referred to as memory demand (m_S). If the solvability of the SE service cannot be fulfilled using the available received field measurements in the servers, pseudo measurements are used by the SE service. Field measurements which are not received in the substations (where the servers are located) are replaced by their corresponding pseudo measurements [11]. Thus, the SE service requires sufficient storage space to store the pseudo measurements. This is defined as storage demand (o_S).

In addition to computational resources, the switching of the SE execution mode from centralized to distributed needs network requirements. The service controller (SC) sends control action commands to the corresponding local managers at the substations to initiate and start running the distributed SE service. Therefore, the communication between the service controller and substations is crucial for transporting the control actions. It is essential to ensure that the service controller can communicate with the local managers at the substations within the relevant time. This time is referred to as delay threshold (d_{SC-S}). A common way to measure the communication between the service controller and local managers is using the internet control message protocol (ICMP) [12].

Measurements required in the distributed mode of SE service include local field measurements gathered via sensors and boundary measurements exchanged with the neighbor areas [13]. Substations holding the distributed SE service need to exchange information (i.e., boundary measurements), in order to deliver the system state variables. This implies that the communication network must ensure that the neighbor substations which are holding the SE service are accessible to each other within the appropriate time. This delay is referred to as inter-substation delay (d_{S-S}) and is also considered as a requirement.

Figure 1 illustrates the structure of the SE execution mode switching. The service controller located in the control room has the global view of the virtualized SE service. In the case of disturbances affecting the running centralized state estimation service, the service controller will perform switching from central to distributed mode. To do so, the local managers in all substations provide the service controller with information about the delays and the available resources of hardware on which the SE service will be allocated to run. The service controller makes the decision by allocating the distributed SE to the substations fulfilling all ICT requirements. Then, the service controller sends the allocation decision as control actions to the corresponding optimal substations via the communication network. The local manager at the chosen substation in each area starts the distributed state estimation service.

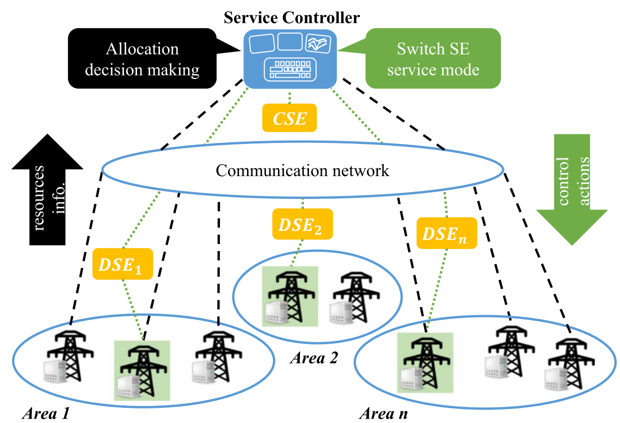

Fig. 1 (abstract P3) Allocation structure of State Estimation Service

Conclusion

This paper addresses the allocation of distributed SE service when performing switching from the centralized mode. This includes covering the ICT requirements. The next step is the modeling of the allocation optimization problem of distributed SE service. The allocation problem will be subjected to the requirements of SE service at the substation (i.e., computational resources and delay between service controller and substation).

Author's contributions

BHH was in-charge of writing the paper. All authors read and approved the final manuscript.

Funding

This research has been funded by German Federal Ministry for Economic Affairs and Energy (BMWi) under the agreement no. 03EI1020E (Resilienz-Monitoring für die Digitalisierung der Energiewende).

Availability of data and materials

There are no sources of data or materials in this article available.

Conflict of interest

The authors declare that they have no competing interests.

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P4

Poster abstract: a flexible simulation-optimization framework for smart grids using distributed agents

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Energy Informatics 2023, **6(Suppl 2)**:P4

Abstract
This study introduces a simulation-optimization framework designed to improve energy distribution in smart suburb settings. Our framework was developed with a focus on key principles and features, such as a fast modeling cycle, the reusability of core components, as well as multi-layered visualization, analysis, and report delivery capabilities. This agent-based simulation environment is able to maintain several distributed optimization algorithms that dynamically optimize the state of the system in predefined intervals. It provides support for modeling systems at various scales, ranging from individual houses to multiple suburbs. Given our contributions, we aim to make rapid modeling of complex energy systems more accessible.
Keywords: AnyLogic; Digital twin; Distributed optimization; Simulation modeling; Smart city; Smart energy system; Transactive energy

Introduction
The introduction of smart meters, responsive loads, electrical and thermal storage, Photovoltaic Systems (PVs), electrical systems, and the distributed generation interconnection of the new Smart Grids (SGs) completely changed the dynamics of traditional grids [1]. Moreover, the urge to efficiently harness the controllability of end-use consumers to make electricity accessible and affordable as well as the global movement for promoting and subsidizing renewable and sustainable energy sources created new challenges in grid management and optimization that are complex and nonlinear [2]. These novel grids need distributed, flexible, scalable, reliable, and adaptable solutions for providing efficient grid operation at every level of the system [3]. Running in parallel with artificial intelligence algorithms (e.g., optimization, prediction, data fusion, etc.) and Internet of things features it can enhance the overall learnability and predictability of the system [4, 5].
Simulating energy systems calls for powerful tools and frameworks. While numerous studies and real-world field projects exist in this field, many of them primarily focus on designing and implementing specific scenarios [6, 7]. Other co-simulation frameworks like Mosaik [8] and HELICS [9] allow for reuse and integration, but their full potential can only be harnessed by users with a certain level of expertise in the platform. The proposed AnyLogic[1]-based framework offers a fast modeling cycle, reusability of core components, as well as dynamic multi-layered monitoring, analysis, and reporting tools.

The architecture
To offer a flexible structure, we created a four-layered architecture as shown in Fig. 1 and explained in the following subsections.

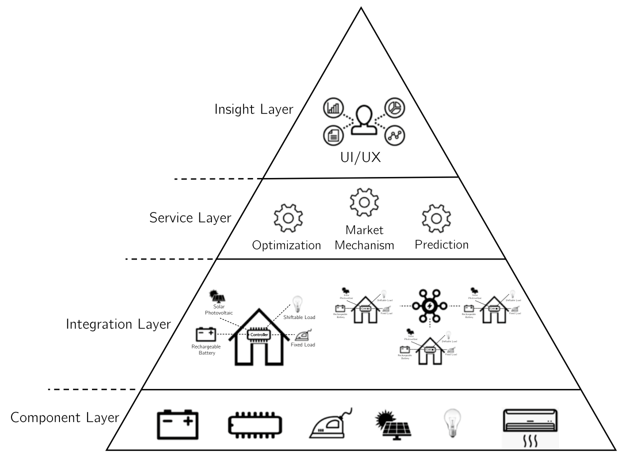

Fig. 1 (abstract P4) The architecture of the proposed framework

Component layer
The Component layer of our framework is designed to provide users with models for both existing and user-defined energy components. These models, which were created in Java using a predefined ontology, can be easily customized to accommodate new energy components. The Component layer includes models for several types of batteries, PVs, storage units, and different types of loads, and a model for house controllers. All of these models can be further modified to meet the user's specific needs. This layer is implemented as different Java classes and is deployed on the AnyLogic environment as reusable components. Each component can be easily configured through the user-friendly AnyLogic interface.

Integration layer
The Integration layer provides features to integrate components defined in the Component layer into a smart grid structure. Its design was motivated by the fact that modeling large scenarios, whether in the energy system domain or not, can quickly become complicated and difficult to extend when integrating new features [10]. To overcome these issues, the i7-AnyEnergy framework was utilized as the second layer of the architecture to create the Integration layer [11]. i7-AnyEnergy offers three main functionalities to facilitate the modeling of energy systems:

(a) Providing representation for components in AnyLogic: i7-AnyEnergy implements every component using AnyLogic Agents, providing a clear understanding of the developed energy systems.
(b) Providing Interfaces and Filters: inspired by the Publish/Subscribe design pattern [12], the Interface/Filter Concept provides a flexible and easy-to-use way to define the structure of energy systems in the AnyLogic UI by decoupling the connection of the components from the underlying microgrid model. Arranging Interfaces and Adapters in a tree structure allows for generating the required hierarchy of the network. Filters allow for the selection of subsets of the tree structure by specifying the desired tag [11].
(c) Computing Energy Flows: Energy Flows are based on the basic principle that energy of a certain type flows from one component to another, as represented by the current power [13]. Although Energy Flows are a vast simplification of reality, we consider this abstraction level as the right one for the given research questions: at first, they allow the reusability for different types of energy. Secondly, we assume that an active power consideration is sufficient due to the low spatial distance of the components in the modeled systems.

[1] https://www.anylogic.com/

For a flexible representation of various types of power system, we resorted to the concept of a Cellular Energy System (CES), which has been initially proposed by the *Verband der Elektrotechnik* (VDE) (i.e., the Association for Electrical Engineers in Germany) [14]. In this study, we adopted the model outlined in [13] to model and simulate a CES based on energy flows. The chosen approach adopts a tree representation of the system and utilizes a recursive structure to establish load distribution functions across the hierarchy. This methodology enables the calculation of the effects of hierarchical load balancing, trying to resolve energy imbalance at the local level. Further details and comprehensive insights can be found in [13].

Service layer
The Service layer provides support for various algorithms and modules that operate on the structure defined for a given SG at the Integration layer. These include optimization algorithms, prediction strategies, data analytics modules, security mechanisms, communication protocols, and more. For example, our framework supports two distinct versions of a distributed optimization strategy, which specifically target residential suburb energy consumption. These implementations serve as exemplars, showcasing how modules operating within the Service layer are structured and function. Both optimization strategies are based on the communication between a global Master Pricing Agent and Local Schedulers dedicated to each household. The first strategy was initially proposed by Shan He et al. [15] and adapts the Franke-Wolfe optimization method, while the second one relies on genetic algorithms [16]. Other services can be implemented in this layer to control and modify the state of the system.

Insight layer
The Insight layer serves as a high-level decision support system, providing users with human-computer interaction features and real-time monitoring information through customizable dashboards, charts, and tables. This layer is designed to aid human decision-makers in modifying parameters that influence automated decision-making performed at the Service layer. AnyLogic development environment's UI features are used as the foundation for the Insight layer [17]. Our framework includes a generic user interface component that creates visualizations for different energy measures calculated by the user's chosen energy component. Selected measures can also be dumped into CSV files or datasets for future training and offline back-testing.

