DEVELOPMENT OF AN ENERGY MANAGEMENT SYSTEM FOR SMART BUILDINGS WITH THE INTERNET OF THING FOR SUPPORTING THE AUTOMATED DEMAND RESPONSE

NICHAKUL NARABONYAWAT

A Thesis Submitted to the Graduate School of Naresuan University
in Partial Fulfillment of the Requirements
for the Doctor of Philosophy in (Renewable Energy)
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has been approved by the Graduate School as partial fulfillment of the requirements for the Doctor of Philosophy in Renewable Energy of Naresuan University

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Keywords Demand Side Management, Demand Response, Load Aggregator, Smart Building, Building Energy Management System

ABSTRACT

This research focused on the development of demand-side management technology, which is an Automated Building Energy Management System with the Internet of Thing (IoT) so-called aBEMS-IoT for the reservation of the DR program to stabilize the power quality and stability of the grid network. The aBEMS-IoT components can be classified into three main parts; the first is controlling devices (Hardware), and the second is a data processing and monitoring system (Software), and the third is the communication system. After the aBEMS-IoT was developed, it was implemented in the target building, such as the building of the Post Engineering office, to find out the technical capability. The two performance tests were performed, which consisted of the laboratory test and the actual building integrated with aBEMS-IoT test. Both of them were tested under the assumed DR program for maintaining the grid voltage and network stability. The results of this research can be classified into two parts; the first part shows the capability of the aBEMS-IoT, and the second part is the impact of demand response using the aBEMS-IoT for flattening the duck curve. The analyzed results of the first part indicated that the aBEMS-IoT could effectively manage the load following the assumed DR program. The response time from the control to the end devices until the process finish, it took about 650 ms and the load power which was

controlled by the aBEMS-IoT in case of the actual system, it was able to connect (load building) and to disconnect (Load clipping) following the assumed DR program. The aBEMS-IoT is the technology for balancing supply and demand by managing the demand side, and it will be the solution for Smart Grid or Microgrid, which will take the grid stability, power quality, resiliency, and reliability. The second part is the load flow dynamic simulation of the demand side management by using the aBEMS-IoT under the assumed Demand Response program for stabilizing power quality and flattening the duck curve. The result of the research indicated that the aBEMS-IoT was able to operate following the control signal of load aggregator for maintaining the power quality and flattening the duck curve. During the daytime, when overvoltage occurred, the controllable load was building to increase power demand for stabilizing the grid voltage as controlled by load aggregator. On the other hand, in the evening time, the peak load was clipped by the aBEMS-IoT for decreasing the load demand. Finally, the demand-side technology, such as aBEMS-IoT is able to maintain the power quality in the acceptable range and also to flatten the duck curve. Demand response and demand-side management technology will be key parameters for the reliability and stability of the grid network.

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Contribution and support from many people helped me in the completion of this research. I would like to take this opportunity to express my appreciation to them.

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Secondly, I am grateful to the School of Renewable Energy and Smart Grid Technology (SGtech), Naresuan University, for the data, hardware, and software, which was used in this research. My appreciation is due to SERT staff for their helping hands and spiritual support throughout my study.

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ABBREVIATIONS

aBEMS-IoT	is an automated building energy management system with the internet of thing
PMS	is the Power Management System
PL-PMS	is Power load is managed by the power management system
PL	is Electrical load power
PL-aBEMS	is Load power which is managed by aBEMS
PV	is Photovoltaic Voltaic
Ppv	is PV power Production
PL-bus1	is Load Power at the study busbar 1
PL-bus2	is Load Power at the study busbar 2
PL- bus 3	is Load power at the study busbar 3
PL-bus4	is Load power at the study busbar 4
PL-bus5	is Load power at the study busbar 5
PL-bus6	is Load power at the study busbar 6
PL-bus7	is Load power at the study busbar 7
Total-Load	is The total load power
Bus1.-no DR	is The grid voltage profile at the study busbar 1 in the case of no demand response
Bus2.-no DR	is The grid voltage profile at the study busbar 2 in the case of no demand response
Bus3.-no DR	is The grid voltage profile at the study busbar 3 in the case of no demand response
Bus4.-no DR	is The grid voltage profile at the study busbar 4 in the case of no demand response
Bus5.-no DR	is The grid voltage profile at the study busbar 5 in the case of no demand response
Bus6.-no DR	is The grid voltage profile at the study busbar 6 in the case of no demand response

Bus7.-no DR is The grid voltage profile at the study busbar 7 in the case of no demand response

Bus 1-DR is The grid voltage profile at the study busbar 1 with demand response

Bus 2-DR is The grid voltage profile at the study busbar 2 with demand response

Bus 3-DR is The grid voltage profile at the study busbar 3 with demand response

Bus 4-DR is The grid voltage profile at the study busbar 4 with demand response

Bus 5-DR is The grid voltage profile at the study busbar 5 with demand response

Bus 6-DR is The grid voltage profile at the study busbar 6 with demand response

Bus 7-DR is The grid voltage profile at the study busbar 7 with demand response

DR power is Demand response power

PL without DR is Load power without the demand response

PL with DR is Load power with the demand response

CHAPTER I

INTRODUCTION

Statement of the problem

This period requires the traditional generation to ramp up quickly to cover the demand. When the load pattern is quickly changed, some of the traditional generations cannot respond, it may affect power quality and stability of the grid. Not only in the evening time but also in the daytime when the PV system is high power production, this case may affect the power quality of the grid network. The duck curve is shown inFigure 1 (1).

