SiMunity: A unified modular approach with diverse facilities and networks

SAHER JAVAID[†1] YOSHIKI MAKINO[†1] YUTO LIM[†1] YASUO TAN[†1]

Abstract: Simulation is an essential step in evaluating and testing new control and management methods for future Smart Grids. In order to produce sound simulation results, validated and established simulation models or frameworks are required. In this paper, we present a unified modular approach of simulator for smart community, called SiMunity. It allows us to specify, compose, and simulate smart community scenarios based on surrounding physical environment, different life styles of residents, and the type of the buildings and facilities available. With SiMunity, we can change different aspects and features of individual home for a local objective as well as whole community for a global objective.

Keywords: Smart Community, Simulator for smart community, community energy management system, renewable power sources, internet of things

1. Introduction

The continuous growth of power demand and the global concerns to reduce gas emissions calls for a significant increase of power generations from renewable power sources. Two key issues in creating a sustainable and energy-efficient society are decreasing peak power demands and increasing the penetration of renewable power sources. In order to achieve a reliable operation of the power system, supply and the demand have to be balanced all the time [1]. To handle these severe power supply and demand conditions, extensive research have been made to save energy [2], [3]. These situations are not only effecting daily life activities but also pushing the limits of power plants to generate more power. The great need of power-saving actions during peak power consumption has become a critical issue throughout the society [4]. Also, the mixture of smart grid technologies into traditional power systems has led to challenging opportunities for the existing grid to be automated, continuously monitored, controlled, and optimized efficiently. As a result, these technologies provide utilities with multiple command and control layers for their current and future benefits [5].

A smart community is a social infrastructure that combines diverse power technologies and ICT to provide safe and comfortable life while reflecting the global environment requirements [6]. The use of ICT technologies in smart communities are aiming to provide stable power supply from renewable energy sources such as solar power generation, wind power generations etc. They also efficiently manage power demand by residential and commercial areas. A smart community is a common system for all the residents of that community which can provide sufficient power supply by designing a combined infrastructure of diverse power related technologies and their visualization [7].

The notion of the smart community has spread throughout the world and a variety of proposals and standards have been introduced by government legislations, enterprises and universities in each country [8]- [9]. Smart communities generally consist of: cogeneration systems, facilities, heat generated by renewable energy sources, e.g., residential use fuel cell, those for energy storage e.g., accumulators and electric vehicles, and energy management systems (EMSs) that connect said elements in a smart manner and realize the optimum operation of energy.

The demand for smart community infrastructures will continue to grow in the decades, driven by major factors of change, such as population growth and urbanization. The new resources available in power system require a new agent/coordinator to manage these resources in the most efficient way. Resources provided by the supply side or the demand side can be managed together in order to provide some services to the grid. New resources such as distributed generation have been being gradually integrated to the grid and for the next years the integration tendency will follow increasing. These resources require a different approach to be managed effectively. The integration of intermittent resources into the grid is a challenging task but these issues can be addressed by an aggregator/ coordinator agent.

This paper proposes a unified modular approach of simulator for smart community called *"SiMunity"* with diverse facilities and networks for future smart societies to provide safe, comfortable, and energy aware power supply. It can manage power transactions between the grid side and the demand side resources. The proposed SiMunity can simulate power consumption and generation of the individual consumer environment as well as the community. This paper aims for early deployment of smart communities by coordinating the advanced information technologies, energy management technologies, and facility management technologies developed to date.

The purpose of this paper is twofold: (1) introduce the general architecture of smart community with all related elements e.g., distributed sources of renewable energy, storage management systems, existing facilities such as homes, building, factories, and schools to increase the ratio of renewable energy used to power those facilities, and (2) achieve a modular approach to combine all facilities to form a smart community. It allows us to specify, compose, and simulate smart community scenarios based on surrounding environment, different life styles of residents, the type of the buildings and facilities available. With SiMunity, we

†1 Japan Advanced Institute of Science and Technology (JAIST)

can change different aspects and features of individual home for a local objective as well as whole community for a global objective.