Conclusion
The increasing complexity and diverse energy sources in smart grids pose unique challenges, but they also present opportunities to create more reliable and predictable power systems. Effective management of these systems requires intelligent algorithms and monitoring strategies that can manipulate system components in real-time. To achieve these goals, it is crucial to have flexible and interoperable simulation environments with rapid modeling features. In this study, we tackled these problems by proposing a user-friendly framework that offers fast modeling cycles, reusable core components, as well as dynamic multi-layered monitoring, analysis, and report delivery capabilities.

Availability of data and materials
i7-AnyEnergy is available at https://github.com/cs7org/i7-AnyEnergy as open-source software.

Author's contributions
G.D., P.L.: design and implementation of overall framework, visualization, writing. P.B.: design and implementation of i7-AnyEnergy, improving manuscript. T.D., A.L., R.G.: supervision, improving manuscript.

Conflict of interest
The authors declare that they have no competing interests.

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P5

Demo abstract: IT platform for provision of ancillary services from distributed energy resources

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Energy Informatics 2023, **6(Suppl 2)**:P5

Abstract
This paper discusses the development and implementation of an IT platform that enables provision of ancillary services from distributed energy resources (DERs). The proposed platform is based on a modular framework that integrates various technologies and applications, and it can gather historical, live, and forecast data, as well as uncertainty models to generate correlated scenarios. The platform calculates the multi-dimensional correlation-based reliability of each DER and proposes an optimal coalition of resources to provide the ancillary services at the desired reliability level. A user interface has been developed to simplify data entry, service selection, and result visualization. The case study is based on real wind turbine data in Lower Saxony,

Germany. The proposed platform contributes to the effective and efficient operation of high-penetrated renewable energy systems while providing a digitalized solution for the provision of ancillary services from DERs.

Keywords: Ancillary services; Distributed energy resources; IT platform; Renewable energies; Reliability

Introduction

The provision of ancillary services (AS) for the reliable operation of power systems was previously made by conventional large power plants' synchronous generators. These services included frequency control, voltage stability, operational management, and restorations. However, due to the advancement of energy transition and digital transformation, the provision of AS will now have to be done by a large number of decentralized and small-scale distributed energy resources (DERs), which impose more complexity on network operations monitoring and management across all voltage levels. Regarding this matter, Energy Research Centre of Lower Saxony (EFZN[2]) launched a pioneering project aimed at advancing and customizing reliable AS for energy systems with high penetration of DERs.

The most important contribution of this paper is presenting a service (IT) platform for the provision, optimization, and orchestration of decentralized AS. The ultimate goal is to propose an operational planning model that calculates the optimal combination of DERs in the presence of uncertainties to provide reliable ancillary services, such as spinning reserve, frequency, and voltage control. The proposed IT platform considers the inherent unreliability of DERs and uses historical and live data to construct optimal coalition to provide reliable AS.

Requirements gathering

In this section, the requirements for the IT platform are identified, analyzed, and documented. This includes gathering user requirements, business requirements, functional and non-functional requirements (FR and NFR), and use-case design. Use cases help to define the system behavior and interactions with the users or other systems, and they provide a clear and concise way of communicating the requirements to the development team. Based on IEC PAS 62559, three use cases have been developed, namely: (1) calculation of correlations between time series using multi-dimensional correlation modeling, (2) evaluation of joint-reliability of a set of time series, and 3) reliability-sensitive optimization for provision of AS. As an example, Fig. 1a shows the use-case diagram for the first use-case.

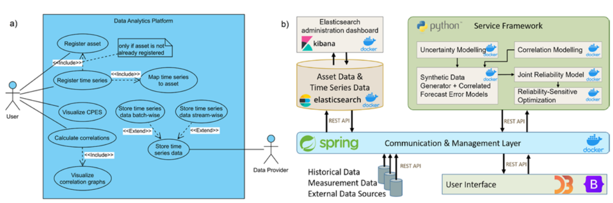

Fig. 1 (abstract P5) a Use-case diagrams for Correlations between arbitrary time series and **b** Proposed modular framework of the IT Platform including the used technologies

The FRs of the IT platform are also defined based on the identified use cases. FRs include asset and time series registration, storing of time series data and metadata, calculating correlations between time series, analyzing joint reliability, reliability-sensitive optimization, and a user interface for initiating and visualizing the results. The NFRs of the IT platform encompass flexibility, extensibility, scalability, integrability, and security. Ensuring these NFRs are effectively addressed is essential for developing software solutions that comply with security standards, can adapt to changing needs, handle increased workloads, and integrate smoothly with other systems.

System framework

This section includes designing the system architecture and data flow diagram. To fulfill the FRs, the proposed service platform architecture comprises four main modules: *communication and management layer*, *database*, *services*, and *user interface* (UI), as illustrated in Fig. 1b. The modules are connected using REST APIs and are containerized. The communication and management layer, developed using the Java Spring Framework, integrates all the components and services. Its primary functions include initializing Elasticsearch indexes, providing REST APIs for data storage and retrieval from Elasticsearch for UI and service layers, and controlling UI requests. Additionally, it calls corresponding services based on user requests, routes web application pages, initializes data streams, simulates data streams through batch data, and synchronizes datasets with different resolutions.

The database module is powered by Elasticsearch and Kibana, which fulfill the platform's requirements as an administration tool for storage, retrieval, data visualization, and administration. The service layer comprises a set of Python algorithms that compute and generate desired results. These algorithms are designed so that the output of one is the input of the next. They include data preparation, uncertainty modeling, decomposition of the multivariate correlation problem, computing the proper copula family [1], visualizing the correlation graph, generating synthetic data, fitting probability distribution function to the error histograms, computing the joint-reliability model [2], selecting the desired ancillary service, and reliability-sensitive optimization [3]. The platform's data flow diagram in Fig. 2 demonstrates the relationships between the various modules and how they interact to produce the final output.

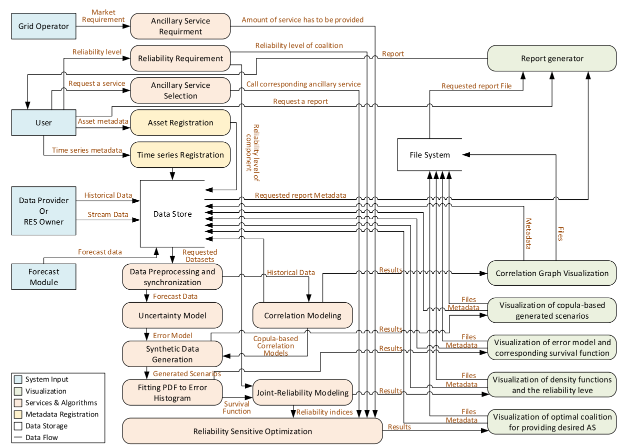

Fig. 2 (abstract P5) Schematic representation of Data Flow Diagram of the proposed IT platform

User interface

This section focuses on the design of the user interface (UI) as an interactive web application dashboard. It allows importing datasets as a batch or stream and running various services based on a custom set of registered datasets, showing the history of executed jobs, running different services such as the correlation modeling between DERs, and presenting visualized results. Since the primary service of the IT platform is to evaluate joint-reliability models, some results are shown in Fig. 3, which are later used to construct an optimal coalition of DERs for providing the desired ancillary service. Bootstrap framework is used to create the UI templates and components, and the JQuery framework creates dynamic and interactive UI components.

[2] Energie-Forschungszentrum Niedersachsen, https://www.efzn.de

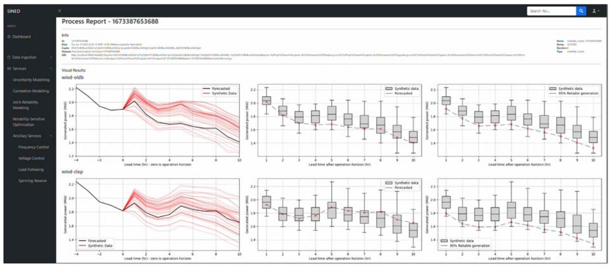

Fig. 3 (abstract P5) User Interface of the IT platforms:Joint-Reliability Evaluation results

Conclusion

The proposed demonstrator offers an overview of the design of an actual IT platform aimed at modeling spatial and temporal correlations, generating uncertainty scenarios, analyzing joint-reliability, and selecting an optimal coalition of Distributed Energy Resources (DERs) to provide ancillary services. This study addresses the challenges associated with requirement gathering, implementation, and user interface design and presents the proposed solutions. While some tools for implementing the IT platform are introduced, this paper is wider than the tools, and the primary focus is to justify the selection of technologies and illustrate the data flow between different modules. Furthermore, it emphasizes the need for further research, particularly in real-time applications.

Funding

The research project SiNED is funded by the Energy Research Centre of Lower Saxony (EFZN) and Lower Saxony Ministry of Science and Culture through the 'Niedersächsisches Vorab' grant programme (grant ZN3563).

Availability of data and materials

There is no data or material publicity available.

Author's contributions

All authors contributed equally to the development of the demonstrator.

Conflict of interest

The authors declare that they have no competing interests.

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P6

Demo abstract: Towards energy-aware coffee breaks: governing electrical appliance use by energy availability

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Energy Informatics 2023, **6(Suppl 2)**:P6

Abstract

The mains frequency is an important indicator of the electrical power grid's ratio between supply and demand. It can be easily measured locally, and is identical throughout the entire grid, thus serving as a vital indicator of the power grid's status. When the electrical power supply exceeds the demand, the mains frequency increases. In turn, when the demand grows larger than the available supply, the frequency decreases. In order to keep the network synchronized, the frequency has very tight limits, and when deviations become too large, countermeasures must be taken. In extreme cases, parts of the electrical grid must be disconnected. To avoid such scenarios, means towards demand side management, i.e., the directed use of non-critical electrical appliances, can help to maintain the mains frequency. In this demo, we present a custom control unit for a commercial of the shelf coffee machine that takes the mains frequency into account for its operation. We introduce a traffic light system (green, yellow, red) to visualize the deviation of the mains frequency from the ideal value of 50 Hz and encourage or restrict the usage of the electrical appliance this way.