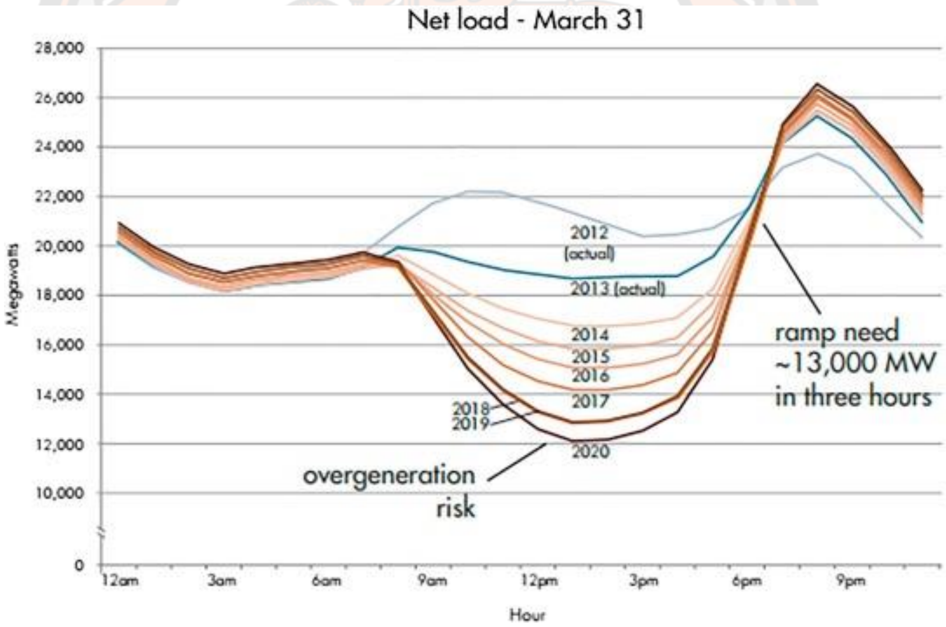

Figure 1 The Duck curve

The duck curve problem occurs in the countries that generate much electricity from solar energy because solar power plants can produce electricity only in the daytime when having solar irradiation. According to the problem mentioned above, many countries find the solution to flatten the Duck Cure by making the grid more advance called Smart Grid and Microgrid. The advance gird can balance the supply and demand for system stability. Demand Response (DR) is significant for the future grid, also known as demand-side management. DR refers to a change in load usage by the user from their normal load consumption pattern in response to changes in incentive payments, the price of electricity or available power quality in the network (2-6).

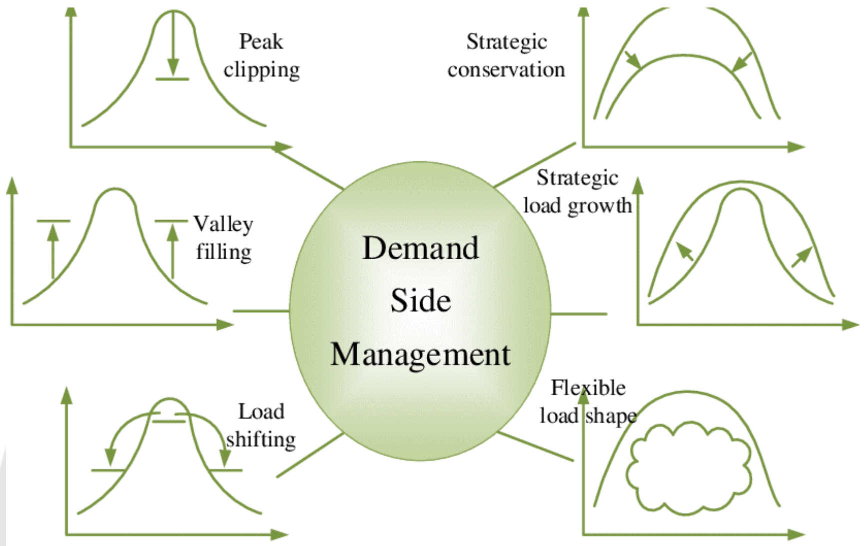

Figure 2 Demand-side management techniques

The main DSM techniques are valley filling, load shifting, peak clipping, load building, and load conservation as shown in Figure 2. The objective of DR can be classified into two groups; the first is for maintaining the power quality in the network and the second is for the economy of operation. The programs of DR depend on the number of customers, load types such as residential, commercial, and industrial. The benefits from the DR program also depend on the level of customer's reaction or satisfaction with the applied program, etc. However, benefits from applying are on both sides of customers and utility. Many utilities apply DR programs for controlling the power quality, stability and reliability of the grid instead of build fossil power plants. Price-based programs are a set of tools used intentionally modify electricity prices in response to various situations such as time of use pricing (TOU), critical peak pricing (CPP), and dynamic real-time pricing (RTP), and day-ahead pricing (DAP) (7-9). When the price of electricity is high, these price-based programs can be used to encourage the end-user to reduce their electricity consumption. Incentive-based programs are another type of tool within the DR concept, which allows utility administrators to switch the noncritical load on and off when demand is too high and could compromise system power quality and system reliability. For supporting the DR programs, the buildings are upgraded to smart building these buildings can be managed the load by internet known as the Internet of Thing (IoT). Also, Big Data analysis can help to manage the load demand better in all sectors (10, 11).

This research focused on the development of the automated building energy management system using IoT called aBEMS-IoT. The aBEMS-IoT consists of three parts as follows. The first is controlling devices which enable to control the load On/Off, increase/decrease the power consumption of the load. The second is a data processing system which is analyzing the data from both sides load aggregator and customers, then after data analysis sends the signal to the control devices for the future process. The third is the monitoring system, which is the summary results of the process for the aggregator and customers. This study will concentrate on the benefits of demand response programs for both side utility and customers. For the utility, will concentrate on the power quality in the distribution system, and the customer will focus on the economic or money-saving follow the DR Programs. The actual BEMS-IoT which is implemented in the commercial building, will be analyzed, and also the impact of DR on power quality in the network will be simulated by Digsilent power Factory Software or other suitable software. The results of this research will be a guide of the utility applying for the DR program and also supporting the coming Smart Grid in the near future.

