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Research Article

Cyber-Physical System-Based Hybrid Energy Management for Microgrids

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Abstract: The need for Renewable Energy Sources (RES) in the grid grows as rising energy demand drives up fossil fuel use, increased deregulation of electricity, and environmental concerns. This also presents significant difficulties for existing networks, which are not equipped to deal with electricity that is highly variable or dispersed. In order to accommodate the intermittent and fluctuating energy production from RES, the electrical system has been modified by the introduction of the Microgrid (MG). In order to keep the grid stable and lower the operating cost of the MG, load scheduling based on demand response is used, in which the prosumers' load is planned according on the priority levels. If prosumers generate more energy than they use, they may sell the extra juice to the utility company. The Peer to Peer (P2P) energy sharing mechanism is used in the suggested solution, allowing the prosumer to distribute the extra energy produced in an MG neighbourhood. P2P is a more efficient means of trading than the present system. Integrating renewable energy sources (RES) like photovoltaic (PV) systems, micro-wind turbines, and energy storage systems (ESS) into a conventional grid design is the focus of this study.

Keywords: Renewable energy sources (RES), Microgrid (MG), prosumers, energy storage system (ESS)

Introduction

In 2012, the NIST created a conceptual model to aid in the preparation, specification, documentation, and administration of the SG's networked apparatus and devices. The NIST has divided the SG into seven categories (with subcategories) that include both SG actors and their respective uses. Figure 1 shows one example of this. Actors are defined as equipment (like smart metres and solar energy producers), systems (like control systems), programmes (like utility management software), and stakeholders (like utility customers) that make choices and share data to carry out applications. For example, home automation, solar power production, energy storage, and management are all examples of applications since they include several actors doing activities within a certain domain.

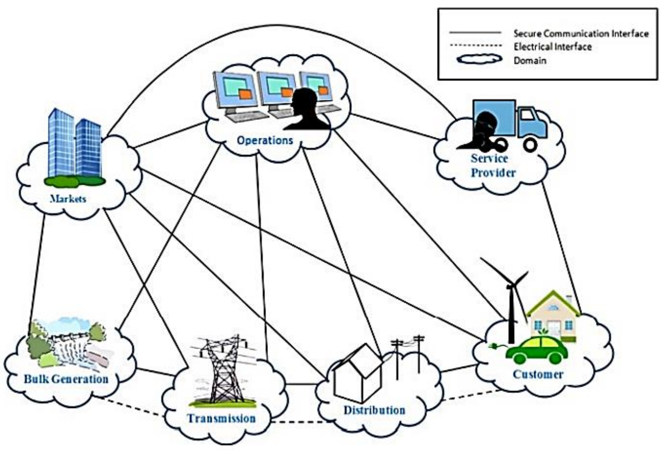

Figure 1: Interaction of actors in different SG domains by NIST (Source: NIST Framework and Roadmap for smart grid Interoperability standards, Release 2.0)

Due to its vertical one-way connection between the generation and load, the present conventional grid cannot handle the fluctuating generation and rapid changes in the distribution, as illustrated in figure 2. Adding more communication, IT, and automation layers is required to transform the classic grid into an SG.