Keywords: Mains frequency analysis; Residential demand side management; Energy availability

Introduction

Electrical power grids consist of electricity generators and consumers. For their reliable operation, production and consumption must be balanced within tight limits. Imbalances have a direct impact on the mains frequency, nominally 50 Hz in most parts of the world (60 Hz in the Americas and some parts of Asia). An oversupply of electrical power leads to an increase in frequency, whereas an undersupply leads to its decrease. The permissible deviations from this nominal frequency are typically very narrow, in order to ensure stability of the power grid. For example, [1] defines the rules for electrical grid systems from the German network of transmission system operators and prescribes countermeasures from a deviation of ± 0.2 Hz already. Therein, is also specified that if the mains frequency falls below 49.0 Hz or rises above 51.5 Hz, partial disconnections of the grid are mandatory. Even though major frequency deviations are rare, they still occur occasionally, like in 2018 [2] and 2021 [3] in the Continental Europe Synchronous Area (CESA) grid.

In order to counteract such scenarios, the operation of non-critical electrical consumers can be scheduled based on the current mains frequency. To this end, we present a custom control unit for a commercial of the shelf coffee machine that considers the mains frequency for its operation. The control unit only passes user button presses through to the coffee machine's control system if the mains frequency is within a specific range. The control unit is based on a traffic light system consisting of three deviation stages: green (low deviation: normal operation, user inputs are directly forwarded to the coffee machine), yellow (medium deviation: a confirmation is required to forward the user inputs) and red (high deviation: the usage is restricted and the user inputs are not forwarded at all).

Related work

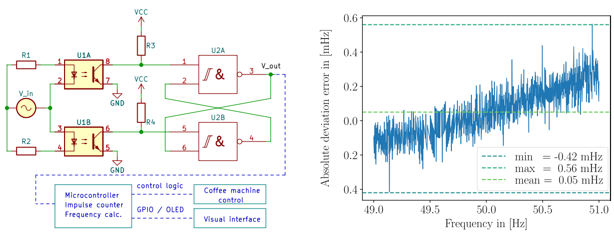
Due to the rising awareness of energy usage and transition to renewable energy, smart meters have become more and more important over the last years. In Germany, smart meters shall even be mandatory in private households from 2032 [4]. As a result, energy data visualisation and feedback has also become an important topic in recent literature and related works. For example, [5] introduced a *Power-Aware Cord* that illuminates when electrical current flows through it, making it possible to visualize even small current flows for individual electrical devices. In [6], the authors presented *Watt-Lite*, a set of three lamps illuminating in different colors and representing the daily min, max and current usage of electrical power. The authors in [7] came to the conclusion that energy data feedback should be designed to be simple and intuitive. A traffic light system using lamps is proposed to reduce the amount of visualized information and thus simplify integration into the daily life of people. We therefore also focus on simplicity and use a traffic light system for our visual grid frequency representation.

Coffee machine control

For our system, we use a commercial of the shelf coffee machine, a De'Longhi Magnifica ESAM 3200.S [8]. Our custom control unit for the coffee machine consists of two parts. The first part takes care of reliably measuring the mains frequency while the second part controls the coffee machine based on the measured frequency and user inputs.

Frequency measurement

For the mains frequency measurement, we designed a PCB based on [9]. The schematic concept is shown in Fig. 1a. On the input side, an alternating voltage V_{in} is applied. The following optocouplers and Schmitt trigger convert the sinusoidal input signal into a rectangular shaped output signal V_{out}. A microcontroller is then used to measure the period duration T_{out} and thus the frequency $f_{\mathrm{out}} = \frac{1}{T_{\mathrm{out}}}$ of the signal. To verify the accuracy of our measurement hardware, we evaluated it using a Rigol DG1062Z function generator [10]. The results can be found in Fig. 1b and show absolute deviation errors well below 1 mHz (0.002 %), which is sufficient for our use case.



(a) Schematic. (b) Evaluation.

Fig. 1 (abstract P6) Our frequency measurement concept. The electrical schematic is based on [9] and shown in (**a**). The evaluation for a frequency range of 49–51 Hz is shown in (**b**). The absolute deviation error rates are well below 1 mHz (0.002 %)

Control unit

To control the coffee machine, we had to capture the user inputs and manipulate the forwarded information based on the current mains frequency. Therefore, we bypassed the user buttons on hardware level through our custom control logic. Depending on the the mains frequency, we differentiate between three different ranges based on two frequency thresholds f_{green} and f_{red} for our control logic, as shown in Fig. 2.

(a) (b) (c)

Fig. 2 (abstract P6) Our interface for visualizing the mains frequency is based on a traffic light system. The integration with the coffee machine is shown in subfigures (**a**) and (**b**). In addition to the traffic light visualization, we also present the numerical value of the mains frequency and an icon corresponding to the current state. Subfigure (**c**) shows a more detailed view of our prototype implementation in different frequency ranges: red (top), yellow (middle) and green (bottom)

Green For frequencies higher than f_{green} we assume a balance or oversupply of electricity and thus encourage the usage of the coffee machine. This is visualized by a green light and a positive icon. The user inputs are directly forwarded to the internal control logic of the coffee machine.

Yellow If the frequency falls between f_{green} and f_{red}, we assume a minor electrical undersupply and visualize this using a yellow light and a neutral icon. In addition, we require a secondary button press for confirmation, before forwarding the user input to the control logic.

Red In case the frequency drops below f_{red}, we assume a major undersupply of electrical power. This is represented by a red light and usage restrictions. We do not allow any usage by not forwarding the user inputs to the internal coffee machine logic.

In our prototypical implementation, we have defined the frequency threshold values as $f_{\mathrm{green}} = 49.95$ Hz and $f_{\mathrm{red}} = 49.85$ Hz. These values can be selected and optimized for the individual use case. Due to the use of a programmable microcontroller, it is possible to adapt the control logic to apply more or less restrictive rules based on user inputs and mains frequency.

Conclusion and outlook

We have presented a custom control unit for a commercial off the shelf coffee machine. The control unit consists of two parts: One for monitoring the mains frequency, and a second one to handle the user inputs and decides on further actions based on the measured frequency. Our system actively encourages or restricts coffee machine usage based on predefined frequency thresholds. For visualization we have embedded a traffic light system and icons. Our first evaluations have shown that our system is capable of reliably measuring the mains frequency with an absolute deviation error well below 1 mHz, which is precise enough for real-world scenarios.

In the future, we plan to conduct real world studies on the psychological effects and behavior of people when using our system. We are interested in finding out whether the visualization of energy data, in the manner of mains frequency, actually affects the usage of the coffee machine. Furthermore, the concept of controlling electrical devices can be applied to almost any kind of household appliances, such as washing machines, dishwashers, etc. Therefore, we also plan to apply our approach to a wider variety of electrical devices and evaluate them based on the previously mentioned criteria.

Availability of data and materials

The program code and the electrical schematics are based on [9]. No additional data and materials were used.

Author's contributions

A.R. and D.S. conceptualized the idea. D.S. and F.S. built and evaluated the prototype. D.S., A.R. and F.S. contributed to the writing of the paper.

Conflict of interest

The authors declare that they have no competing interests.

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P7

Poster abstract: empowering end users with non-intrusive load monitoring for improving energy efficiency

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Energy Informatics 2023, **6(Suppl 2)**:P7

Summary

Energy flexibility is an important milestone on the route to a sustainable and carbon-neutral future energy supply. In this context, Non-Intrusive Load Monitoring (NILM) is a promising approach to provide a detailed picture of the energy consumption of households without the need to install expensive sensors. NILM is a data-driven approach that aims to disaggregate the total energy consumption of a single household or building into the consumption of individual appliances. The primary hurdle in NILM pertains to identifying the best solution from an unbounded collection of potential solutions for the underdetermined disaggregation problem. To address this issue, Machine Learning (ML) techniques provide a promising avenue. Among these techniques, Deep Neural Networks (DNNs) have been identified as a viable solution for the problem of load disaggregation. However, the high computational demands and the limited diversity in training data hinder the deployment of these models on low-cost, low-demanding systems that are commonly accessible to end-consumers such as embedded systems in smart meters. Therefore, there is a need to focus on developing models that can be easily deployed on such systems to enable end-users to benefit from the advantages of NILM techniques.

Introduction

The challenge of NILM involves using algorithms to estimate individual appliance power loads from a single aggregated energy consumption measurement. Initially, these algorithms utilized techniques such as Factorial Hidden Markov Models (FHMMs) and Combinatorial Optimisation (CO). Recent advancements have shifted towards Deep Learning (DL), which has shown better performance. Deployment of deep neural networks on low-cost devices is limited due to computational and storage demands; addressing this is critical for real-time applications and privacy, especially that energy consumption data collected by smart meters are sensitive consumer information, and privacy is a paramount concern among individuals, acting as a major inhibitor for real-time data collection in practice [1]. The choice of training datasets and preprocessing steps significantly affects model performance, making the development of accurate NILM algorithms challenging but essential for energy efficiency and cost savings.

Research questions

Solving the NILM problem for resource-constrained systems is a multifaceted challenge that requires three interlinked research questions to be answered simultaneously.

The first question (RQ1) investigates the feasibility of different generic DL-based compressing techniques for NILM models. This is crucial to ascertain if these models can be economically deployed on low-power, low-cost systems. RQ2 aims to pinpoint the most effective techniques concerning model optimization in regards to accuracy and their optimal parameter space. It involves discerning the optimal trade-offs, which requires apt metrics and understanding the parameters that significantly impact performance. Identifying these techniques facilitates their application in specific domains like edge computing. RQ3 delves into understanding data aspects that can enhance model performance. This involves exploring data preprocessing techniques that boost performance without necessitating model retraining. Special attention is given to models trained on cross-domain data to ensure their robustness and generalization in real-life applications. This is particularly significant in distributed learning frameworks and involves understanding the hurdles of integrating data from varied sources and methods to address them. Alongside these primary questions, secondary objectives include assessing the reliability and scalability of NILM models. Furthermore, data privacy is a pertinent issue; thus, methods for data encryption and techniques to maintain data privacy while still augmenting model performance are explored.