Purpose of this study

1. To develop an automated building energy management system using IoT (aBEMS-IoT) for the smart buildings.

2. To test the technical capability of the aBEMS-IoT in the laboratory and investigates the technical performance of an actual aBEMS-IoT in the implemented building under the assumption of demand response program.

3. To study the impacts of applying an aBEMS-IoT in the distribution system under the assumption of a demand response program.

Research concept

The increase of energy demand, the high share of RE generations, affects the power quality, stability, and reliability of the distribution and transmission grid. Fluctuated power production from the RE systems has reshaped the daily load profile of electricity by creating the duck curve. This curve creates a negative impact on the distribution network such as power quality and maybe a blackout in case of immediate change of load power or a high amount of power flow from the RE system. Demand Response (DR) is known as load management for the reduction of demand during a weak period keeping the distribution capacity constraint and avoid a capacity shortage. The demand response potential for a commercial building is high because big building consumes much electricity, from the literature review, the smart building used energy management system can reduce peak load by 10 -15 %. This research focuses on the development of automated building energy management by using IoT (aBEMS-IoT). The aBEMS-IoT will consist of the three parts as follow.

1. Controlling devices (hardware) which enable to control the load On/Off, increase/decrease the power consumption of the load. The loads in this research are air-conditioners, lightings, and plug for electricity appliances

2. Data processing (Firmware), which is analyzing the data from both sides load aggregator and customers, then after data analysis sends the signal to the control devices for the future process.

3. A monitoring system which is the summary results of the process for the aggregator and customers.

After aBEMS-IoT is developed, it will be implemented in the commercial building; this building is upgraded to a smart building. This study will concentrate on the benefits of demand response programs for both side utility and customers. For the utility, will concentrate on the power quality in the distribution system, and the customer will focus on the economic or money-saving follow the DR Programs. The actual aBEMS-IoT, which is implemented in the commercial building, will be analyzed, and also the impact of DR on power quality in the network will be simulated by Digsilent power Factory Software or other suitable software.

Limitations of the study

This research developed the automated building energy management system for a building that can operate under an assumed DR program for maintaining the grid network into the acceptable range. The grid voltage in the 22 kV distribution system is simulated by Digsilent Power Factory software (license of Naresuan University).

Scope of this study

This research focused on the development of the automated building energy management system with IoT (aBEMS-IoT). The aBEMS-IoT consists of two parts as follows. The first is controlling devices (hardware), which enable control of the load On/Off, increase/decrease the power consumption of the demand. The loads which are controlled by an aBEMS-IoT consisting of the air conditioner, lighting, and plug for electric appliances. The second is a data processing and monitoring (Firmware), which is analyzing the data from both sides aggregators and customers. The monitoring system is the summary results of the process for the aggregator and customers. After aBEMS-IoT is developed, it was tested for a capability test in the laboratory. Not only test in the laboratory but also test in the actual implementation, the aBEMS-IoT was implemented in a big factory for managing the load demand. All functions of aBEMS was tested in this factory. Moreover, it was studied on the impact of the aBEMS-IoT under the assumption of the DR program. The benefits of implementing the aBEMS-IoT under the assumption DR program was investigated for both utility and customers. The benefit of the utility was indicated by maintaining grid voltage into the desired range and flattening the duck curve, and the benefit of customers will concentrate on the economic operation under the assumed DR Program.

Keywords

Demand Side Management, Demand Response, Load Aggregator, Smart Building, Building Energy Management System.

Benefits of the study

1. The automated building energy management with IoT (aBEMS-IoT) was developed for managing the load demand in the building.

2. The results of this research gave much knowledge of building energy management under the DR Program.

3. Hardware and software are suitable for automated demand response for supporting the DR Programs.

4. The results of this research gave the solution to flatten the Duck Curve.

5. The result of this research provided the solution for improving the power quality, stability, and reliability of the distribution system in case of load-side management.

6. The results of research gave the solution for mitigating the negative impacts of the decentralized RE systems, which are growing rapidly.

7. The results of the study can serve as a guide for the Smart Grid development of the national grid (PEA, MEA) to be applied in pilot projects and planning for the national grid in the near future.

CHAPTER II

LITERATURE REVIEW

Literature reviews

Jin M et al. (1) studied the Microgrid optimal dispatch with demand response. In the face of extraordinary challenges of upcoming fossil fuel limitation and security and reliability of the distribution network, there is a growing interest in adopting distributed systems, renewable energy, energy resources, such as Microgrids (MGs), and appealing flexible electric load demand in system operations to potentially motivation a model move in energy production and demand load patterns. Prior study on MGs dispatching has researched on decentralized technologies such as combined heat and power (CHP) and heat pumps to encourage energy efficiency and economic benefits; however, the flexibility of power demand has many benefits for the balancing of demand and supply. The research aims to develop the Microgrid operation with the demand side management, optimal operation with demand response (MOD-DR), which plugs in the coordinating of both the demand and supply sides in the integration of the distributed energy resources such as RE system, storage, DR and MG to achieve the economic benefits and resilient solutions. The main contribution of this study is that the formulation, a multi-objective optimization with usual restraints, and utility trade-off based on the model of the large-scale Microgrid with the flexible loads' pattern, which leads to the origin of strategies for incorporating of uncertainty in scheduling pattern. Evaluation using real datasets is analyzed the uncertainty effects and demand response potentials, demonstrating in the prototype a 17.5% peak load clipping and 8.8% cost savings for MOD-DR or DR compared to baseline, which is on par with the Oracle for perfect predictions. As for DR that pursues changes in consumption patterns through incentive payments or the price of electricity, there are several solution groupings, which focus on direct load control, price elasticity, utility maximization, and integrated operational models. De Jonghe et al. researched an elasticity-based operational and investment model to determine the optimal generation mix; however, their model is based on LP and has not included technologies like CHP, energy storage, or renewables systems. MILP is employed to obtain optimized device operational periods and power consumption levels in response to dynamic pricing information to balance user utility and energy costs.