2. Proposed Smart Community Architecture

The smart community is a shared common system that aims to integrate all types of facilities such as homes, buildings and even whole area for the development of the smart community energy management system. A home or building user can participate in the smart community environment after agreeing to the terms and conditions with respect to local geographic region, zones, and terrain. For example, a home user can get benefits of the shared environment of smart community rather than staying isolated. Architecturally, the smart community is divided into three domains: facility domain, community domain, and network domain as shown in Fig.1.

2.1 Facility Domain

The facility domain targets not only independent, distributed facilities such as residences, buildings, factories, schools, and shopping malls but also the shared power generation systems and power storage systems for the community. It considers even the whole area for the development of the smart community.

For example, in Fig. 1 residential houses are considered equipped with home energy management system (HEMS). This can be designed with various home automation systems (e.g., security systems, healthcare systems, entertainment systems, lightning systems etc. These automation systems are responsible for continuous monitoring of power consumption by all home appliances/consumer electronics (CEs), power generation of roof top photovoltaic (PV) systems, storage battery management systems, activity recognition systems for daily home user's activities, and overall home environment monitoring systems. These systems send their monitored data to a home gateway inside the home in a single or multiple hop way. The home gateway also provides a home's communication interface with the outside community to link with the community domain. Consumer premises in a smart community must relate to the community network and should be able to intelligently process and manage requests to/from the outside e.g., supply side.

Energy management systems (EMSs) such as the home energy management system (HEMS), building energy management system (BEMS), factory energy management systems (FEMS), school energy management system (SEMS) can provide the technology needed to meet these requirements [10]- [12]. Furthermore, they include power/heat storage facilities and power generation equipment that make the customer "a prosumer" which can supply power and consume power at the same time. These systems can act as a buffer in controlling energy supply and demand in consumer premises. They could have a major impact on the society when their power supply runs out or roof top PVs generate more power than power consumption by all CEs.

2.2 Shared Power Generation and Storage Systems for Smart Community

In recent years, the development and deployment of large-scale solar systems have been growing rapidly. As these are the important power sources for smart communities to reduce dependence on traditional power sources, the continuous power generation monitoring and control is necessary. The collection of measured power generation data will help to analyze and understand the fluctuating power generation behavior according to the weather conditions and overall system efficiency. Moreover, this can also be used to predict or forecast power generation for near future power usage.

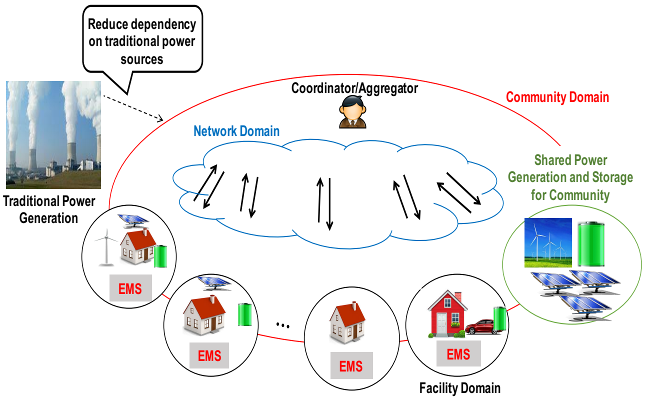

Fig. 1. Proposed Smart Community Architecture.

Another objective is to provide a stable power supply to smart community even during the times of commercial power outage in natural disaster situations. To keep the reliability of the smart community power grid is challenging task. Because of the unstable power generation from wind turbines, and photovoltaics. The deployment of storage battery can play an important role in ensuring the safety and reliability of the smart community power grid [13]. It can also help to reduce gas emissions and contribute to the environment by maximizing the output from the renewable power sources.

2.3 Community Domain

The fundamental part of the smart community architecture is the community domain, where a connected community network is formed by facility gateways (representing their hosting facilities) for cooperative and distributed monitoring of the community environment and information dissemination among individual facility. The core of the community domain is "aggregator or coordinator" [14]- [16]. The aggregator coordinates the end users and tries to achieve a group-level objective (e.g., power balancing, reductions in gas emissions to provide environment friendly system). An energy aggregator agent can help to manage effectively the multiple resources from the demand side. It is placed between the demand side consisting of a group of consumers and the distribution operator. It provides the distribution operator cumulative energy available, from storage and renewable power sources at any time during the day. Depending on electricity market conditions and load demand the it make decisions to buy power from the aggregated load of resources available from the demand side or from the utility side.

