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M. S. Forkaliuk
O. V. Bisikalo

CROSS-SECTOR ENERGY SYSTEMS CO-SIMULATION FRAMEWORK DESIGN

Vinnytsia National Technical University

Анотація

Дане дослідження зосереджене на розробці системи моделювання для аналізу місцевих міжгалузевих стратегій енергетичного балансування, спрямованих на вирішення проблем інтеграції відновлюваної енергетики. Система інтегрує інструменти для управління електроенергією, опаленням, охолодженням та зарядкою електромобілів з метою зменшення споживання енергії та її волатильності при мінімальному впливі на комфорт користувачів. Оцінюються нові міжгалузеві стратегії енергетичного менеджменту з акцентом на спільноти відновлюваної енергетики та взаємопов'язані системи. Дослідження включає інтеграцію програмного забезпечення, стохастичне моделювання та оцінку ефективності, що дає змогу отримати уявлення про оптимізацію енергетичних систем для сталого розвитку. Проведені дослідження висвітлять потенціал міжгалузевої інтеграції для підвищення енергоефективності та гнучкості, що сприятиме переходу на 100% відновлювані джерела енергії.

Ключові слова: спільноти з відновлюваної енергетики, енергетичний баланс, міжгалузева інтеграція, моделювання на основі подій, оптимізація енергетичної стратегії, зарядка електромобілів, системи опалення, електромережі.

Abstract

This study focuses on developing a simulation framework to analyse local cross-sector energy balancing strategies, addressing the challenges of renewable energy integration. The framework integrates tools for managing electricity, heating, cooling, and EV charging, aiming to reduce energy consumption and volatility with minimal impact on user comfort. Novel cross-sector energy management strategies are evaluated, emphasizing renewable energy communities and interconnected systems. The research involves software integration, stochastic modelling, and performance evaluation, providing insights into optimizing energy systems for sustainability. The enabled studies will highlight the potential of cross-sector integration to enhance energy efficiency and flexibility, supporting the transition to 100% renewable energy sources.

Keywords: Renewable energy communities, energy balancing, cross-sector integration, event-based simulation, energy strategy optimization, EV charging, heating systems, electrical grids.

Introduction

Renewable Energy Communities (RECs) are emerging as transformative solutions in the transition towards sustainable energy systems. Defined under the European Union's Renewable Energy Directive (RED-II), RECs empower communities to produce, consume, store, and sell renewable energy while fostering environmental, economic, and social benefits [1]. By prioritizing local collaboration and energy sharing, RECs enable efficient utilization of energy resources and provide a framework for integrating diverse renewable energy sources, such as solar, wind, biomass, and geothermal, as shown in Figure 1.

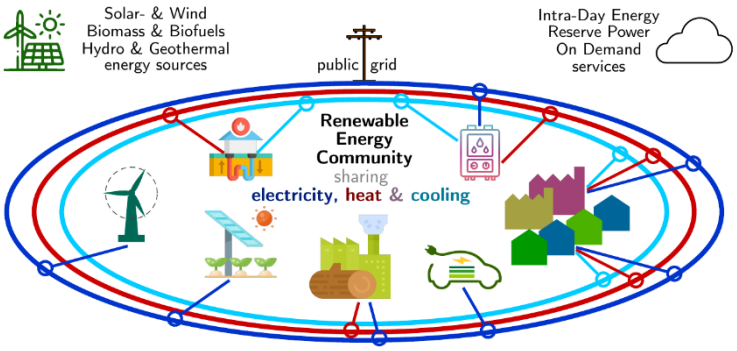


Figure 1: REC example with electricity, heat, and EV sharing [2]

The operation and optimization of multi-energy RECs involve intricate interactions between multiple energy sectors, including electricity, heat, mobility, and energy storage. Cross-sector integration is pivotal in achieving synergies, such as leveraging surplus energy from one sector to meet the demands of another [3]. This requires sophisticated simulation frameworks capable of modelling energy flows, optimizing demand, and evaluating the dynamic behaviour of interconnected systems [4]. Tools and methodologies for such frameworks need to accommodate sector-specific complexities while enabling seamless interoperability.

In this context, the development of a simulation framework that links established sector-specific tools to model and optimize REC operations is both a challenging and necessary endeavour. Such a framework facilitates the empirical evaluation of diverse REC configurations and cross-sector management strategies. It also supports the exploration of innovative solutions for enhancing energy efficiency, minimizing losses, and optimizing resource allocation.

The research task presented in this work aims to address the challenges of identifying and integrating appropriate tools to construct a versatile cross-sector simulation framework. The approach not only leverages the strengths of existing sector-specific tools but also ensures flexibility for future enhancements. Through effective tool selection and integration, the framework aspires to provide a robust platform for advancing the design and operation of Renewable Energy Communities with cross-sector balancing capabilities.

Simulation framework composition

The development of a cross-sector simulation framework for multi-energy Renewable Energy Communities (RECs) requires careful selection of tools capable of managing and optimizing energy flows across multiple sectors, such as electricity, heating, mobility, and storage. The goal is to create a versatile and integrative platform that can simulate complex energy interactions, support dynamic modeling, and offer reliable performance for the evaluation of various energy management strategies across sectors.

A thorough comparison of available tools for each sector revealed that no single tool could address all requirements simultaneously. Instead, a combination of specialized tools is chosen to leverage their unique strengths while mitigating their individual limitations. The selected tools were evaluated based on their support for key features, such as power and heat flow analysis, energy flow management, stochastic demand modelling, controlled EV charging, and dynamic responses to external control signals.

For power-flow analysis, pandapower [5] is chosen due to its robust capabilities in electric power flow analysis at any grid level, seamlessly integrating with the Python-based pandas library for data manipulation and analysis. This tool provides an effective foundation for electricity grid modelling, which is essential for the integration of renewable energy sources and the management of fluctuating power demands.