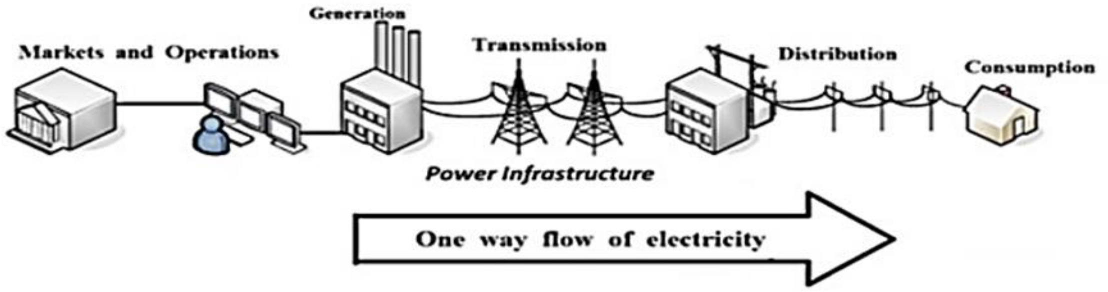

Figure 2: Schematic diagram of a traditional grid

Energy Storage System

During island mode operations, when the DER cannot keep up with the abrupt shift in demand, energy storage systems (ESS) are crucial for the MG. The primary goal of the ESS is to maintain the power quality by balancing the generation and the load. When peak demand occurs, the ESS releases the stored energy to the grid. During times of high demand, the system will convert energy back into electrical form from another available source. Energy storage systems (ESS) provide the power needed for a seamless changeover from island mode to grid-connected mode. Flywheels, supercapacitors, pumped hydropower, batteries, and electric vehicles (EVs) all fall under the category of "storage option." The ability to store energy during periods of low power demand makes EVs a practical choice for the future. Critical restrictions in choosing an ESS include energy storage capacity, power density, reaction time, operational life, cost, monitoring, and operating parameters. There are several uses for electrochemical batteries, such as grid management, transportation, power quality maintenance, and more. The setup time for the battery storage system is minimal, and it offers a great deal of customization options. Because of its hazardous components, the battery's usefulness is reduced in mission-critical settings, and battery recycling ranks high on the list of priorities when deciding on a storage solution. Nonetheless, the lead-acid battery remains the most popular storage technology because to its low price and abundant availability.

Peer To Peer Energy Sharing (P2P)

To effectively manage the DER in MG and offer local market solutions, P2P energy sharing is a viable option. P2P sharing allows prosumers to take an active role in the local energy market by exchanging energy directly with one another. Prosumers have the option to sell excess energy to neighbours or the grid at any time, and the conditions of the exchange are determined by the prosumers themselves. Peak demand, transmission loss, operating costs, and unreliability are all reduced thanks to P2P. Peer-to-peer (P2P) energy sharing has overtaken P2G in terms of popularity. A third party, known as an energy sharing coordinator (ESC), mediates service provision between the end user (the consumer) and the producer (the prosumer) in the P2P Energy sharing model. The DER of prosumers and the regional energy market are both under the ESC's watchful eye. Power usage and demand are tracked in real time by smart metres placed at each prosumer site. The ESC also provides estimates for the monthly energy costs incurred by each prosumer and customer.

Cyber Physical System

The United States National Science Foundation (NSF) first used the term "cyber-physical systems" (CPS) in 2006 to describe a wide variety of advanced engineered systems that incorporate embedded computing technologies (the "cyber part") into the physical world. According to Gunes et al. (2015), the European view of CPSs places more emphasis on connection with the cloud cyberspace and human aspects, whereas the American view places more emphasis on integrating embedded systems and the physical environment. With the use of CPS, it is possible to achieve system interoperability, flexibility, and reconfiguration while decreasing energy consumption and maximising system efficiency. Leito proposes using a hybrid of mechatronics and information technology to manage mechanical processes and infrastructure (figure 3). This hybrid would take the form of a network of interconnected, software- and hardware-based devices and infrastructure that could make decisions on their own. The energy system relies on both cyber and physical components, and its performance might be hindered by flaws in the control schemes. Recent studies have analysed contemporary systems of control at length.

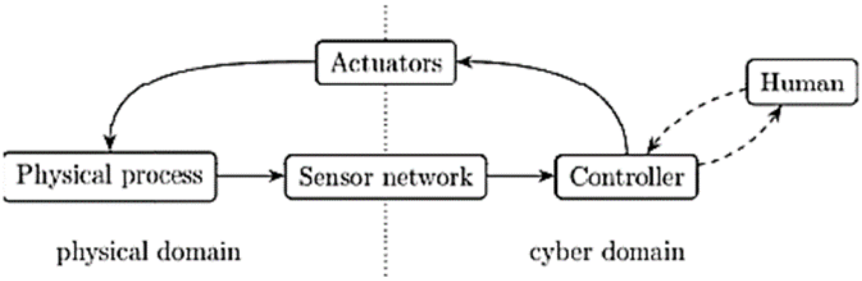

Figure 3.Block Diagram of Cyber Physical System (CPS)

The goal of this initiative is to raise the percentage of time that RES linked in the MG are really being used. In the proposed system, a Cyber-Physical Based Energy Management System (CP-EMS) facilitates P2P energy sharing. To facilitate P2P energy sharing in low voltage distribution networks, a unique CP-EMS-based aggregated control system is implemented. The suggested system employs restricted measurements and one-way communication for real-time P2P Energy Sharing, in contrast to traditional techniques of P2P sharing involving a third-party coordinator. Instead of sorting prosumers willing to share in the market by transmission loss or market pricing, this technique arranges them according to the supply ratio or available energy to share. In this system, the selling price is not determined until the end of the day when bills are being tallied.

