Energy Proceedings
Vol 50, 2025
ISSN 2004-2965

Realizing Smart Energy Sharing- *real*SES© Platform#

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ABSTRACT

The idea so-called Realizing Smart Energy Sharing (*real*SES) will contribute in development of a comprehensive management platform for energy sharing/trading in smart communities involving many connected prosumers. The designed and developed prototype is finally going to proof the concept of the state-of-the-art 5G-enabled renewable energy trading platform, integrated in microgrids, equipped with artificial intelligence and machine learning, as well as blockchain technologies to facilitate the prosumer ecosystem in the future distributed energy world. In this paper, after an overview on the *real*SES architecture, a simplified example of managing and optimizing energy production within a typical hybrid system, as an integral part of the *real*SES platform, is briefly outlined. More details and discussion can be provided in the extended version of this study.

Keywords: energy management platform, energy sharing and trading, smart communities, distributed generation, ICT-enabled energy systems.

1. INTRODUCTION

Having a strategic framework to reduce global dependence on conventional energy resources, diversify the economy, strengthen investment opportunities, and develop public service sectors [1], the energy transition beside developing smart cities is high importance for all. On the other hand, the Paris Agreement and the outcomes of the UN climate conference [2] identifies the role of community-level greenhouse gas emissions on global warming and asks the communities/cities to increase penetration rate of distributed generation and small-scale renewable energy system in their energy mix to achieve the essential energy transition. To this aim, the idea so-called "Realizing Smart Energy Sharing, *real*SES" will contribute in development of a comprehensive management platform for energy sharing/trading in smart communities involving many connected prosumers [3].

From the entire power grid point of view, a complete set of architectural solutions is necessary to handle the future smart energy sharing network using distributed technologies like high-speed networks, edge and high-performance computing at different positions in the network, as well as efficient energy and data interactions between different parts of the network in addition to the fully-integrated renewable energy sources (RES) as a digitized virtual power plants (VPP) in each community [4].

The *real*SES is a modular software platform for planning and design of microgrids and distributed energy resources (DERs); handling the entire energy equation - both electrical and thermal. The platform will be ideal for operating both grid-connected and islanded cases and includes options to include load curtailment, net metering, and market participation. The proposed concept will then result in increased energy efficiency and resilience to environmental issues through enabling effective trade of distributed energy resources while keeping the stakeholders' data safe and secure. Finally, the developed toolset is very well aligned with the UN Sustainable Development Goals (SDGs) so that the outcomes of the proposed project can be addressed to SDG7, SDG9, SDG11, and SDG13 [5]; achieving a better and more sustainable future for all.

This paper's remainder is prearranged as follows: In Section 2, the proposed software will be introduced as a whole; including the technologies/approaches used. In Section 3, an example of the models developed in the back-end of the software to manage the production of distributed renewable resources is briefly discussed. Eventually, a conclusion is presented in section 4. In future works, a case-study for optimization of energy consumption that can be an input to the machine learning (ML) section of this software and its outcomes will be presented, where all the simulated parts for modeling and optimization of supply side and demand side are integrated into a local power market for an efficient and flexible energy trading.

This is a paper for the 16th International Conference on Applied Energy (ICAE2024), Sep. 1-5, 2024, Niigata, Japan.

2. *real*SES ARCHITECTURE

Figure 1 depicts a schematic of the proposed *real***SES** platform within a smart community, connecting several prosumers for energy sharing and/or trading locally.