Methodology

This study focuses on optimizing NILM models by compressing and evaluating them across diverse datasets. To address feasibility (RQ1), a literature review is being conducted to comprehend existing research in optimizing NILM models using Artificial Neural Networkss (ANNs). Data, including models, datasets, and performance metrics, are being collected. The compression techniques: pruning, quantization, weight sharing, pooling, depthwise convolution, and transfer learning are adapted to diminish model size, computational complexity, and memory requirements while preserving accuracy. Preliminary analyses are being carried out on various model architectures to evaluate the feasibility of each method.

For RQ2, the efficacy of these compression methods on NILM models is being scrutinized by examining their impact on accuracy, inference speed, and memory demands. Methods are independently evaluated with configurations derived from the literature. The results will inform the final selection of configurations. Common metrics, including model size and inference speed, are used to quantify the results.

Addressing RQ3, dataset selection considers factors including appliance diversity, public availability, and variety in capturing environments. Analyzing similarity measures between datasets helps avoid overfitting and provides insights into data structures for targeted training.

Lastly, a pipeline is designed to standardize the model development process, including data collection, preprocessing, model training, and evaluation stages. This pipeline facilitates experimentation with different models, hyperparameters, and data processing techniques while ensuring reliability, reproducibility, and scalability. The Non-Intrusive Load Monitoring Toolkit (NILMTK) [2] is utilized for data loading, and recent datasets like DEDDIAG [3] and HIPE [4] are considered.

First results

Datasets (RQ3) The most suitable publicly available energy datasets are captured in residential settings [5]. Varying other factors such as suitable data sampling rate and the time duration of the data capturing enough samples for different patterns (for instance to capture consumers habits in different seasons of the year) are also important factors that need to be considered. For compatibility with previous research, I always ensure that I use at least one popular dataset, such as UK-DALE [6] and REFIT [7]. I have also made sure to include datasets that are captured in non-residential settings, such as BLOND [8] and HIPE [4].

Disaggregation Model Parameters (RQ1, RQ2) The Sequence-to-Point (S2P) and Sequence-to-Sequence (S2S) models were used as a starting point, and the effects of different parameters that control these models, as well as the effects of different data preprocessing techniques, were studied. The model accuracy defined as the difference between ground-truth consumption and model prediction served as a metric to quantify different aspects about the data quality and parameter selection. Previous research exploring different characteristics of the data [9] and later the temporal data resolution [10] on multiple disaggregation algorithms, including sequence-based models, encouraged me to further explore the impact of sequence lengths of these models, as stated without explaining in the original paper [11]. The results of this analysis as published in [12] and clearly show that there is no single optimum value for the sequence length, but rather it highly depends on the appliance types in the aggregate data.

Compression (RQ1, RQ2) Making these models cost-efficient without loss of accuracy is a challenging task that can be achieved at multiple stages of the ML-pipeline. Techniques such as quantization and pruning were employed. Quantization was observed to compress the model size at the expense of accuracy, while pruning improved performance. The research explored optimizing models for specific platforms through mixed-precision parameters during training or inference. The result of this study has been published in the proceedings of the thirteenth ACM International Conference on Future Energy Systems (ACM e-Energy) [13].

Data Clustering (RQ3) I explored data clustering techniques, observing differences in energy consumption between workdays and weekends. By training models on data with daily resolution clustered via the *k*-means algorithm, higher accuracy was achieved for office building energy data. The clustering effectively separated different daily patterns, and using models like ResNet, a reduction of up to 40% in disaggregation error was achieved. The results of this work were presented in the latest edition of the NILM Workshop [14].

Conclusion and outlook

For the foreseeable future, I am planning to continue working on the aspects discussed in Research Questions to solve the NILM problem and facilitate its usage on limited edge devices in terms of processing power, memory demand, and accuracy. Studies such as [15] show that research in this area not only has direct benefits on the target model, but may also lead to improvements in our understanding of the original models, as we found out in [13]. Thus, the results of research in this area can be brought back to the original models, for instance, in the form of regularization techniques. Among other, I am planning to explore the possibility of integrating the time dimension as a new dimension into the model to improve its performance at no extra cost. Furthermore, I am planning to explore the effect of state-of-the-art ML-models such as transformers and different learning techniques on NILM models under distributed and decentralized learning strategies such as Federated Learning (FL) or Split Computing [16].

Funding

This research received no external funding.

Availability of data and materials

Data used in this study have been sourced from multiple resources, with a particular emphasis on employing energy consumption data primarily from the UK-DALE [6], DEDDIAG [3], BLOND [8], and HIPE [4] datasets.

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P8

Poster abstract: the effect of coupling the industry and energy sectors for the German transition to climate-neutrality

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Energy Informatics 2023, **6(Suppl 2)**:P8

Summary

Sector-coupling of the industry with the energy system has been considered in energy transition studies. However, either the development of the industry sector or the development of the energy system are exogenous factors. A research gap remains in studying the feedback, synergies, and conflicts between the sectors' transformation paths to climate-neutrality. This project addresses this gap by developing a joint techno-economic optimisation model that represents both the industry and the energy system endogenously. To quantify the effects of an integrated transformation, the optimisation results are compared against the optimisation results of a decoupled model configuration.

Keywords: Industry defossilisation; Capacity expansion model; Energy system optimisation; Sector coupling

Introduction

Given its emissions intensity and reliance on fossil fuels and feedstock, the industrial sector plays a crucial role in achieving Germany's net-zero emissions goal by 2045 [1]. Due to the high energy demand of the industry sector (29 % of final energy demand in Germany [2]), the defossilisation of the industry sector is highly connected to the defossilisation of the energy sector. In the context of this study, the industry sector comprises production processes and energy carrier use (as fuel or feedstock) of the most energy- and emission-intensive branches, namely steel, cement, and basic chemicals production. This study's energy sector encompasses only electricity generation, storage, and distribution.

Many defossilisation options of industry processes entail their direct electrification, or their indirect electrification via hydrogen or synthetic hydrocarbons [3]. The switch to electric process routes causes electricity demand to rise significantly [3] and only leads to climate-neutrality if zero-emission electricity is available at the plant's location[4]. Therefore, the choice of technology, the location of the industrial plants and the timing of the technology switch potentially have an effect on the energy system.

Most studies on industry transformation take projections or assumptions about electricity prices and availability of low-emissions grid electricity as exogenous input (e.g. [5, 6, 7, 8]). Similarly, most studies on energy system transformation take final energy demand, including that of industry, as exogenous input, e.g. via hourly load time series (see reviews by [9, 10]).

In both cases, the transformation of one sector is static, potentially leading to sub-optimal outcomes from the system perspective.

This project investigates the cost-optimal transformation of the industry sector towards climate-neutrality while accounting for interplay with the energy system in a model-based approach. It analyzes the differences between integrated optimal transformation and individual sectoral transformations to understand if pursuing an overall optimum leads to different outcomes. In the integrated transformation, industry and energy sectors are coupled via an energy balance, and the total cost of both sectors are minimised simultaneously. In the individual transformations, costs of the sectors are minimised separately and parts of the energy balance are exogenous. Different outcomes would indicate feedback, synergies and conflicts between industry and energy system transformations. The project focuses on the following research questions:

- How does technology choice, overall costs and distribution of costs in an integrated transformation differ from individual optimal transformations?
- Are industrial plants relocated in an integrated transformation with the energy system and what effect does it have on energy system transformation?
- Is the timing of transformation steps different in an integrated approach?

Related work

The first research question has been partly examined in past research. Here, coupling of industry and energy system defossilisation is realised through the co-optimisation of technology choices in both sectors [11, 12, 13]. However, options in the industry sector only involve technologies for process heat, hydrogen, and hydrocarbons provision while the choice of process routes is exogenous. Going one step further, [14, 15, 16] additionally co-optimise the choice of industrial process route with energy system transformation. Their results show the share of industrial process routes that is cost-efficient for the overall coupled system. However, it is unclear whether this result comes from sector coupling or whether it would also be the cost-optimal solution of decoupled industry sector optimisation. Thus, no statement about feedback between the sectors can be made.

The second research question of industrial plant relocation in interaction with energy system transformation has been explored by [7] and [17]. They fix industrial electricity and hydrogen demand, while the placement of plants is varied. Their results suggest that allocating plants to regions with favorable renewable electricity conditions is cost-efficient from a system perspective and leads to additional expansion of renewable generation and less expansion of dispatchable power generators and negative emission technologies. A gap remains in plant relocation with endogenous industry transformation.

Finally, interactions in the timing of transformation steps have been addressed in some of the studies with partly integrated sector transformation described above. [13, 11] find that the energy system is defossilised at the beginning of the pathway, while electrification of end-use sectors happens later. [15] obtain a similar result for the defossilisation of industrial process heat which switches to biomass at the beginning of the pathway and to electric process heat generation later, when energy system defossilisation is already advanced. As stated above, it is unclear whether these dynamics are related to the coupling of sectors.

Methodology

Optimisation under cost minimisation and a CO_2 budget is performed to derive the transformation of the industry and energy sectors. Decision variables are the expansion and decommissioning of industrial plants and the expansion, decommissioning and dispatch of power generator, storage and transmission capacities. The coupling point between the sectors is the energy balance, in which industrial plants make up part of the electricity demand which the energy system must supply in every time step. The electricity demand of industrial plants depends on the process route and thus is an output of the optimisation. A main constraint in the industry model is the yearly demand for materials which must be be met by the industrial plants.

Requirements for the electricity system model are the simultaneous optimisation of capacity expansion and hourly dispatch, the options to perform overnight as well as pathway optimisation, and the representation of today's system as a starting point. The open-source model PyPSA-Eur [18] meets these requirements. It uses the PyPSA framework for energy system modeling [19] to build a model of the current European electricity system and loads using open-source data. The electricity system is represented as a network of lines and nodes. Renewable and thermal generators, storages and loads are assigned to the closest nodes. Electricity is exchanged through the lines between the nodes performing a linear power flow.

A model representing the German industry sector at process level is developed based on the PyPSA framework [19] such that it can be coupled to the energy system model. Different process routes and technology options are modeled in detail along with their emissions and demand for energy carriers and feedstock. The model is developed based on literature review. Information on process route options is taken from reports of research projects on industry defossilisation, technology papers, Life Cycle Assessment studies, and databases. The major challenges in model development are finding an adequate level of detail regarding the technology representation and spacial resolution, as well as open-source data availability.