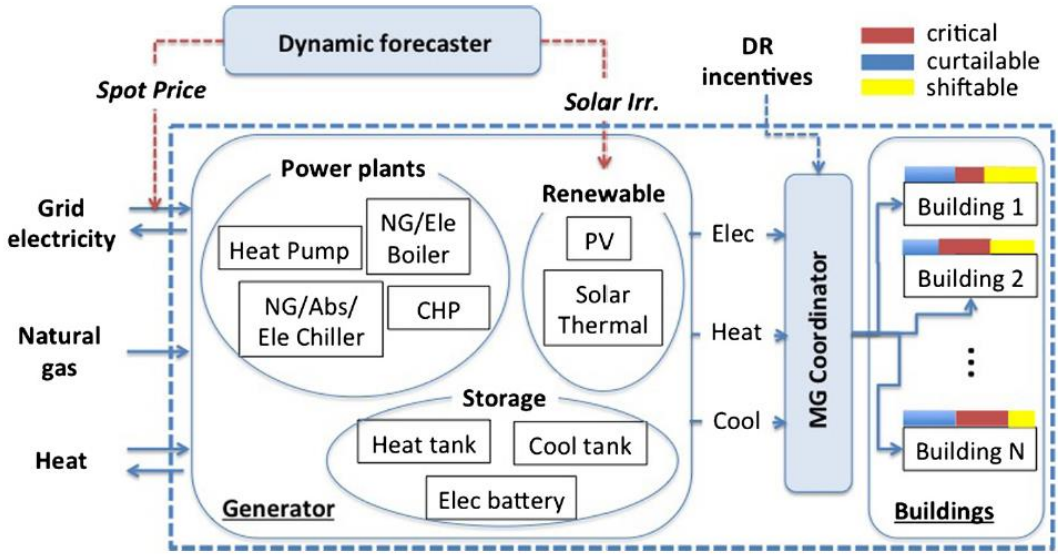

Figure 3 The Dynamic forecaster for the group of smart building

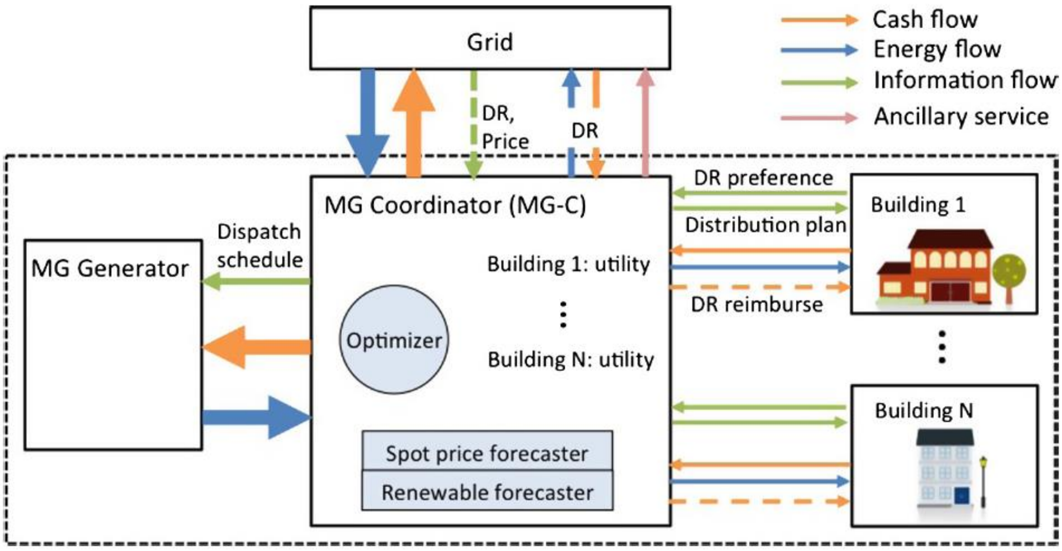

Figure 4 The flow of cash, energy, ancillary and information

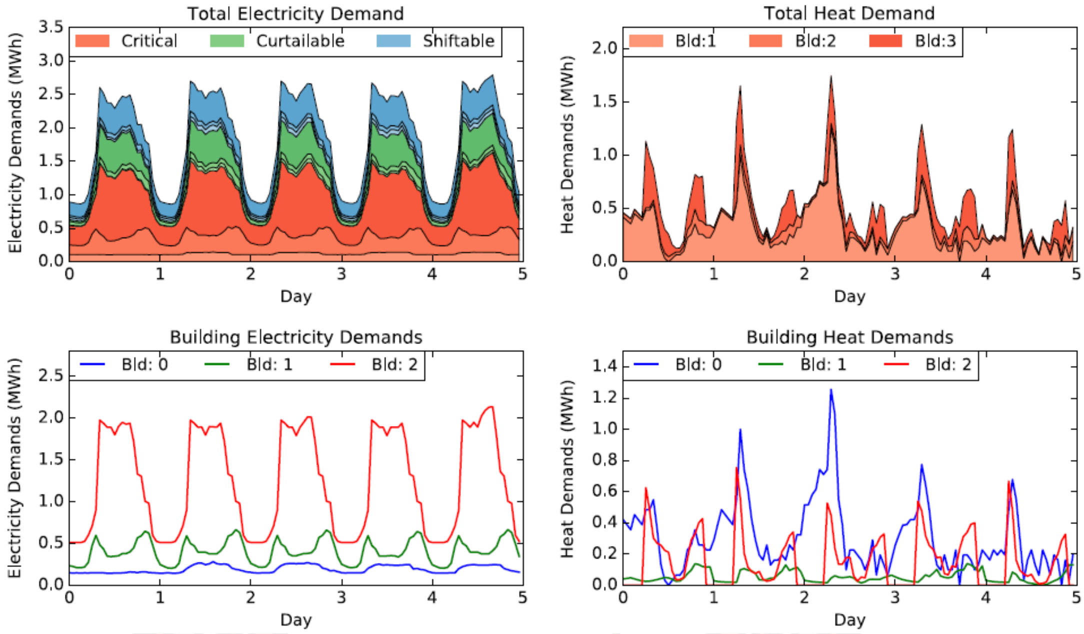

Figure 5 Electricity load Profile

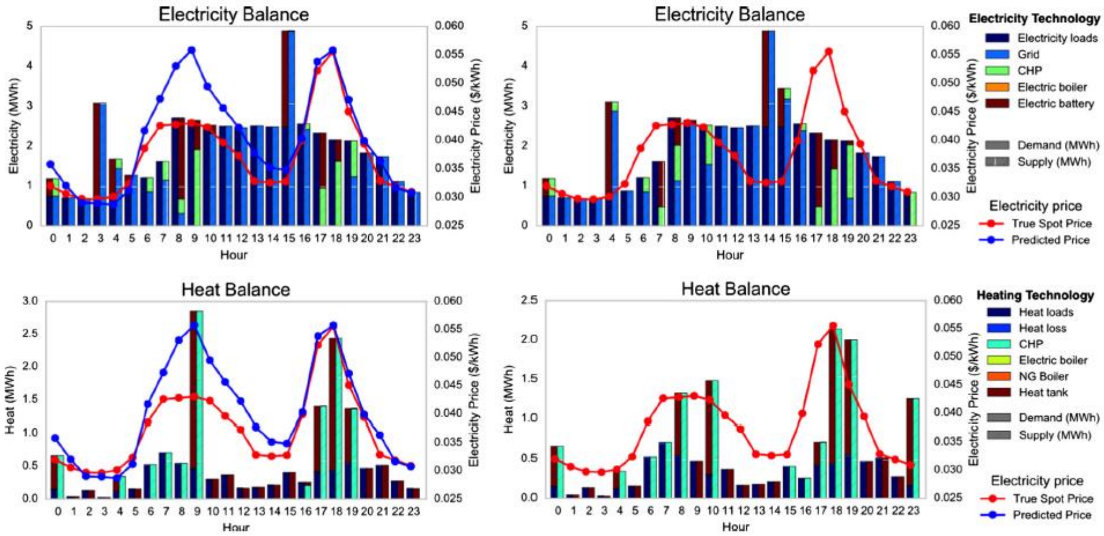

Figure 6 Electricity and heat balances for day-ahead dispatch based on CLS forecasts

The MOD-DR proposed in the study engages consumers, distributed generators, and the grid in a multi-objective trade-off to derive mutual benefits, and facilitates future work on the economic analysis of real-time pricing mechanism, DR contracts, and MG valuations. While previous work on storage capacity planning often assumes deterministic renewables and electricity price for simplicity, the study indicates that uncertainty plays a critical role in determining the operational savings. The diminishing return effect as the capacity scales up is particularly marked under real-time pricing schemes, where the price exhibits fluctuations. Day-ahead dispatch, based on the expectancy of the electricity tariff and availability of renewables, can exploit the spark spread and the time-shifting capability of storage, thus achieving more efficient operations. The adaptive strategy, additionally, can lower the cost further by making adjustments to account for current and past information, which reduces the need for PV firming and makes the MG responsive to DR called on short notice; nevertheless, the implementation relies on robust communication and control infrastructure, which might not be readily available for some users. From the results of the optimal dispatch plans, CHPs are operated more often as the spark spread increases. On the other hand, an electric battery is charged at night when the electricity price is low, and discharged later in the day to satisfy demands, as long as the price prediction captures the peak and valley hours. Renewables can also be harvested with accurate forecasting to complement grid imports, which is conducive to lowering both the electricity bill and carbon dioxide emissions. By inspection of the utility-cost trade-off curves, as the loss of satisfaction increases, there is initially a substantial drop in the operational cost, which then diminishes as we enter into the deep DR region. The transition can be often exploited by initiating the right amount of DR on a district level to achieve considerable savings while maintaining relatively low levels of dissatisfaction.