One of the main requirement and challenge to make the feasible an aggregator agent is to design strategies for management and operations attached to the smart community concept. Typically, an aggregator will set up arrangements with members of groups such as home owner and offers smart community services to all the users. On the other hand, an aggregator can offer a large customer pool to the suppliers, and may be able to get more competitive offers from the power suppliers, as a result. A reliable shared data storage and processing system is places for the monitored power data of the whole community. It is protected by advanced sensor technologies to avoid unauthorized access, which will trigger alarms, notifying community residences and authorities. Data stored on the community shared data storage system is personal, sensitive, and confidential. For facility privacy, they are selectively accessible by only to authorized parties.

2.4 Network Domain

The network domain provides an interface between community energy management system (i.e., aggregator) and community facilities including smart homes, buildings, shared generation and storage. With the development of IoT technology [17]- [19], the information can be shared in both directions between the aggregator and demand side. This domain provides a mechanism to use energy intelligently by sharing data in both directions between the supply and demand sides of the system using IoT devices. Consumer premises in a smart community must be connected to a network and be active in sending and receiving information to/from the outside while being appropriately controlled in accordance with requests from the aggregator.

All facilities in smart community are equipped with interfaces for wireless communication, it can be a smart meter or any device that can measure, store, and forward power data to the community domain. Each facility is responsible to send its sensed data to smart community management system. Network domain also supports the demand response program and load management in term of reliability and flexibility by an efficiently management of the energy. Load nature is high volatile, it creates, blackout and distress problems within seconds and these problems has reduced by using demand response program.

3. Proposed Unified Modular Approach of SiMunity

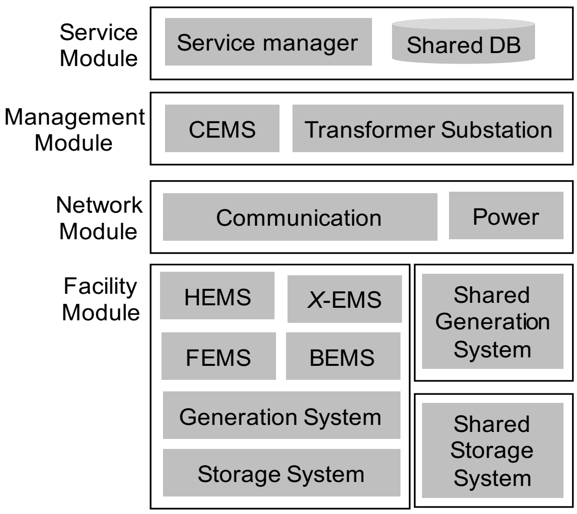

Fig. 2. Modular Framework of SiMunity

The energy management system for smart community consists of many elements including consumer premises such as homes and office buildings equipped with CEs such as various types of equipment (air conditioners, lighting, etc.) and electric vehicles (EVs), rooftop solar power generators and shared large-scale power generating stations, and battery management systems for smart community. These elements need to be managed in an integrated manner to form a complete system for smart community. The implementation of the smart community is mostly implemented in a distributed manner due to the independent facilities with different power consumption and generation behaviors.

For this purpose, we propose a unified modular approach, called "SiMunity. It allows us to specify, compose, and simulate smart communities with different scenarios and conditions based on surrounding physical environment, different life styles of residents, the type of the buildings or facilities available, and the power generation utilization. With SiMunity, we can change different aspects and features of individual home for a local objective(s) as well as whole community for a global objective(s).

The framework of SiMunity is implemented as various software modules, installed on different PCs suitable for execution on a distributed environment. The SiMunity is comprised of different node PCs representing modules in the framework. By using multiple simulation nodes, the simulation is completed in distributed approach.

The overall SiMunity framework can be divided into 4 modules: service module, management module, network module, and facility module as shown in Fig. 2. In the following subsections, we will explain the contents and implementation of each module in detail.