Conclusion and outlook

The project will provide insights for research on the sector-coupled transition to climate-neutrality with main focus on the industry sector. It will reveal which feedback between energy system and industry are most relevant, which aspects in sectoral transformations may hinder each other, and which synergies exist.

The findings will advance research in energy system modeling in several ways. Firstly, an open-source optimisation model of the German industry and its defossilisation options will be provided. Secondly, the model will demonstrate an approach to represent industry processes endogenously in a large energy system model.

Possible future work could extend the energy system model to supply and distribution of gases, heat and hydrocarbons. Since these are all used in the industry sector, additional dynamics could be identified. Furthermore, material flows from the industry sector towards the energy system could be represented in the model.

Previous studies have shown that power system transformation impacts the demand for materials such as steel, cement and aluminium (e.g. [20]) which could increase the material demand that must be met by the industrial processes. This effect could also be represented endogenously in the model such that the feedback are accounted for. Finally, the presented approach could be extended to analyse interconnections between more sectors and include more regions.

Acknowledgements

Many thanks to Prof. Dr. Martin Weibelzahl for shepherding and to Prof. Dr. Anke Weidlich and Dr. Mirko Schäfer for the supervision.

Funding

The author's PhD project is supported by the German Federal Environmental Foundation (Deutsche Bundesstiftung Umwelt, DBU).

Availability of data and materials

Data sharing is not applicable to this article as no datasets were generated or analysed during the current study.

Author's contributions

The author analysed related work, identified research gaps, an developed a research proposal related to her PhD project and developed the research method.

Conflict of interest

The authors declare that they have no competing interests.

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P9

Poster abstract: the role of coupling points for self-organized multi-energy grid operation

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Energy Informatics 2023, **6(Suppl 2)**:P9

Abstract

Deploying weather-dependent renewable energy resources (RER) in the distribution electricity grid can increase the demand for energy flexibility. Couplings with other energy sectors can help to fulfill this demand and result in a multi-energy system (MES). Controlling these coupled grids is challenging due to the different requirements of the different stakeholders, especially the prosumers, and the enormous challenges of resilient operation in such non-homogeneous grids. Especially the coupling points (CPs), which connect the different grids, may introduce difficulties but also opportunities. To cope with such complex systems, a self-organized approach is advantageous. This can be implemented by designing a system based on agents controlling the different actors. Further, it is necessary to analyze, first, the behavior of these agents in the coupled network and, second, the resilience properties of coupled networks.

Keywords: Multi-energy system; Self-organization; Resilience; Complex network

Introduction

Operation schemes in today's electric power system are well-established and researched. However, the increasing coupling of energy sectors is apparent in current developments. Due to the increase of couplings across different energy sectors, grid topologies are more complex and dynamic than ever. Additionally, the physical energy systems get coupled with *information and communication technology* (ICT) to enable communication between the different parts of the network. This leads to the extension of the (multi-)energy system to the cyber-physical energy systems (CPES) [1].

As a result, the overall system and its operation methods gain in complexity. Coping with this, complex topologies of the energy grids, the communication network, and the energy flows due to the couplings require sophisticated approaches. Therefore, using organic computing [2] methods for the grid operation together with complex network theory for the system design seems natural. Here, system design is understood as the process of creating an organized approach, defining the behavior of the systems' actors in a complex application.

Research questions

To cope with the difficulties of multi-energy operation, the system has to be looked at as a whole. To overcome issues such as multi-energy flow and to increase resilience in a self-organizational manner, uncertainty and interdependence are integral system attributes from the view of the individual. Dealing with these attributes is complex and involves actions from every part of the system, for which implementing some level of distribution is beneficial.

The designed system shall improve the network's resilience using the coupled networks' capabilities. Here, resilience is understood as the system's ability to mitigate network faults due to mid- to high-impact events. As a modeling approach, agents will be designed to represent these actors and interact in a particular communication structure with each other. Following these ideas, the following research questions can be formulated.

RQ1: Which system design would be feasible to resiliently operate an MES in a self-organized way?

RQ2: Which agent behavior within the system is able to maximize the potential of CPs while also minimizing their operational risks?

RQ3: How do the structure and the underlying agent dynamics influence the system's behavior?

Research approach

The problem is broken down into the following parts.

1 An analysis of the self-organized system structuring of CPs in the MES. For structuring, multi-agent systems, which form coalitions, are used
2 Defining and quantifying resilience in MES
3 A self-organized system draft for solving the overall problem

Related work

To my best knowledge, self-organization has never been applied to control multi-energy networks. However, in power systems, there are some notable applications in structuring virtual power plants (VPPs) [3], network resilience [4], smart-grid control [5], voltage control [6] and scheduling of VPPs [7]. Due to the different system models and scopes of these tackled problems, none of their approaches is directly usable in this problem's context, but some could be used for subproblems or as inspiration.
The literature on resilience in MES can be categorized into two clusters: resilience improvement of coupled energy networks and measuring resilience in MES. In [8], the authors evaluate the effect of introducing microgrids on the resilience of the MES. [9] proposes a multi-stage recovery algorithm for MES after an extreme weather event. To assess the recovery, a demand curtailment performance metric is used. Finally, the authors of [10] show a possibility of multi-energy planning with resilience constraints. For resilience measuring [11] reviews power system assessment methods and defines MES resilience. One specific possibility to measure resilience is shown in [12], where the authors defined a multi-energy load-shedding metric.
Regarding the coalition formation in adaptive topologies of complex networks, Auer et al. [13] investigate the formation dynamics using a so-called adaptation rate. This rate determines the speed of topology changes and, simultaneously, the speed of the coalition formation. A higher adaptation rate leads to fast topology adaptations with low coalition formation speed and vice versa. This behavior is applied to a network over time to investigate the coalition size and degree distribution, determining the influence of the adaptation rate on the network structure.

Methodology and first results

This section describes the methodology for each of the three steps presented in Research approach. For the first two, the first results of those are shortly introduced.
Network analysis As coupled networks are complex networks, methods from the complex network theory can be a way to investigate coalition formation in adaptive complex MES. The goal is to describe the dynamics of coalition formation and evaluate the behavior of topology changes using metrics from complex network theory. The analysis and its methods should provide meaningful insights about three main questions: 1. is complex network theory suitable for analyzing MES for the defined goals? 2. how does a given coalition formation behave in an MES (e.g., concerning coalition size and adaption strategy)? 3. what are the essential dynamics of coalition formation, and can they be foreseen using the graph structure?
This analysis has already been conducted in prior work and can be found in [14]. This study found correlations between CPs locality and coalition dynamics. Further, it showed the behavior of the formations approach as a whole on adaptions of the grid's topology.
Resilience in MES After the more general network analysis focusing on the network structure regarding the coalition formation, the next step is analyzing and quantifying the resilience attributes of MES. This shall fulfill two purposes; first, it is necessary to evaluate the overall system, as resilience is included in the requirements for the system. Second, it might be possible to relate resilience to the network structure, enabling the usage of resilience metrics for coalition formation and optimization of the coalitions. One crucial requirement is to assess the resilience a) with constrained information and b) within a short period due to the time constraints of coalition formation.
The coupled grids' resilience shall be assessed with a focus on the influences of the grids on each other concerning the coupling points. Therefore, an event generation method will be used, which generates high-impact events that represent some disturbance applied to the system. The vitality of each network component is calculated based on its time, location, type, and the grid it is part of. The impact metric will be measured by analyzing the performance metric of the network in response to the generated events. Further, the relation of the network's graph structure to the resilience influences is investigated. The first results of this methodology suggest a correlation between the locality of CPs and the network's resilience.
Self-Organized system One idea to implement self-organization in a system is to utilize coalitions of agents who cooperate in their coalition and build the backbone structure of a multi-energy network. This will structure the MES and enables reactive distributed optimization as an operational strategy. So, the idea is to divide the MES into dynamic, locally founded coalitions.
As a general philosophy, holonic structures can be used. Due to the flexible, hierarchical structure, holonic architectures can integrate all the requirements and concepts for coalitions with multi-agent systems in cyber-physical energy systems. In this system, each agent would have two responsibilities: finding and maintaining a coalition and negotiating and optimizing the coalition's objective. The most critical open points are formulating the objectives for each level and exchanging information between agents.

Conclusion

Due to the complex structure of MES, self-organization may be applied to construct a resilient operating system. To design such a system, the dynamics of the agents, which act in the system, must be analyzed. Further, there is an additional need to find new ways to describe the resilience of coupled networks in this context. Ideas for the system design can build upon the analysis designs and use their results for an intelligent and adaptive approach.

Acknowledgements

The author would like to thank his supervisor Prof. Dr. Astrid Nieße from the University of Oldenburg, and his shepherd Dr. Friederich Kupzog from the Austrian Institute of Technology.

Funding

This work is funded by the DFG (Deutsche Forschungsgemeinschaft) within the SPP 1984.

Availability of data and materials

There is no additional material for this article.

Author's contributions

RS wrote the article, performed the literature review, formulated the approach, and executed the simulations.

Conflict of interest

The authors declare that they have no competing interests.

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P10

Poster abstract: algorithms for condition monitoring of complex power electronic systems in photovoltaics

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Energy Informatics 2023, **6(Suppl 2)**:P10

Summary
Rapid growth in solar power generation necessitates robust condition monitoring systems to ensure operational reliability of solar power plants, with a particular emphasis on inverters, whose optimal performance and safety are vital for maximizing energy production and minimizing downtime. The primary objective of this contribution is to devise a novel methodology for the condition monitoring of inverters in solar plants, employing advanced time series prediction techniques. An overview of the related PhD project status and its motivation is presented, followed by the research questions. Preliminary results using a reservoir computing (RC) approach for time series forecasting are presented, before concluding with an outlook on the potential impact of this research.
Keywords: Renewable energy; Solar power plants; Condition monitoring; Time series forecasting; Reservoir computing

Introduction
Inverters are a key failure point in photovoltaic (PV) systems, often due to component issues with capacitors or insulated-gate bipolar transistors (IGBTs) [1, 2]. In order for PV energy to remain competitive, increasing focus is on optimizing maintenance, particularly through predictive techniques that use data analysis to foresee system conditions and failures [3,4].
In this work, a unique inverter data set will be examined to develop a model for optimizing maintenance strategies. Machine learning (ML) has shown great promise in interpreting system data for predictive maintenance, especially when using time series forecasting [5, 6]. Despite challenges posed by the reliance of PV systems on solar irradiance, time series forecasting has been effectively applied in power generation forecasting [7].