Literature Review

Pirak et al. (2014) refers to a method suggested for main frequency management using smart metres and controlled load blocking for residential loads, with an eye on end-users' way of life and security. Because AMI is not a singular technology, it encompasses a wide variety of technologies that may interact between customers and system operators, making it the first step towards grid modernisation. Benefits not seen in conventional grids are made possible by AMI, which gives crucial information for customers to make choices.

Gamarra et al. (2015) presented a survey of current developments in MG planning and methods for planning using optimisation algorithms.

Fathima et al. (2015) hybrid MG, optimisation techniques, and practical applications were all explored. Efficiency, according to Colmenar-santos et al. (2015), is mostly due to two factors: remote monitoring of hybrid generation and automated SG control for unstable distribution networks.

Meng et al. (2016) describe the primary goals of MG energy management systems (EMS) and MG supervisory controllers (MGSC).

Olatomiwa et al. (2016) reviewed EMS strategies for different configurations of standalone and grid-connected hybrid systems.

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Khan et al. (2016) provide an overview of heuristic, agent-based, MPC, evolutionary, and other methodologies, optimisation techniques, and tools for handling energy management issues in MGs.

Materials and Methods

The proposed system uses renewable energy sources like photovoltaic (PV) systems and wind turbine systems combined with battery banks to provide an EMS for an MG consisting of consumers and prosumers. The household load is wired into the traditional grid, which draws power during peak demand and distributes excess power to other users during times of overproduction. The system also incorporates a battery bank for energy storage, which enables the energy to be stored during periods of plenty and drawn upon during periods of scarcity. To get the most out of renewable energy sources, a demand response-based EMS is developed. As a result, both CO2 emissions and the utilisation rate of the installed RES are reduced. This section of the chapter continues on with the development of a P2P sharing strategy. The prosumer buys energy from an electrical provider when the RES energy supply is inadequate, and sells extra energy to the same supplier when there is a surplus. Prosumers may keep their money in the community when they use peer-to-peer energy sharing to buy and sell energy with one another. The last section of the chapter focuses on the creation of a real-time CP-EMS using money allotted by the Ministry of New and Renewable Energy (MNRE).

Several optimisation techniques, including Interior search algorithm (ISA), Dragonfly algorithm (DA), and Grey Wolf Optimizer (GWO), will be used to test the grid-connected microgrid with the demand response system. One wind generator and one solar generator are both linked to the grid, and there are three users in total. The scheduling flexibility provided by the prosumers is used to do the optimisation. The goal of the planned work is to increase the proportion of renewable energy used across the grid by encouraging prosumers to pool their surplus power inside the microgrid. In this section, we run simulations of the energy management model that has been put into place. The machine with Windows 7 Ultimate64 bits, an Intel® CoreTM i3-2350M CPU running at 2.30 GHz, and 4 GB of RAM is used to develop and run the model.

From either the utility power grid or the RES and ESS, the home system meets all energy requirements. If there is an excess of electricity, the MG may sell it back to the grid. Through the collection of client scheduling preferences, this study advances energy management based on the demand response approach. Algorithms like ISA, DA, and GWO are then used to further refine the system. Additionally, a peer-to-peer (P2P) energy sharing algorithm is simulated and tested under a variety of conditions. Finally, a CPS-based real-time energy management system is built, and its efficacy is evaluated.

Energy Optimization Simulation Using DR

The purpose of the system is to verify the demand response system's grid-connected MG and to evaluate it in relation to other optimisation algorithms like DA, ISA, and GWO. Three consumers, one wind generator, and grid-connected solar photovoltaics make up the system. Solar and wind generators have a 24-hour set scheduling period. The power is fed in during times of overproduction and fed back into the grid when it's needed. Customer input is used to determine the amount of RES penetration and the scheduling of loads during peak demand. The hourly demand of MG houses and the generation from RES is shown in Figure 4. The mini wind turbine in the MG gradually creates electricity, while the solar photovoltaics provide maximum power between 10 a.m. and 3 p.m. Wind turbines provide the most electricity between 4 and 10 at night. At 7:00 p.m. the evening, the load peaked at 16 kW. When there is a large discrepancy between load and RES generation, or when production surpasses load power and is therefore classified as surplus and sold back to the grid, power scheduling often rises. In this section, we run simulations of the energy management model that has been put into place.