Rotger-Griful S et al. (2), they studied on the topic of “Implementation of a building energy management system for residential demand response”. Demand response (DR) is a solution to maintain the power quality in case of the fluctuations in the power generation by RE systems in a scenario of higher renewable energy system penetration. Though, DR already gives a solution for creating the new business cases, this still absences maturity in other zones, especially in the residential areas. This research studied a novel building energy management (BEMS) to reinforce the approval of residential demand response by controlling the loads. The aim of a consumer-centric BEM monitoring system to interact with the customer residents for optimization to control the distributed energy resources (DERs) and also provides DR to an aggregator. The BEMS is considered with a multimodal objective: exploit flexible consumption through demand response and run the building for the energy-efficient purpose. The system architecture, hardware, and software are designed in detail. A prototype of the BEMS has been developed and implemented in 12- residential households. The technical performance, the scalability, the data monitoring capabilities, and the interaction with the residents and controllability of DERs of the BEMS are studied and demonstrated. Moreover, this research presents the estimated total flexibility and capability of the potential testbed. The system presented is a multi-modal, centralized BEMS for residential demand response provision. A centralized architecture for a BEMS as the one proposed in this article is widely used in the literature The BEMS acts as a bridge between the electrical utility and the consumer, thus requiring consideration of the needs of both. The term multi-modal stands for the dual goal of the system: demand response provisioning and local energy-efficient control. The high-level requirements of the BEMS are:

1. Monitoring energy usage and relevant external information of the building (e.g., weather forecast)

2. Controlling DERs within the building in an optimal manner (energy efficiency)

3. Enabling demand response provision and load aggregation to a third party (aggregator)

4. Empowering consumers by provided that them with information and energy-related recommendation

This section details the design and implementation of the BEMS taking into consideration the feasibility studies of the previous section. The BEMS in the context of its data sources and other connections is shown in Figure. 7. This figure is described below. Wireless sensors transmit to their gateways using the wireless ZigBee protocol. The gateways are connected to the Smart AMM server via Ethernet and communicate using the proprietary Smart AMM.