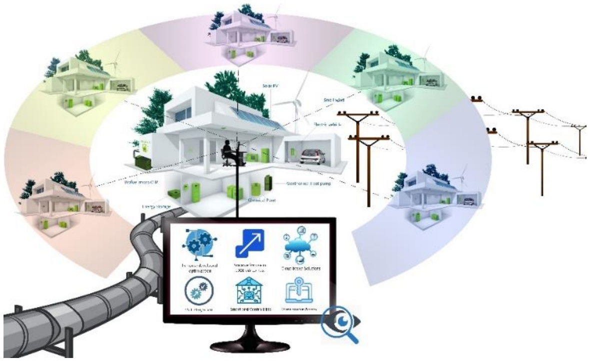

Fig. 1 The platform schematic

In state-of-the-art research community as well as business market, many solutions are being developed to address different challenges in decentralized energy market [6]-[8]. However, there are considerable gaps in enabling new stakeholders such as aggregators and energy service providers to take their increasing roles by innovative services and technologies [9]. Customers at the energy communities and/or neighborhoods levels will increasingly become "active" and should be able to manage themselves a combination of generation, use, and storage of their own energy. Hence, such a user-friendly toolset to be used and continuously developed over the time for management of decentralized RES at the community/neighborhood scale is extremely required.

At the same time, a significant challenge to realize optimal design and operation of such integrated multi-functional systems is complexity [10]. To tackle this difficulty, novel simulation strategies [11]-[13] and optimization methodologies for the energy systems [14]-[16] as well as adaptive to the market artificial intelligence (AI) [17-18] and ultra-reliable 5G-enalbeld infrastructure for communication [19] should be employed.

Therefore, the primary objective of the proposed software platform is to develop a comprehensive energy trading tools in which Distributed Energy Resources (DERs) and scenario-based poly-generation solutions as well as Demand Response (DR) for residential and commercial buildings will be simulated, integrated, optimized, and 5G-based communicated for more efficient and flexible energy sharing in smart communities (both On-Grid and Off-Grid). The overview of the *real***SES** architecture is demonstrated in Figure 2.

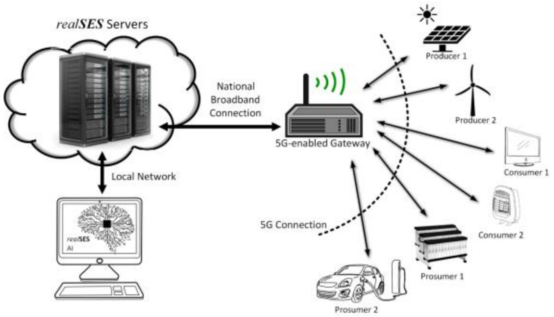

*Fig. 2 An overview of the real***SES** *architecture*

Based on that, some secondary objectives of the developed decision-making tools could be listed as: 1- Realizing online condition monitoring and control of demand side-supported by 5G technology, to actively manage local energy production and consumption; 2- Designing DER alternatives taking Social Science and Humanities (SSH) aspects into account to ensure sustainability of the design; 3- Increasing openness to collaborative research on transparent modelling of integrated DERs; 4- Applying AI and ML technologies for better management and democratization of energy market; and 5- Benchmarking commercialized optimum technical solutions and business models to be implemented in different countries and regions.

Figure 3 demonstrates some examples of the proposed user interface in the *real***SES** App.

Fig. 3 The user interface of the
*real***SES** *prototype software*

3. SUPPLY-SIDE MANAGEMENT

Beforehand, the only energy resource serving electrical/heat demand was the upstream (national) grid, and no consideration was given to the different types of generation resources that could exist and act in the place of energy consumption (i.e., loads). Recently, however, operators (now referred to as "prosumers") have been urged to use these on-site resources in conjunction with the upstream grid due to the development of new technologies in the field of energy systems, such as distributed generation (DG) systems, to ensure the provision of a reliable power supply and to lessen the role of national grids in the provision of electrical and/or heat power. In order to meet the energy needs of a local community, multiple non-renewable and renewable energy sources, including solar photovoltaic (PV), fuel cell (FC), and battery storage, are integrated in this project's proposed hybrid energy system.