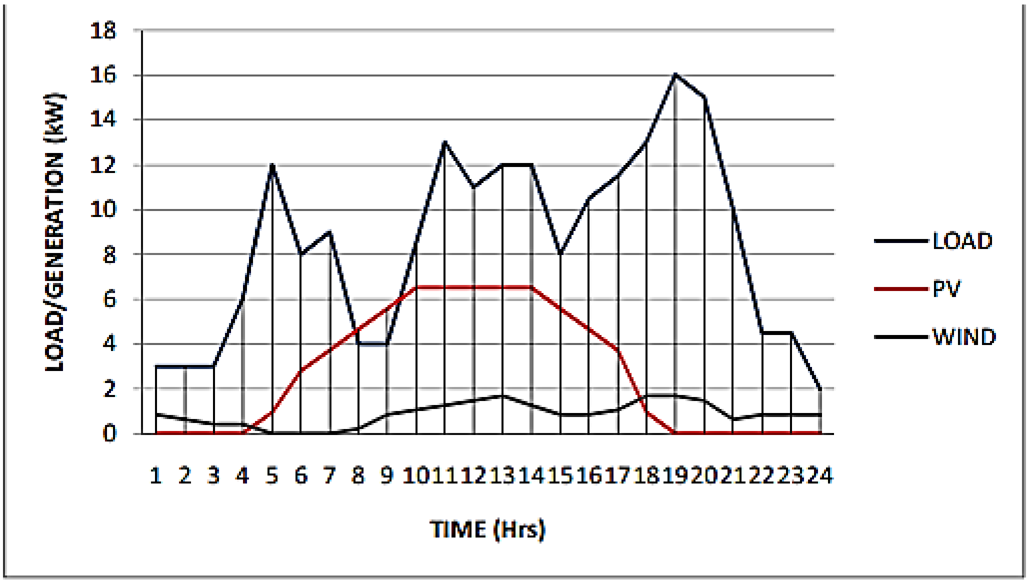

Figure 4: Hourly demand and generation of 3 home system.

Model development and simulation occur in MATLAB 2014A during a 24-hour period separated by one-hour intervals. DA, ISA, and GWO are only few of the optimisation techniques used in the simulation. The rising prevalence of renewable energy systems like solar and wind makes optimisation in the electrical MG context difficult because to the volatility of energy demand and the unpredictability of power output.

Simulation Results of ISA

There are 300 people in the search population for the ISA algorithm, and 500 total iterations are performed. The simulations also include a readiness to restrain while connecting the MG to the grid. Let's call the amount of energy saved by each prosumer x, and the prosumer's consumption pattern. We may write down the reduced cost function as (, x). Prosumers are ranked from least willing to most willing to cut down on consumption. Three different prosumers have shown values of 0.1, 0.2, and 0.3 for their willingness to schedule load. Each consumer's schedule is within the higher and lower limits, and the maximum load drawn from the grid is limited to 15 kW.