Research questions
The main objective of this research is to develop a time series prediction model to accurately predict the state of a PV inverter from a complex data set with globally distributed locations. In addition to the main task, there are three sub-questions that need to be answered.

1. "How does dimension reduction affect time series forecasting?"
2. "How to adapt current time series forecasting methods to produce reliable predictions for high-dimensional data of technical systems?"
3. "How can the predicted data be combined with anomaly detection in a power electronics context?"

Related work

Recently, three new approaches to time series forecasting emerged: long short-term memory (LSTM) networks, RC and next generation reservoir computing (NGRC). LSTM models proved effective for chaotic systems due to their capability to learn long-term dependencies and capture temporal patterns in sequential data [8]. RC emerged as a promising approach requiring less training time and computational effort [9]. As a result of the challenging parameterization of RC approaches, Gauthier et al. [10] developed the NGRC approach. NGRC exploits the mathematical identity to nonlinear vector autoregressive (NVAR) models by using a linear activation in combination with a feature vector consisting of the current observations, k time-delay observations of previous values, and nonlinear functions of these observations.
Applying time series forecasting in predicting solar power generation is a central research topic. Approaches to this range from autoregressive integrated moving average (SARIMA) models [11], artificial neural networks (ANNs) [12, 13] to LSTM networks [14]. The latter showed notable performance in the presence of high fluctuation in power generation. Most of the aforementioned approaches incorporate external parameters like solar radiation or cloud cover percentage to predict power generation. No efforts have been made to adapt the encouraging RC results for practical implementation in this context. Although LSTM networks have shown promising power forecasts in the PV context, approaches to simultaneously forecast internal variables of the inverter are missing. In conclusion, there is a gap in multivariate forecast of the inverter states from an engineering perspective. This contribution aims for modeling and forecasting power generation and several internal variables of the inverter to allow for a comprehensive assessment of the inverter state, based solely on data collected by solar power plant inverters (without external variables).

Methodology
This research adheres to the Design Science Research Methodology [15]. During the design and development phase, the primary objective is to acquire an in-depth understanding of the PV inverter data set and evaluating various time series forecasting models. The developed models are then applied to the inverter data set, and model performance is evaluated using key metrics.

Results
Preliminary results using the NGRC methodology were achieved due to its improved understanding and lower sensitivity compared to traditional RC. A strong focus was placed on data pre-processing to handle missing values and normalize data. Forecasts were generated from an hourly downsampled data set from September to December 2018. The NGRC model was trained with adjusted parameters to manage the day-night rhythm and mitigate self-amplification effects.
In the prediction phase, the output value of the NGRC model is fed back to the input allowing future time points to be predicted based on the learned dynamics in the training phase. As a result, the model succeeded in capturing the day-night rhythm as shown, e.g. for one sensor time series, in Fig. 1, but had varied performances for different parameters and exhibited increased differences after the 7th to 10th day due to self-amplification. Figure 2 shows the evaluation of forecast accuracy using various metrics. Quantitatively, the variables T_A and T_B, representing internal temperatures of the inverter, show inferior prediction accuracy. Overall, the prediction accuracy tends to decrease as the lead time τ increases.

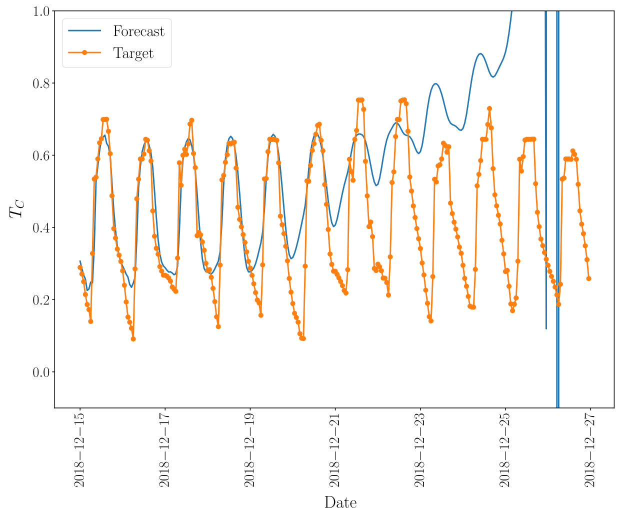

Fig. 1 (abstract P10) NGRC forecast of the internal inverter temperature T_C, after training on a data set of 104 days

Conclusion and outlook

This paper outlines a PhD research project focused on developing a new method for condition monitoring of inverters in solar power plants via time series prediction methods. Preliminary findings indicate that the NGRC model can capture and replicate the dynamics of the PV inverter, although it needs further optimization. Future studies should focus on the exploration of diverse parameter combinations and the application of varied dimension reduction methods. Comparative assessments between the NGRC approach and other time series forecasting models are essential as well. Considering deterministic night and day behavior of the data, it would be beneficial to decompose it into its seasonal components to better capture inherent patterns and dependencies, hence potentially improving forecast quality. The research could significantly contribute to the advancement of predictive maintenance strategies, leading to cost savings and improved reliability of PV systems.

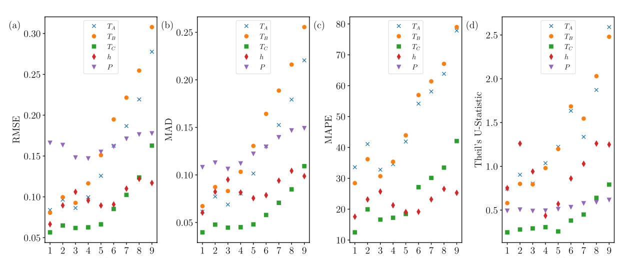

Fig. 2 (abstract P10) NGRC forecast accuracy, as measured by RMSE (**a**), MAD (**b**), MAPE (**c**) and Theil's U-Statistic (**d**). Presented are measures of forecast errors for three device temperatures T_A, T_B, T_C, humidity h and power P output. The NGRC algorithm is trained on a non-shuffled data set of 104 days. The forecast is made for the last part of the data set which was not used for training. The errors rise with increasing lead time τ measured in days d

Acknowledgements

I would like to thank Prof. Dr. Sarah Hallerberg and Prof. Dr. rer. nat. Sebastian Lehnhoff for the supervision. Also, I would like to thank Prof. Dr. sc. Andreas Ulbig for his commitment and helpful guidance in the shepherding process.

Funding

The contents of this PhD project are elaborated within the research project "Digital-Twin-Solar" (020E-100395227), which is funded by the German Federal Ministry for Economic Affairs and Climate Action.

Availability of data and materials

No data and materials are published.

Conflict of interest

The authors declare that they have no competing interests.

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P11

Poster abstract: effective adaption of neural networks for low voltage demand forecasting after concept drifts

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Energy Informatics 2023, **6(Suppl 2)**:P11

Summary
To accomplish climate targets, the power grid faces many changes, recently and for the next years. The changes include an increasing number of suppliers through the expansion of renewable energies while the number of consumers also rises considering e-mobility, heat pumps, and digitization. This scenario requires grid management including reliable and accurate forecasts to ensure a safe and stable energy supply. Using models from learning methods in changing environments is challenging because the models are trained on past data but need to perform on current data. This work presents details to occurring research questions on how the performance of those models changes under a concept drift, how we are able to detect that the model needs an update to perform well and how this update is accomplished. As a result, we propose a plan for a methodological approach to find answers to the stated questions.

Keywords: Load forecast; Neural network; Concept drift; Continual learning

Introduction

The transformation of energy supply and demand is necessary to achieve the climate targets. It includes the growth of renewable energy sources as well as an expansion of e-mobility, heat pumps, or other carbon-saving consumers. As a result, the volatility of generation as well as demand will highly increase and an intelligent distribution in the power grid becomes indispensable.

Proactive network management is an important aspect to ensuring a stable network and secure power supply. To have a good overview and take the best precautions or actions, particularly short-term load forecasts covering time frames up to one week ahead for supply as well as demand are needed. As a result, the quality of grid management depends on the forecasting quality.

Considering the increasing number of participants in power grids, effective load forecasting models are needed to capture the dynamic processes regarding supply and demand. As neural networks are able to map any non-linear function in theory, they provide an adequate base for modern load forecasting models [1].

Besides the network architecture, essential factors for the performance of neural networks are the data and the training process. In research, we apply learning algorithms on a fixed data set for training as well as validation and testing. We are able to adopt this procedure for applications, if the situation is also fixed, or has a nearly fixed state space for the future. Predictive maintenance of production machines is an example of this case. Large machines are rarely modified, so trained models work well and, after rearrangements, we can train models on the new data.

In contrast, the power grid changes rapidly due to an increasing number of suppliers (renewable energies) and consumers (e-mobility, heat pumps ...) nowadays and the high number of changes will last for several years. We train forecasting models on past and current data but the models are used in a changing grid environment afterwards. To ensure a secure application of forecasting models with a reliably good performance, there is the need for an update mechanism of learned models in such environments [2].

There arise the following research questions to solve this requirement.

- RQ1: How strong does model behavior change with data from a changing environment during inference?
- RQ2: How to detect the necessity for a model update?
- RQ3: How are we able to update a model effectively?

Answers to these questions involve benefits for the power grid operators. Having reliable methods for model updates, we ensure the quality of the results. In addition, early detection of the necessity for a model update further decreases the loss of performance over time. All in all, with increasing accuracy of the forecasting model, the user is able to create better schedules and plan grid operations, which ensures a stable grid and decreases costs.

Related work

Multi Layer Perceptrons (MLPs) are long-established for the application of power load forecasting [3] as low dimensional time-series data can be processed well with those and the hardware requirements were fulfilled early. There is also work using Convolutional Neural Networks (CNNs), Recurrent Neural Networks (RNNs), or combinations of both [4, 5]. Recently, transformer networks were also applied to load forecasting as they are able to handle long-term dependencies also well [6].