3.1 The objective functions and problem constraints

In this work, a multi-objective optimization model is set up to address the battery/PV/FC hybrid system's cost-emission problem in the presence of a demand response (DR) program. The suggested model's primary objective is to minimize the total cost of the hybrid system and its CO_2 emissions, two objective functions that are in competition with one another. The weighted sum strategy is then used to solve the given multi-objective optimization problem (Min ($\boldsymbol{F}$); where $\boldsymbol{F} = w_1\boldsymbol{f_1} + w_2\boldsymbol{f_2}$).

3.1.1 Emission function

Recent attention has been paid to environmental challenges, making clean energy production essential. Hence, the amount of emission created by pollutants should be considered when planning the development of energy networks. The emission objective function is described in the formula that follows. The amount of CO_2 as environmental pollution is minimized in this objective function as follow:

Min $\boldsymbol{f_1}$ = Min [Emission_{total}] = Min [Emission_{gas} + Emission_{grid}]; in which

Emission_{gas} is the quantity of CO_2 emissions resulting from gas consumption, which is calculated by multiplying the carbon intensity of the used natural gas by the total gas consumed by both the fuel cell and backup burner over the course of one year.

Emission_{grid} is the quantity of CO_2 emissions attributed to the thermal power plants in the national grid, which is determined by multiplying the carbon intensity of the grid's power by the amount of power purchased from the upstream grid over the course of one year.

3.1.2 Cost function

Minimizing the cost of the entire system is another main goal of this scenario. The entire cost of the system is calculated by subtracting the profit from the sale of power from the total cost of purchasing gas and electricity. These expenses and profits were attained in the expressions described below:

Min $\boldsymbol{f_2}$ = Min [Cost_{total}] = Min [Cost_{gas} + Cost_{grid} – Sale_{solar}]; in which

Cost_{gas} is the cost of total gas purchased, which is summation of the quantity of gas used by the backup burner and fuel cell. In addition to the expenses associated with gas consumption, a monthly base fee must also be paid.

Cost_{grid} is the entire amount of energy purchased over the course of a year multiplied by the cost of energy purchased, which yields the cost of obtaining electric power from the upstream grid. A basic price is also considered each month in addition to the costs for the energy that is purchased.

Sale_{solar} is the benefit from selling the surplus power generated by the solar PV system back to the upstream grid at a predetermined and agreed-upon price.

3.1.3 Loads formulation

Both thermal and electrical loads models as well as their storage units and constraints are explained in this section very briefly. In the proposed approach here, the electrical load in the combined system consists of solar PV, fuel cell, and battery as previously mentioned. In this way, the balance between generation, consumption, and storage will be considered.

Here, the fuel cell and backup burner produce heat, which is directed into a heat storage tank. This stored heat is then gradually released to meet the thermal load requirements. To maintain control, the total heat available in the storage tank at any hour is calculated by adding the heat stored from the previous hour, the currently available heat, and the heat used for meeting the thermal load. It's important to note that there are limitations on how the heat is charged into and discharged from the heat storage tank to manage this process effectively.

In this study, the electrical load, taking into account DR model, is satisfied by a combination of power sources that includes the upstream grid and the hybrid energy system. Below is the argument stated mathematically:

$\text{Electricity}_{with\ DR\ plan\ implementation}$ = $\text{Electricity}_{grid}$ + Electricity_{PV} + Electricity_{FC} + $\text{Electricity}_{battery}$; in which

To be more specific, the power discharged from the battery is represented by the equation's final term. The upstream grid, the fuel cell, and the solar PV system all supply power to the battery storage. It is important to observe that the incoming energy to the battery storage should not exceed the battery's charging capacity. More detail and a precise mathematical representation could be provided in the extended version of the paper.

3.1.4 Demand response model

The performance of the combined solar PV and battery system has been examined in this work by taking the load response program into account using the time-use model (TOU), in which the electricity tariff is considered in the form of various rates for each period of time. Based on that, there are often three tariff modes: low load, medium load, and high load. These tariffs, which can have daily and seasonal price variations, call for measuring tools on the part of the consumers. In any case, the TOU system incorporates a multi-level tariff to accommodate price variations.