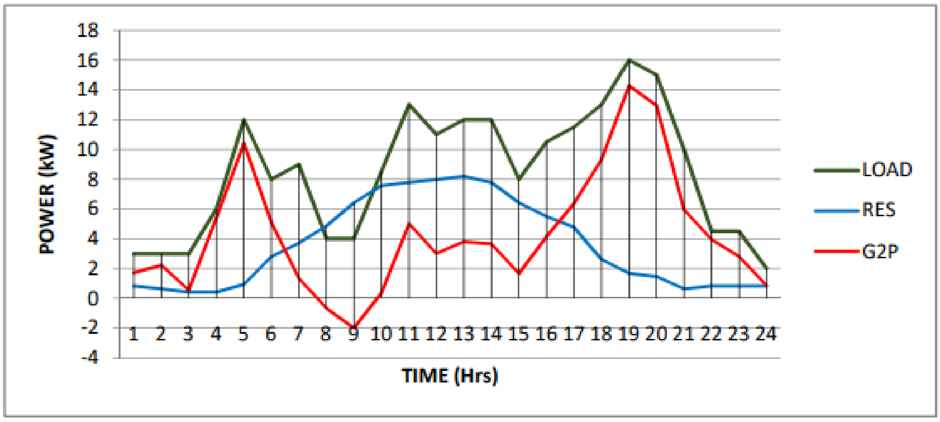

Figure 5: Power supplied by grid to homes in ISA

The combined output of the MG's solar panels and wind turbines is seen in Fig. 4. The demand after scheduling is shown graphically in terms of total MG load, RES generation, and MG power consumption. During the hours of 6:00 pm and 9:00 pm, when the figure's demand is at its highest, the grid's output of electricity is likewise at its highest. When renewable energy sources (RES) are insufficient to meet demand, conventional grid power is increased. From 8:00 AM to 10:00 AM, the MG's surplus electricity is sold back to the traditional grid since RES output is greater than the load. Scheduling results for the MG were calculated using MATLAB (see Figure 5), which demonstrates that when demand rises, more load is planned by the three customers in the grid. Figure 5 shows that the RES surplus coincided with the times of day when the EMS curtailed the least amount of load from consumers. This occurred between the hours of 8:00 and 10:00.

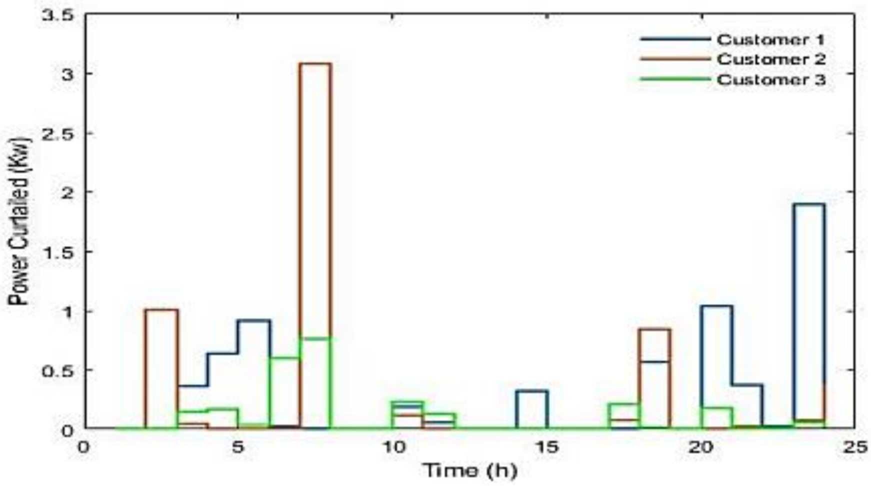

Figure 5: Hourly scheduling of homes in MG using ISA

In a simulation lasting 24 hours, the ISA algorithm allocates 16.4 kW of electricity, the PV produces 65.2 kW, and the mini wind turbine generates 20.79 kW. The MG uses 203.5 kW daily, and with ISA optimisation, the system can save that cost by roughly Rs 143.48. Assuming the cost of electricity supplied to the grid and bought costs both remain at Rs 1.5. The community typically sets aside Rs 0.1 every month to cover maintenance and any unforeseen costs that may come as a result of a breakdown in the RES, which includes photovoltaic (PV) and wind turbines. Every day, the MG puts out around 2.67 kWh into the grid and draws in about 104.78 kWh from the power company to meet demand.

Microgrids MG with 4 Home Systems

The simulations in an MG with four residential systems run for 48 hours. Every house has its own Solar PV or wind power system as well as its own ESS. In a time-sensitive system, we use a Lead Acid battery as a means of data storage.

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Input Variables	H_1	H_2	H_3	H_4
Total Load	77	61.5	65	61
Peak Load	8	8	6	5
Average Load	3.2	2.56	2.7	2.54
RES	32.6 (PV)	20.79(WIND)	32.6 (PV)	20.79(WIND)
SOC % Max	100	100	100	100
SOC% Min	20	20	20	20

Table 1: Input variables to 4 Home System

The system's performance is evaluated by testing it with a number of different input variables, which are listed in Table 1. Three scenarios are used to evaluate the system, each with a unique combination of ESS state-of-charge (SOC) and applied load. To avoid degrading the performance of the battery, the ESS cannot drain more than 20% of its capacity. The system's load is also adjusted to test its distribution mechanism..