Models for problems without a fixed data set but with a data stream with continuous new data because of a concept drift or new data from new tasks require adaptive training processes [7]. Besides online learning methods with a continual training process on a data stream, transfer learning uses a pre-trained model and a fixed data set, but the technique also enables the adaption of a model with a few new data samples [8]. Moreover, few- or zero-shot learning techniques [9] from computer vision enable neural networks to cope well with unseen or very few data samples in classification tasks. There exists a lot of work on continual learning, especially for multiple classification tasks and image data [8, 10]. An example is the usage of multiple encoder networks, one for each task [11], or replaying old training data [12] to avoid catastrophic forgetting of the model [13]. Though there are many solutions regarding multi-task problems, especially regarding image data, Maltoni et al. [14] state that it is not trivial to adapt a multi-task training process to an incremental problem with new data for a fixed task.

Alvarez et al. [15] use Hidden Markov Models for a probabilistic prediction in combination with an adaptive online process including a data stream instead of multiple offline updates to adapt the model parameters. Also, combinations of classical methods and neural networks can be used to implement an adaptive learning method like Autoregressive Integrated Moving Average (ARIMA) and an RNN in [16]. For many model types, transfer learning can be considered including a transfer of model parameters, transfer of representations, or self-training [17]. Schreiber and Sick [18] investigate different transfer learning methods in combination with a model selection technique, while Henze et al. [19] use deep learning as well as classical methods like PCA to extract general feature representations which can be used for the adaption of models to new data. He et al. [20] show that a neural network with continual learning strategies like elastic weight consolidation, synaptic intelligence, or learning without forgetting improves the load forecasts with a sequential data stream. Moreover, they propose the CLeaR framework consisting of neural networks and data buffers for the adaption of a model to a changed probability distribution in the data stream [21, 22].

Methodology

To answer the first research question, we investigate how the model behaves using the data from the changing environment. The first step is to select a data set of load data suitable for our problem. Therefore, it needs data samples from a large time frame as well as enough changes in the underlying input data distribution. If there is no appropriate data set available, we will simulate some data to compare the methods in our experiments. After literature research on load forecasting models, we select and implement forecasting models based on neural networks to evaluate their behavior on the data set with concept drift. For that, we need a definition of a metric when we consider the model's performance as 'good'. We analyze and compare the results from our experiments to see which types of concept drift influence the different models in which ways. The results provide the benchmark for the experiments answering the other research questions.

To answer the second research question about the detection of concept drifts, there are several definition steps at the start. We need metrics and criteria for different types of events in the data stream as well as thresholds for the model's performance. Afterwards, using existing literature, we want to find, implement and improve a detection mechanism for the model predicting the new data. Evaluating and analyzing the results, we are able to answer research question two.

The third research question considers updating mechanisms for the neural networks. Besides retraining from scratch with new data, there are options to update a model. Following literature research, we want to select and adapt an update method. Together with the definition of a successful model update, we evaluate the implementation of the mechanism to find improvements afterwards. Finding the 'best' update method, we want to take different aspects like performance, run time, computational effort, or number of data samples into account. Having implemented an improved update mechanism and defined the criteria for the best method for our application, we evaluate the results.

Conclusion and outlook

The transformation of the power grid in order to increase sustainability comes along with challenges for a stable and cheap utilization of the grid due to higher volatility of supply and demand. This requires good forecasting models for planning the best grid operations. We want to explore solutions for adaptive forecasting models to remain good forecasting quality in a changing grid environment. These include the understanding of the models under concept drift, how to detect it and how to update the models. Besides related work on the topic, we propose a methodology to solve the research questions. We will start with the first research question by doing a literature review, experiments and analysis to build a foundation for finding the most suitable concept drift detection and model update method for our application of load demand forecasting using neural networks.

Acknowledgements

I would like to thank my shepherd Dr. Konstantin Hopf, the reviewers for giving valuable feedback, and Prof. Dr. Clemens van Dinther for his support.

Availability of data and materials

No data is used for this work yet.

Conflict of interest

The authors declare that they have no competing interests.

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P12

Poster abstract: the evaluation of flexibility activation mechanisms in the built environment and their effectiveness for congestion management in distribution systems

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Energy Informatics 2023, **6(Suppl 2)**:P12

This extended abstract gives a brief description of my doctoral research topic, which focuses on the effectiveness of flexibility activation mechanisms for a DSO to allocate flexibility from the built environment for congestion management in the distribution system.

Keywords: Distribution systems; Power flow; Flexibility; Flexibility activation mechanisms; Congestion management

The energy transition leads to the increased introduction of distributed energy resources (DERs) such as solar PV, electrical vehicles (EVs), electric heat pumps (HPs), and Battery Energy Storage Systems (BESS) in the Dutch distribution networks. The implementation of these technologies and the increasing penetration levels already lead to several congestion and voltage challenges in considerable parts of the distribution system. The traditional approach from distribution system operators (DSOs), preventing congestion problems by expanding and reinforcing the network, is not always feasible due to high costs, limited manpower, and long lead times. Despite good investment plans, the Dutch system operators indicate that they are not able to continue to expand the network at an adequate pace [1]. This is caused by a shortage of technicians, long-term spatial procedures, limited space in the subsurface and limited financing options. Although, physically reinforcing the network at these bottlenecks would ensure sufficient transmission capacity, it is unclear whether grid reinforcement will always be an effective solution in the future. In certain cases the social costs of required grid reinforcements are high and the use of flexibility may be a more suitable solution from a social costs point of view [2].

In order to utilize flexibility from the built environment to mitigate or avoid congestion in the day-to-day operation of a DSO, mechanisms to activate flexibility need to be developed and implemented. The electricity market regulation and directive of the Clean Energy Package (CEP) [3][4] indicate that three main types of activation mechanisms can be identified, namely:

1 Tariff structures;
2 Market-based (re)dispatching;
3 Non-market-based redispatching.

Network tariff structures can be used to implicitly influence the demand for transmission and distribution capacity, incentivizing prosumers to avoid high peaks and spread out their load. Intended tariff instruments that will be evaluated within the research include dynamic network tariffs, static and dynamic bandwidth tariffs, and variable network tariffs, which, in addition to an energy component, also include a weighted component of peak consumption. Within market-based (re)dispatching mechanisms, flexibility is traded as a commodity in a market. This could, for example, be implemented using a local or an integrated flexibility market where flexibility can be bought by a network operator to mitigate their congestion problems. Recently, the Dutch Authority on Consumers and Markets (ACM) released an update to the Dutch grid codes related to congestion management. These grid codes state that network operators can obtain congestion management services by purchasing either capacity limitation services or redispatch services [5], which among others will be evaluated within the research. The new grid code states that if the earlier mentioned congestion management services do not sufficiently resolve the anticipated physical congestion in the daily preparation and daily operation, the network operator will apply non-market-based redispatch to the electricity-generating units present in the congestion area [5]. This could for example be in the form of dynamic capacity or (temporary) transportation restrictions. In practice, mechanisms from these three categories can thus exist in parallel, operating on the different described time scales.

As also indicated by [6], most studies only use one type of mechanism or method to mitigate congestion by implementing e.g. new market frameworks or comparing tariff instruments. There are only limited studies where one combination of different types of instruments are combined [6][7]. Therefore, there appears to be a gap in research to explore in detail how these different mechanisms (and different combinations of mechanisms) would work in an operational setting, and which criteria and aspects are important to incorporate flexibility from the built environment into the day-to-day operation of a DSO. Additionally, it is still unknown to what extent uncertainty and limited observability of a DSO will influence the effectiveness of the utilization of flexibility from the built environment for congestion management. Currently, most DSOs have limited observability in their distribution system due to a lack of available measurement data which will influence the day-to-day operation regarding violations of network constraints and congestion management [8].

The aim of this research is therefore to study and assess the effectiveness of different combinations of these so-called flexibility activation mechanisms on the mitigation of congestion problems in the distribution system. The system that this research focuses on does not only include the physical system, containing the physical distribution network and the (flexible) assets of prosumers, but also the commodity system in which the energy is traded as well as the communication between these systems. An overview of these systems, the relevant actors and the communication between them is illustrated in Fig. 1. Depending on the presence of various assets, types of prosumers, aggregators, flexibility activation mechanisms, and different markets, not all technically available flexibility may be accessible or usable for the grid operator. Additionally, congestion problems in a city center can be different and might be solved differently compared to congestion in more rural areas. This can be due to the underlying distribution network, as well as the fact that different prosumers connected to the network might have different flexibility resources, or have a different willingness to participate in flexibility services. Therefore it is important to evaluate the effectiveness of the implementation of the different combinations of flexibility activation mechanisms on congestion problems for a variety of typical Dutch low voltage (LV) networks and prosumer compositions in different future scenarios. Within the GO-e research project [9], TNO clustered all Dutch neighborhoods based on features relating to demographics, buildings, and financial data of the inhabitants [10], resulting in 8. The resulting 8 were characterized intuitively into archetypical neighborhoods. Based on this clustering, the involved DSOs selected five LV networks within their service area for each of the archetypes, resulting in a set of 120 LV network models. Together with data on the expected growth and distribution of flexible assets, these networks will be used to evaluate the aforementioned mechanisms. This evaluation will be done using large-scale simulations, which will contain networks with over 100–1500 houses with a selection of flexible assets and smart controllers optimizing their dispatch. Within these simulations, different scenarios will be modeled for different combinations of various market and weather conditions, and various penetrations of flexible assets. It is assumed that a portion of the existing prosumers and/or aggregators participate in the implemented mechanisms, where the adoption rate can be varied for the different mechanisms. The effectiveness of the various combinations of flexibility activation mechanisms can then be evaluated compared to a baseline scenario where no congestion management measures are taken.