3.1 Service Module

The service module consists of two sub modules: service manager or SiMunity manager module, and shared database module. The overall management of the simulation is managed by the service module. The deployment of this module is presented in Fig. 3. A service manager or SiMunity manager is responsible for designing one or many smart communities with all related elements required to form a community as explained before. For this purpose, at first, the SiMunity manager designs community profile(s) consisting of numerous facilities and set all simulation parameters for related modules. Then, the profile is sent to all facilities in the designed smart community. After receiving the profile details, each facility register itself to the manager to show the node is ready to start simulation. For example, one community profile contains the information related to the type of facility i.e., school, houses, shopping malls, and factories along with their number or ID. It also mentions how many power generation and storage systems are existing in that community.

After designing and sending detailed profile, it collects and confirms the connection of each node by analyzing *"Node registration request"*, the manger then sends the *"start simulation message"* to each related facility of the designed community.

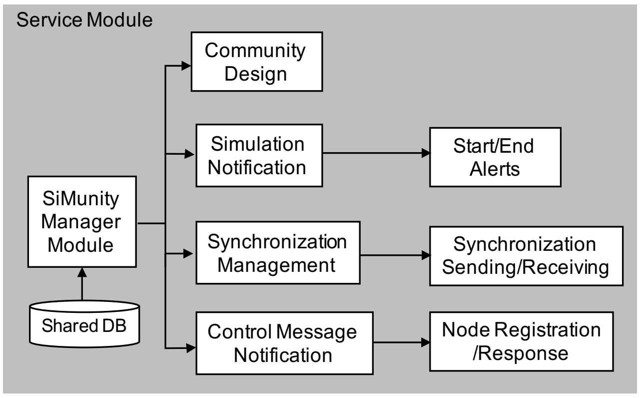

Fig. 3. Service Module Deployment and Responsibilities

The manager also receives *"End simulation message",* when the simulation finish performing simulated community profile. During simulation, manager node also implements time synchronization functionality in the form of message passing, used by the other modules. The power consumption results calculated from the other modules are stored to their corresponding internal databases.

Currently, SQLite is used as a shared database stored on a single file. After the end of the simulation, the file containing the results is automatically transferred to a computer node where the SiMunity manager is operating. The manager can now confirm the obtained data. Finally, the manager module reads the community description file and distributes the appropriate community setting to the rest of the modules. It sends/receives simulation start/end notifications, and controls synchronization messages among modules.

3.2 Management Module

The management module is further divided into two sub modules: community energy management system (CEMS), and Transformer substation. The deployment and responsibilities are given in Fig. 4. The core of the community design and implementation is CEMS, that manages energy (both consumption and generation of individual facility as well as shared community facility) over an entire area, such as community. This module receives information regarding the consumption of electrical and thermal energy from other facility modules and then based on this information, it proceeds to issue Demand Response (DR) commands to other modules, thus controlling the total energy power consumption of the simulated community. By changing the settings of this module, it is possible to control the overall power consumption trends of the community.

It continuously collects information from the consumer side and also absorbs the information from the transformation substation side for the latest information. A smart community aims to promote the introduction of renewable energy, improve energy conservation through effective use of local energy, and achieve urban development that is robust against disasters, so we can expect CEMS to play a centralized role in optimizing energy supply and demand across the entire community. Furthermore, a CEMS implemented for a number of benefits; not only is it

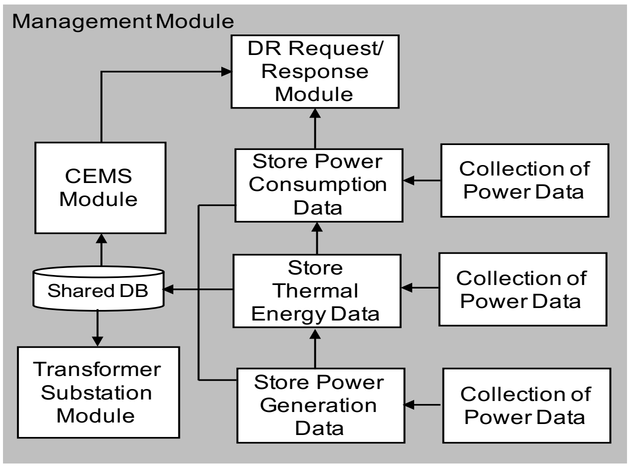

Fig. 4. Management Module Deployment and Responsibilities

flexible to the addition or removal of power-consuming and power-generating facilities within the target area, but it also enables high-speed and close information exchange with other consumer-side EMSs.