For heating system modelling and demand analysis, AixLib [6] and OpenModelica [7] are selected. AixLib offers a comprehensive library for thermal system components, including heating networks, heat exchangers, and household demand models. OpenModelica, as an open-source platform, enables flexible modelling of dynamic systems and facilitates the design and simulation of interconnected heating systems.

In the context of electric vehicle (EV) charging optimization, smartDCsim [8] is integrated into the framework. This tool models the charging behaviour of EVs and enables optimization of smart charging strategies based on load shifting and cost minimization. The ability to adapt and integrate the tool into a larger simulation environment makes it an ideal choice for this sector.

By combining these tools, the simulation framework achieves a flexible and scalable environment capable of modeling and optimizing the interactions between the electricity, heating, mobility, and energy storage sectors. The selected tools ensure that the framework can handle the complexity of cross-sector energy systems while providing the necessary functionalities for detailed analysis and optimization.

Research results

The developed co-simulation approach relies on a framework that links different system models and tasks, each executed by various specialized tools, as sketched in Figure 2. The simulation framework uses an event-based approach to improve efficiency by evaluating the system only when an event, or change, occurs. This avoids redundant calculations during stable periods, making the simulation computationally efficient.

The simulation core is centred around the EventStack, where events are stored in chronological order. Each event is linked to a specific system model, representing an electricity, heating, or EV charging system, and triggers actions within the corresponding modelling tool. The EventHandler processes events one after another, ensuring that events are executed sequentially and new events are generated and added to the stack continuously, to maintain the flow of the simulation until the generation of subsequent events is intentionally stopped to end the simulation. The simulation core coordinates and synchronizes the entire simulation process across

the linked external tools like pandapower for electricity grids, OpenModelica for heating systems, and smartDCsim for electric vehicle charging, which handle events specific to their sectors.

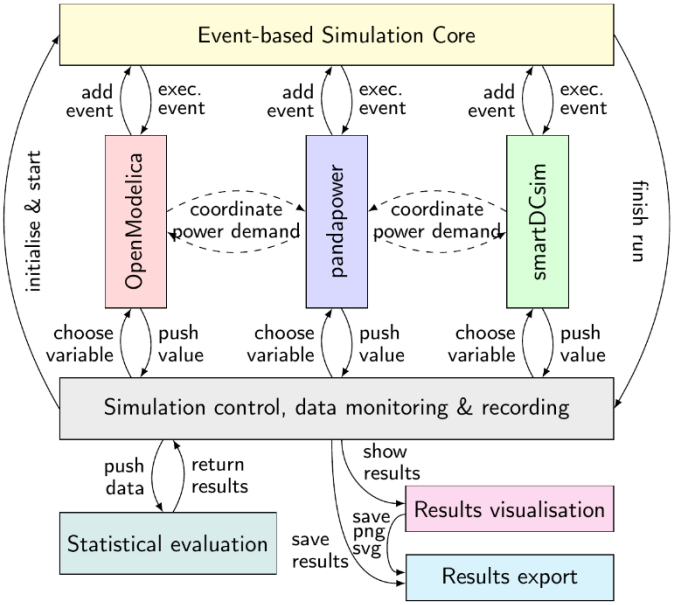


Figure 2: Co-simulation framework modules architecture

The Simulation Control Module is responsible for initiating the simulation, managing parameters, and ensuring the proper integration of external tools. It records data generated during the simulation, which can later be analyzed by the Statistical Evaluation Module. Results are visualized and exported for further analysis, providing valuable insights into the behavior and performance of integrated energy systems. The event-based approach simplifies the simulation of systems with discrete changes, allowing for detailed modelling of dynamic interactions without unnecessary computations during stable periods. This design enhances the flexibility and efficiency of simulating cross-sector energy management strategies.

Conclusion

The development of a simulation framework for analysing cross-sector energy balancing strategies within Renewable Energy Communities (RECs) demonstrates significant potential for integrating various energy systems, such as electricity, heating, mobility, and energy storage. The use of a combination of specialized tools for modelling and analysing sector specific systems enables the creation of a flexible and efficient environment for optimizing interactions between the different systems.

The key achievement is the implementation of an event-based approach, which significantly reduces computational efforts during stable periods and focuses attention on significant changes. This enhances the efficiency and accuracy of simulation studies, allowing for a deeper exploration of the interdependencies between different components of energy sectors.

The integration of popular and powerful simulation tools such as pandapower for electric grids, OpenModelica for heating systems, and smartDCsim for electric vehicle charging provides comprehensive modelling and optimization of interdisciplinary aspects of energy networks. Further development and refinement of this simulation framework hold the potential to support the transition to 100% renewable energy sources and improve energy efficiency within RECs by providing a flexible evaluation tool.

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Форкалюк Марія Сергіївна — студентка групи 1АКІТР-24м, факультет інтелектуальних інформаційних технологій та автоматизації, Вінницький національний технічний університет, м. Вінниця, e-mail: forkmasha100@gmail.com

Науковий керівник: ***Бісікало Олег Володимирович*** — д-р техн. наук, професор, завідувач кафедри автоматизації та комп'ютерно інтегрованих технологій, Вінницький національний технічний університет, м. Вінниця, e-mail: obisikalo@vntu.edu.ua

Forkaliuk Maria S. — student of the Department of Automation and Intelligent Information Technologies, Vinnytsia National Technical University, Vinnytsia, email : forkmasha100@gmail.com

Supervisor: ***Bisikalo Oleh V.*** — Dr. Sc. (Eng.), Professor, Head of the Chair of Automation & Intelligent Information Technologies, Vinnytsia National Technical University, Vinnytsia, e-mail: obisikalo@vntu.edu.ua