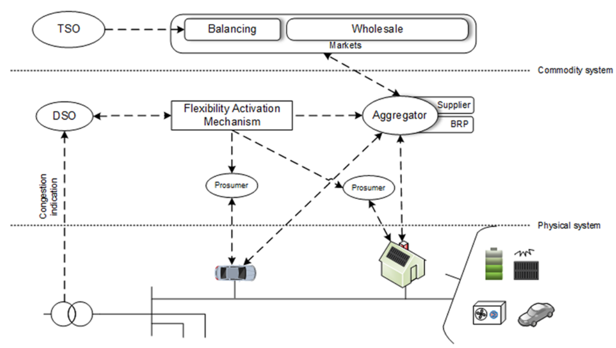

Fig. 1 (abstract P12) Overview of the operation of the systems and the interaction between the different actors in the system [10]

An agent-based simulation proved to align best with this objective, which comes with a high computational load for the simulation tasks. For this reason a new open-source scalable simulation framework for time-discrete agent-based simulations of energy systems was developed. In [11], this framework is further explained and demonstrated on a case study where the effectiveness of a dynamic bandwidth tariff on cable and transformer overloading in a LV network is evaluated. Within this study, the system consists of one of the aforementioned LV networks based on an archetypical neighborhood. The households in this system all contain an inflexible base load, and a selection of flexible PVs, HPs, and BESSs. Each of the connections also has a Home Energy Management System (HEMS) which optimizes the dispatch of the connected flexible assets for each 15-minute interval time step. The optimization is performed with a 12-hour horizon and considers bandwidth tariff information provided by a DSO, day-ahead market prices, and weather data. The methodology developed for this first case study will be further expanded to be applied to different combinations of various market and weather conditions, penetrations of flexible assets, and combinations of flexibility activation mechanisms. Adding to this, aggregators, who can provide flexibility for congestion management but who can also be active on different markets, are still to be added to the simulations. Up until now, the optimization for all HEMS models was purely based on minimizing costs. Future work will introduce different optimization objectives for different types of prosumers within the simulation, based on the research of social scientists of TNO within the GO-e project. Currently, all actors in the simulation have perfect knowledge about the future within their optimization horizons. Future work will introduce more uncertainty about the future in the optimization as well. This uncertainty can also be added for the DSO actor with regard to the observability in the network, in this way, it can be determined what degree of observability would be required for the implementation of the different mechanisms. In addition to the effectiveness, this could influence how feasible a mechanism will be in the day-to-day operation of a DSO.

Acknowledgements
The doctoral research topic described in this abstract is part of the GO-e (Gebouwde Omgeving Elektrificatie, Built Environment Electrification) research project, which investigates whether smart flexibility services can mitigate congestion problems and offer an alternative for the reinforcing of the electricity network in the built environment. The consortium is a collaboration of the three largest Dutch Distribution System Operators (DSOs) (Alliander, Enexis and Stedin), energy suppliers, market platforms, engineering companies, universities and research institutes [9]. The consortium is partly subsidised by the RVO (Netherlands Enterprise Agency) in the MOOI scheme of the Top Sector Energy (MOOI: Mission-driven Research Development and Innovation).

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Poster abstract: A project on the potential of flexibility from the built environment for congestion management in distribution grids

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Energy Informatics 2023, **6(Suppl 2)**:P13

Abstract
This extended abstract presents the motivation, research questions, methodology, and challenges & outlook on my PhD-project.

Keywords: Distribution systems; Congestion management; Flexibility; Agent-based Simulation; Built environment; Coordinated decision-making

Introduction
The increasing penetration of (renewable-based) distributed energy resources (DERs) like photovoltaic cells (PV), electric vehicles (EV), heat pumps (HP), and Battery Energy Storage Systems (BESS) within the distribution grid, poses new challenges for the DSOs around the world [1]. The electrification of heating demand and mobility, together with the increase of volatile and local renewable generation can cause larger, bidirectional, and unpredictable power flows, increasing the risk of voltage problems and cable/transformer overloading (i.e. congestion) in the distribution grid [2]. Traditionally, DSOs prevented and mitigated congestion by reinforcing their networks. However, Dutch system operators indicated in 2021 that they are not able to continue to expand the network at an adequate pace [3]. A potential alternative to grid reinforcements is using the available flexibility from DERs in the grid to shift load away from points of congestion in both space and time. Multiple studies showed that, depending on the activation mechanism and available resources, flexibility from DERs can be used successfully for congestion management in the distribution network [4]. Here, an activation mechanism refers to an instrument DSOs can use to incentivize controllers of flexible resources to allocate flexibility in a certain way [5]. In most countries, simple implementations, like time-of-use tariffs, have been in place for many years, but new market-based platforms like PICLO flex (United Kingdom) and GOPACS (the Netherlands) have emerged over the last few years. Though several pilots have been conducted, it is still very much an open question to what extent the flexibility of residential users can play a role in congestion management in future distribution grids. Not only is it still an open question how the technical available flexibility from the built environment compares with the emerging congestion, but it is also not clear what (combinations of) instruments can best be used in various neighborhood types for allocating this flexibility for congestion management purposes. To get more insight into these open questions, this PhD-project attempts to answer a series of research questions.

Research questions
The main research question for the project is:
To what extent can DSOs reliably procure flexibility from the built environment for congestion management in their future distribution grids?
To answer the main research question, a number of sub-questions need to be answered:

1. What are the key developments in the distribution grids related to congestion, and flexibility for congestion management purposes?
2. How can a DSO estimate the technical amount of flexibility from the most flexible devices in the built environment?
3. What kind of flexibility activation mechanisms could a DSO use to activate flexibility for congestion management?
4. What part of the available flexibility in the built environment can DSOs expect to procure with combinations of mechanisms for congestion management in its low-voltage networks?
5. What part of the available flexibility in the built environment can DSOs expect to procure with combinations of mechanisms for congestion management in higher grid levels?
6. To what extent do national incentives for flexibility activation in other markets interfere with the procurement of flexibility from the built environment for congestion management by DSOs?
7. To what extent does uncertainty in DSO, aggregator, and household decision-making influence the required action of a DSO to successfully procure flexibility from the built environment for congestion management purposes?

The next section describes what approach will be taken to answer these research questions consecutively.

Methodology

Agent-based modeling

This PhD-project is a simulation-based study using an agent-based approach. We want to decentralize decision-making by actors like DSOs, aggregators, prosumers, and home energy management systems (HEMSs) as much as possible because these actors have 1) limited and imperfect information on which to base their operational decisions, and 2) their own objectives to optimize for. Because a large number of simulations are expected, we developed a novel simulation framework for discrete-time agent-based simulations in energy systems. A schematic representation and the technologies of which it consists is presented in Fig. 1. The uniqueness of this framework is its intrinsic design for scalability. It allows the user to flexibly increase the number of computational resources from a cloud provider, it can distribute the computational load of the agents in separate containers for parallelization, and the systems are described via the Energy System Description Language (ESDL), which is an open-source modeling language developed by our project partner TNO. This framework allows us to put more complex decision-making algorithms like stochastic model-based control and optimal power flow calculations into the HEMS, aggregator, and DSO agents than existing agent-based studies.

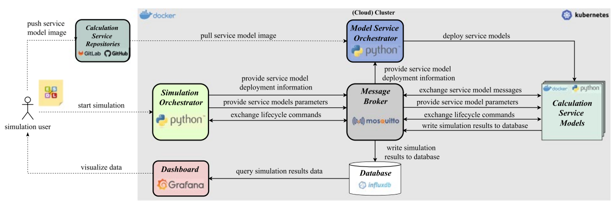

Fig. 1 (abstract P13) Overview of the developed scalable distributed simulation framework for time-discrete simulations of energy systems

Flexibility activation mechanisms

For the characterization of the mechanisms for congestion management, we like to follow the classification introduced by the Clean Energy for all Europeans package [6]:

1 Tariff structures
2 Market-based (re)dispatching
3 Non-market-based redispatching

There have been many studies focusing on specific implementations of these different instruments. For example, several works discuss and compare various tariff instruments like time-of-use tariffs, critical peak pricing, locational-based pricing, and power-based pricing [4][7][8]. The market-based instruments, like local electricity markets, seem to be the most actively researched [9]. There are several studies that compare the effectiveness of instruments from these categories with each other. In the study of Verzijlbergh et al flat grid tariffs, dynamic network tariffs, advanced capacity allocation, and a distributed grid capacity market were compared [10]. In another study, the focus was shifted to investigating the robustness of various tariff instruments and a flexibility market to aggregators trading on the balancing market [11]. However, one could wonder whether comparing instruments from the 3 categories is really meaningful, as multiple instruments from each category can be used together in the future. This point was also raised by [12], and a gap in the literature was identified on studies integrating different types of instruments together. The study shows that combining the different instruments is beneficial, as it better protects against extreme congestion situations, and reduces the risk of having very high dynamic tariffs.

Design of experiments

The main goal of the simulations is to compare the effectiveness of combinations of congestion management instruments, taking realistic prosumer behavior, conflicting agent interests, and uncertainty in agent decision-making into account. The effectiveness of these instruments will be compared internally for various grid types, asset adoptions, and weather, and market conditions. For the grids, we received 5 low-voltage grids from each of the 3 large DSOs in the Netherlands for 8 archetypical Dutch neighborhoods, resulting in 120 grid in total. We will gradually increase the complexity of agent decision-making to investigate the role of several factors: 1) coordination between instruments by the DSO, 2) data-driven prosumer modeling from a large-scale survey social study performed by our project partner, 3) the effect of aggregator trading on national markets, 4) and the effect of agent uncertainty about future prices, weather, and loads.

Challenges & outlook

The main challenges for this project lie in the modeling of the decision-making by HEMSs, aggregators, and the DSO. The scientific contribution of simply defining various instruments mathematically and applying them as decision rules in a deterministic and uncoordinated manner is not that great. The complexity lies in the coordination of instruments over time, and between various actors. The resulting decision problems easily result in multi-actor multi-phase games, which can be very difficult to solve in practice, especially under partial information and uncertainty. The main challenge of this project is to find new coordination schemes between the instruments and actors that accurately take the available (uncertain) information to the agents into account, such that the schemes can be integrated into the agent-based simulations. Now the framework is finished, the first instruments are implemented in an uncoordinated manner, and the first coordinated schemes are being formulated.

Funding

We furthermore thank the Netherlands Enterprise Agency for partially funding this research through the GO-e project (MOOI32001).

Availability of data and materials

There are no sources of data and materials in the abstract that are not listed in the references.

Conflict of interest

The authors declare that they have no competing interests.

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