Within this smart community, the CEMS will be used to control the charging/discharging of storage batteries according to supply-and-demand conditions in the target area through the use of supply-and- demand management equipment. This approach will enable the provision of a high-quality, uninterruptible power supply. The CEMS will also be used to achieve load control via a BEMS.

3.3 Network Module

The network module includes: communication infrastructure, and power network. This module provides a communication interface between CEMS and facility modules (i.e., residential houses, schools, factories, offices, shopping malls etc.). It also provides a communication exchange between shared power generation and storage systems with CEMS.

With the development of advanced communication technologies, the information can be shared in both directions between the CEMS and transformer substation. This module also updates transformer substation about power consumption data of the community continuously. This domain provides a mechanism to use energy intelligently by sharing power consumption, generation, and storage data in both directions using IoT devices. Consumer premises in a smart community must be connected to a network and be active in sending and receiving information to/from the outside while being appropriately controlled in accordance with requests from the CEMS. All facilities in simulated smart community are equipped with interfaces for wireless communication that can measure, store, and forward power data to the community domain. Each facility is responsible for sending its sensed data to smart community energy management system.

This module also communicates DR information to/from the CEMS and facilities for the implementation of the Demand Response applications to reduce power consumption by all facilities and reducing dependency on traditional power sources.

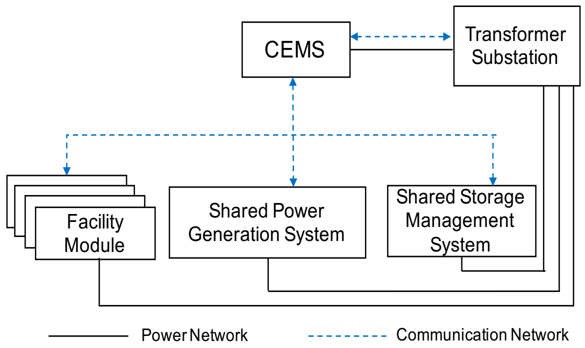

Fig. 5. Representation of Communication and Power Network

3.4 Facility Module

This module is dedicated for facility energy management system, which targets independent, distributed residential homes, buildings, factories, schools, and shopping malls but also the shared power generation systems and power storage systems for the community. It also considers local power generation sources of that facility i.e., rooftop PV generation systems etc. for example, energy management systems for building are responsible for various automation systems (e.g., security, healthcare, entertainment, and lightning systems etc. These automation systems are monitor power data by all home appliances, power generation such as PV, storage battery management systems, and activity recognition systems for daily home user's activities. Consumer premises in a smart community must relate to the community network and should be able to intelligently process and manage requests to/from the community energy management system.

It calculates the current electrical and thermal power consumption as well as any excess power, and sends this information to community energy module, and transformer substation module. Moreover, it implements HEMS functionality, receiving the DR commands of the community energy management module and controlling the devices in the house accordingly thus performing energy management in the home. The messaging protocol currently used in the simulation follows a unique format, based on OpenADR [20]. However, if it is necessary, other protocols that are actually being deployed in the real world may be used, assuming that all other modules can use it. In such a case, the simulator can operate in real time, and use a real system as a module in the simulation.

Energy management systems (EMSs) such as HEMS, BEMS, and FEMS can provide the technology needed to meet these requirements make the customer "a prosumer" which can supply power and consume power at the same time. These systems can act as a buffer in controlling energy supply and demand in consumer premises.