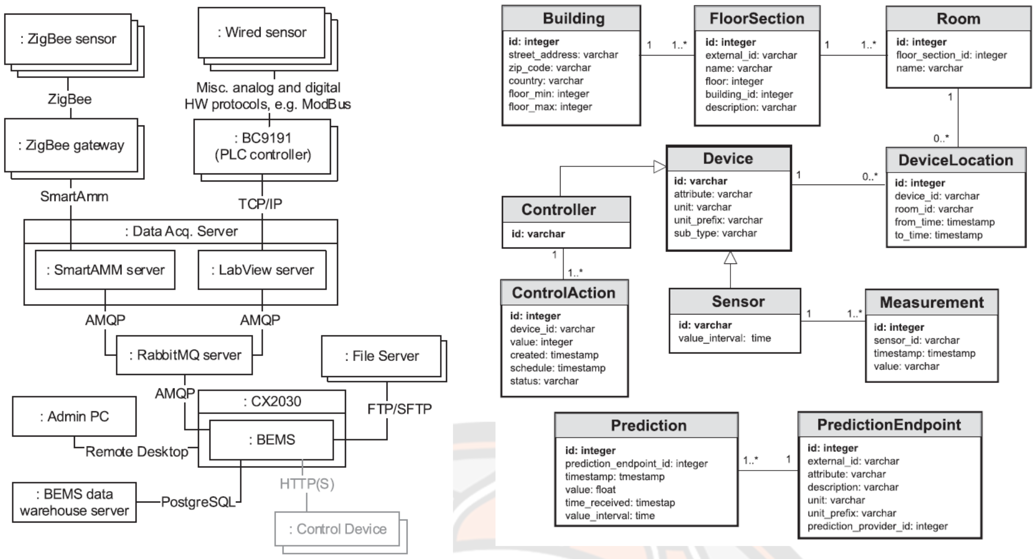

Figure 7 UML component & connector view of the BEMS with data sources

The Grundfos Dormitory Lab is a highly energy-efficient building equipped with the state of the art pumping solutions, lighting, ventilation systems, etc. High efficient buildings generally present lower electricity consumption than other facilities thus limiting the demand response potential. With the multi-modal functionality in mind (i.e., energy efficiency and demand response provision), the demand response potential of several different electricity loads in the building has been evaluated in field trials and simulations.

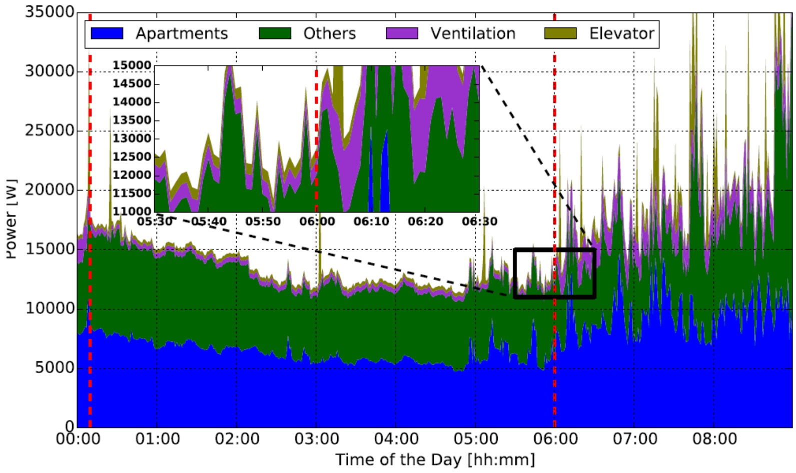

Figure 8 Average instantaneous power break-down of the building

Shifting potential based on experiences from our field trial experiments. It is seen that sources, which can be automated (direct control), such as the ventilation system, have a high shifting potential (44%) whereas sources that require residents to make decisions on shifting consumption (indirect control), for instance, laundry and elevator usage, have a relatively low shifting potential (8% and 2% respectively). The ventilation system of the testbed is one of the loads that presents a more appealing demand response potential. The performance of this system can be remotely controlled and provides a 1.5 kW for down-regulation and a 4.5 kW for up-regulation in a relatively short time. Furthermore, this system is capable of following a one-minute different power profile. All this can be done without affecting the comfort of the residents significantly. The potential of one system alone is not significant but by pooling a portfolio of several systems, it can be of high interest for the electrical grid. However, a demand response action from the ventilation system can be rather fast (on the second-time scale). The DR potential of the elevator in the testbed has also been assessed. Although this electrical load accounts for 4–5% of the total electricity consumption, it was observed that it is hard to provide demand response through the elevator. The Green Lift intervention showed that it is possible to trigger a temporary behavioral change on the way people use the elevator but that translating this to load shift can be complicated.