In the event of a catastrophic situation or during peak periods, this tariff may be applied. When load responsive programs are used, a portion of the load is moved from time slots, which are less expensive, to peak hours, smoothing out the load profile and lowering system costs overall:

$\text{Load}_{\textit{with DR plan implementation}} = \text{Load}_{\textit{base}} + \text{Load}_{\textit{variable}}.$

3.2 The simulation approach and brief discussion

As mentioned above, the two primary goals are to lower the overall system expenses and decrease the release of environmental pollutants. We examined these objectives both in scenarios without load response programs and in situations where load response programs were in place. The outcomes were then compared to validate the beneficial impact of incorporating demand response models on the hybrid system's emission cost performance. Every calculation and formula applied in this study considers a yearly timeframe, and, the GAMS software is used to address the cost-emission problem associated with the hybrid system being studied when a DR model is incorporated.

The fuel cell in use can generate both heat and electricity. The electricity produced by the fuel cell serves two purposes: powering the load directly and charging a battery. This battery functions as an energy reservoir, storing energy from various sources. When needed, the stored energy is discharged to supply electricity to the load at different times. Additional details about the battery storage, photovoltaic system, and fuel cell used in this setup can be found in [20].

As mentioned earlier, the study initially focuses on assessing the cost-emission performance of a solar PV/battery/FC hybrid system without incorporating the DR model. In this phase, the weighted sum approach is employed to address the multi-objective problem, leading to the discovery of multiple solutions. While all the solutions found are considered optimal, our primary interest lies in identifying the one that effectively balances the two conflicting objective functions, with equal weighting assigned to both ($w_1 = w_2 = 0.5$). For the second case, and in the presence of DR model, the similar approach is applied and the same results for w_1 and w_2 are obtained.

In the process of optimizing the developed hybrid system's planning, the model also delves into an examination of the electric storage component, which is, performance characteristics of the battery. Based on the results obtained, the quantity of battery charging and discharging remains relatively consistent in both scenarios, whether with or without the implementation of a demand response program. One feasible optimum solution can be discharging the battery more during peak hours than charging it during those same hours. This strategy is driven by the fact that electricity costs from the grid are higher during peak hours, aligning with the overarching objective of minimizing costs for the entire integrated system, in which the battery plays a vital role.

However, by incorporating the DR model, several positive effects are observed. Firstly, the usage of the battery storage for charging and discharging is reduced, which in turn extends the lifespan of the storage system. Additionally, there is a decrease in the amount of power acquired from the grid during peak periods, with an increase in energy purchases during mid-peak and off-peak hours. This shift in energy procurement results in an overall reduction in the total cost. Furthermore, the consumption of purchased gas is reduced, with gas now being acquired during mid-peak and off-peak periods instead of during peak periods.

4. CONCLUSIONS AND FUTURE WORK

The proposed energy management software platform for smart neighborhoods includes front-end, back-end, and a central core, which helps share and trade energy produced by different prosumers with the help of machine learning, Internet of Things, and communication tools and technologies. For this purpose, the sustainable design of a local electricity market is also desired, which is a part of this innovative project.

In the leading steps, and next to the development of programming for the technical part of the software, the market design's effectiveness will be assessed considering different quantitative metrics such as electricity price, data security, profit earned, and reducing emissions. Throughout the process, we will actively engage representatives from various stakeholder groups, including consumers, both large and small power generators, network operators, and government officials. These stakeholders will be involved in every phase of the research project, encompassing market design, simulation, and sophisticated optimization model development.

ACKNOWLEDGEMENT

I would like to express my very special thanks to my all colleagues in *ENERGIRING GROUP* for their time and efforts they provided throughout this project, from idea generation to MVP implementation. Their useful advice, suggestions, and kind support were really helpful to me during this research project's completion.

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