4. SiMunity Modules and Communication

The communication between SiMunity modules is presented in Fig. 6. The communication between various modules is done by sending and receiving of messages. Each community domain requires one CEMS module for overall energy management of considered smart community. In the beginning,

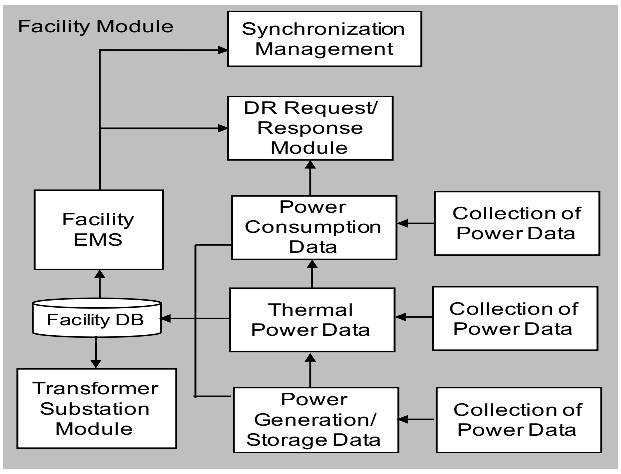

Fig. 6. Facility Module Deployment and Responsibilities

The management information is exchanged between SiMunity Manager and facility module. Management information contains information related to: (i) community profile (ii) Registration request/response, and (iii) Simulation start/end message.

The community detailed profile is sent to all related facilities. Each facility has its own unique profile. For example, the information of a house has the following type of information: type of house, power consumption profile, thermal energy profile, distributed power profile, and various consumer equipment. By changing the setting or the parameters of this module, it is possible to control power consumption and generation of individual facility. It is also possible to simulate a group of residential houses. The functionality is same as explained for each house but applicable to apply to multiple houses that shows the implementations extends to a group of houses. After receiving community profile, each facility registers itself with the SiMunity manager as well as CEMS module. The manager then send start simulation request to all related facilities and CEMS, which make simulated smart community to start consuming and generating power till the specified period (i.e., hours, day, or week).

All facilities operate according to the community profile while keeping their time synchronized until it receives end simulation message from the manager to finish the tasks.

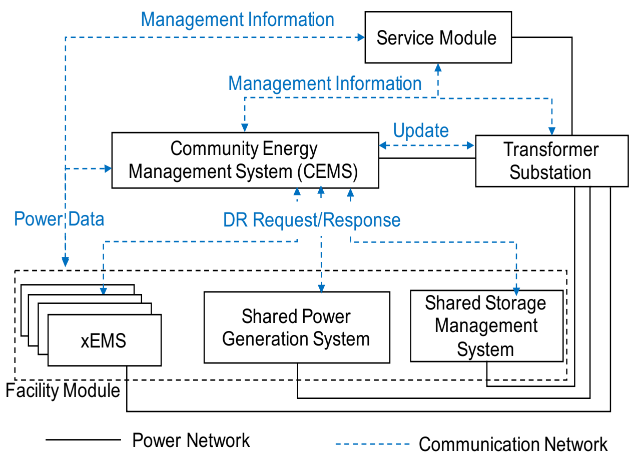

Fig. 7. SiMunity Modules and Communication

The facilities module including shared power generation and storage modules can communicate with CEMS via a simple protocol based on OpenADR.

It is also possible to change the communication protocol among the modules by altering their implementation. All facilities with HEMS, BEMS, FEMS, and SEMS functionality, receiving the DR commands from CEMS module, which can control all facilities with CEs thus performing energy management in the home.

5. Concluding Remarks

A smart community can be considered an essential component to realize a sustainable, low-carbon, and disaster-tolerant society, thereby providing a base for community inhabitants to lead a simple, healthy, and energy-saving way of life as well as ensuring safety, security, and a high quality-of-life in the community. In particular, a smart community can be essential for senior citizens in an aging society. Smart community enablers such as information and communication technology (ICT) and electric vehicles (EVs) can perform essential roles to realize a smart community. With regard to ICT, the necessity of a dedicated wireless sensor backbone has been identified. In this paper, we proposed (i) architecture of smart community with all related elements e.g., distributed sources of renewable energy, storage management systems, existing facilities such as homes, building, factories, and schools, and (ii) achieved a modular approach to combine all facilities to form a smart community.

In future research and development activities, we plan to incorporate more accurate forecasting techniques, develop supply-and-demand management and control techniques as well as diverse applications based on those forecasting techniques, and expand the types of facilities and equipment that can be added or connected to the system. We also plan to research and develop behavior recognition and prediction techniques targeting community residents and building occupants using smart devices and sensor networks.

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