Gong C, et al. (3), they studied on the topic of “Distributed real-time DR for energy management scheduling in the smart grid”. The Demand Response (DR) is a hopeful technology to manage with the ever-increasing peak demand in the grid network. The energy management of a smart home may select to charge electricity into the battery when the electricity price is low in off-peak time on the other hand, discharge electricity from the battery to supply the home load demand when the electricity price is high in peak time. The circumstance of this research is that the temporally and spatially joined in the energy consumption, battery charging and discharging electrical energy. The constraints give the DR problems more challenging than the standing ones, and thus the standing distributed algorithms cannot be engaged to find the proper solution to the issues. In this research, we focus on the real-time two-way communications between the utility and multiple residential users or load aggregators, and each user is used as a smart home energy management system. A real-time algorithm is proposed to find the proper energy management scheduling patterns for each user and utility company to maximize social welfare. To overcome the problem transported by the temporally and spatially coupled constraints, dual decomposition technique is engaged and the primal problem is decoupled into several independent subproblems that can be resolved in a distributed method by each user and utility without revealing or switching their private data. Simulation results presented to demonstrate that the proposed distributed algorithm can bring potential benefits to society.

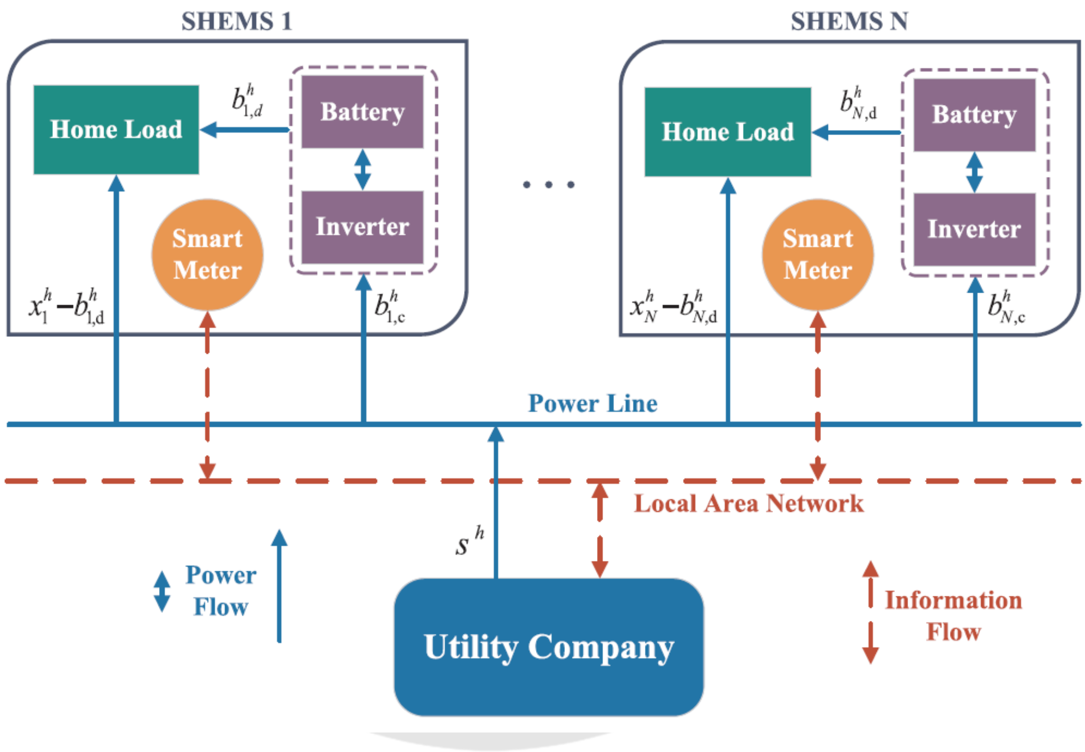

Figure 9 Block diagram of the system model composed of a utility company

In this paper, the real-time two-way communications between the utility company and multiple users are investigated. It transmits bidirectional information, which contains the total energy demand of each user and the electricity price. The energy supply, energy demand, and battery energy constraints are all taken into consideration, which makes the demand response problem a temporally-spatially coupled optimization problem. A distributed real-time algorithm is aimed to find the optimum energy management-scheduling scheme for each user and utility company to maximize social welfare. To overwhelmed the obstacle brought by the temporally and spatially coupled constraints, the double decomposition technique is engaged. The original problem is decoupled into several independent subproblems, which can be resolved in a distributed technique by each user and utility company. At each time slot to locally determine the optimal energy demand, battery charging and discharging energy, and energy supply without revealing or switching their private data, separately. The simulation results determine that the well-distributed algorithm can carry potential benefits to society or customers. In the future, the renewable energy resources for residential users and the distributed algorithm with better performance will be considered in demand response problems.

Golmohamadi H et al. (4), studied A multi-agent-based optimization of residential and industrial demand response aggregators. Nowadays, the distribution network aims to the high penetration of renewable systems. Instability and intermittency of renewable systems require to be compensated through alternative forms of flexibility. This proposes of this research is a novel agent-based structure to integrate the flexibility potential of industrial and residential consumption. In this methodology, a central demand response provider (DRP) is recommended to coordinate the responsive plans of industrial and residential DR aggregators (IDRA, RDRA). The proposed IDRA integrates the flexibility potential of whole production lines for two energy-intensive heavy industries, i.e. cement manufacture and metal smelting. Besides, the RDRA uses the thermal and electrical storage capabilities of thermostatically-controlled appliances (TCAs) and energy storage systems connected with the roof-top PV system through home energy management systems. The integrated flexibility is operated in the electricity market to maximize the income of the market members in a competitive environment, instead of subsidizing responsive consumers by supportive regulations.