Real Time CP-EMS System

Five kilowatts (kW) of solar photovoltaic panels handle the energy monitoring and control in real time. In addition, there are AC and DC measuring sensors installed in an energy metre for continuous monitoring. In addition to the Zigbee wireless connection between solar PV panels, the system makes use of a Thermostat temperature sensor to monitor the panels' temperatures.

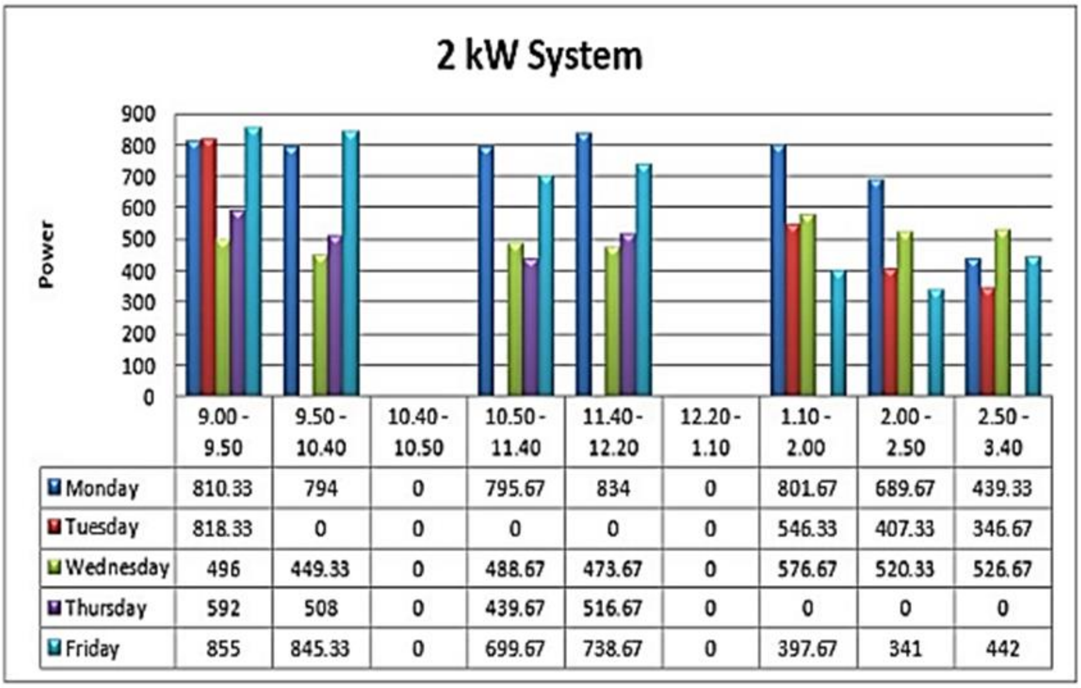

Figure 6: Real Time Daily Load Curve

The load curve was drawn from 9.00 am to 3.40 pm, which corresponds to college working hours, and from 10.40 am to 10.50 am and 12.20 pm to 1.10 pm, which correspond to college break times. Experiments have been conducted utilising the Real-time EMS to test the suggested method. The goal is to reduce reliance on the power grid while increasing solar and wind energy production.

Conclusion

By combining conventional grid infrastructure with renewable energy sources (RES) such solar photovoltaic (PV) systems, micro-wind turbines, and energy storage systems (ESS), this study examines energy management for a home user in an MG setting. The primary goal of the system is to reduce clients' power bills as much as possible. Maximising usage of renewable energy sources and arranging loads in homes in accordance with demand reduces costs. Each customer's desire to participate in load scheduling is measured, and incentives are distributed accordingly. The issue was analysed using a number of different optimisation techniques, and the results were compared in a number of different scenarios. Since users' convenience is sacrificed in the sake of cost optimisation on the grid, scheduling is a tried-and-true strategy. To help the MG and its prosumers save money on power, we've implemented a P2P sharing system. With limited resources for sensing and communicating, a real-time MG model based on P2P collaboration is created. This model is built upon the already established conventional grid, therefore there is no need to make any adjustments to the existing infrastructure.

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