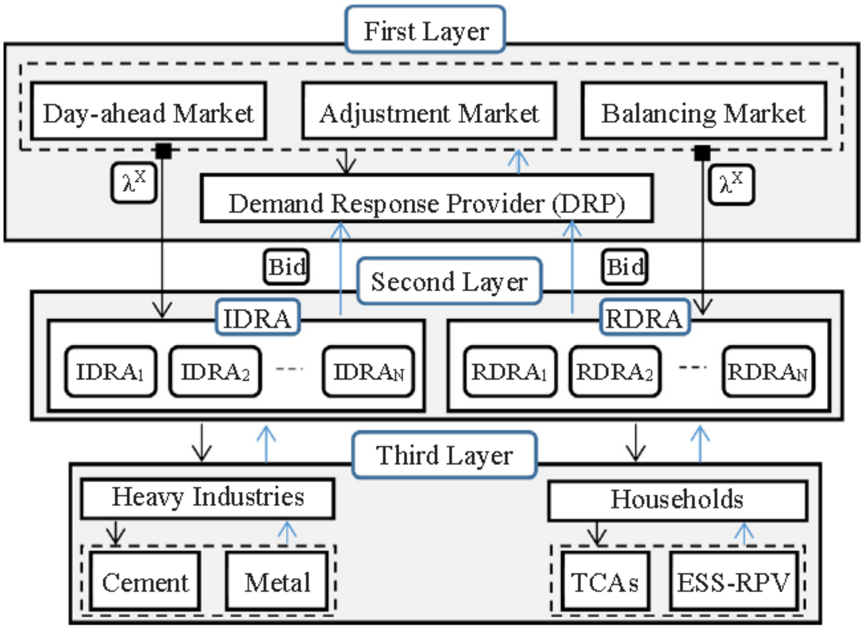

Figure 10 The framework of the multi-agent system.

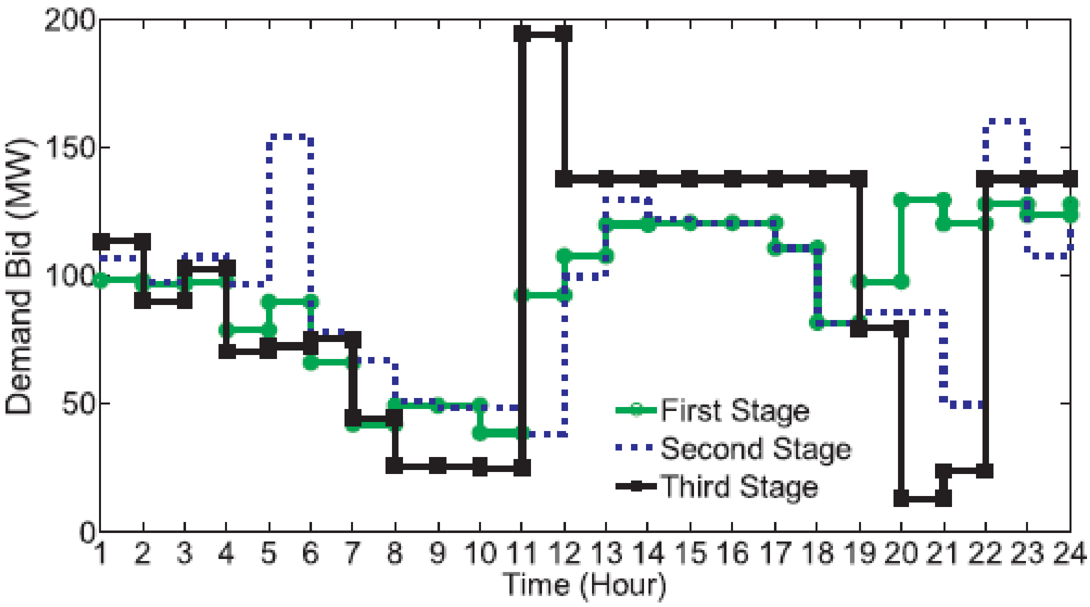

Figure 11 Integrated values of DR traded in three trading floors of the electricity market

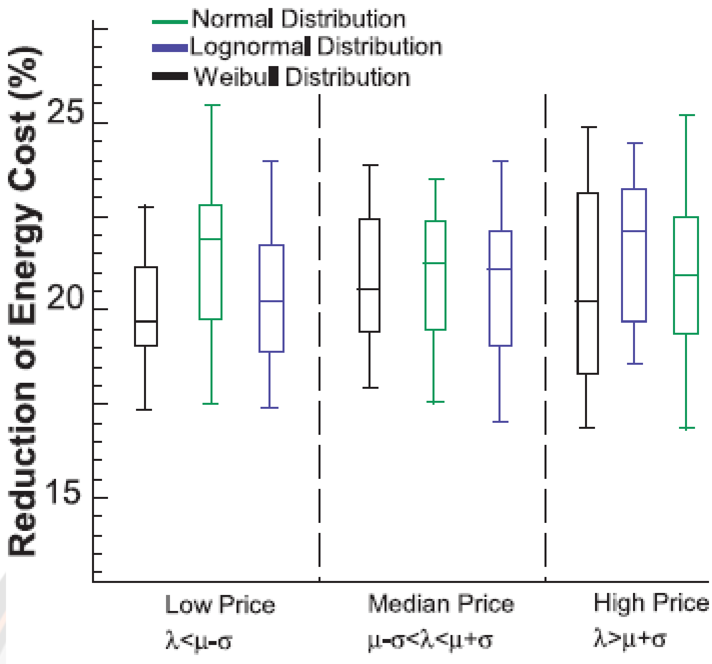

Figure 12 Sensitivity of energy cost reduction concerning price PDFs

This research recommended a novel market-based approach to integrate the flexibility potential of different responsive consumers (DR), residential and industrial sectors, into a power system distribution with high penetration of intermittent power or buffer between the supply and demand. The ultimate purpose was to offer up/down-regulation for the grid when a shortfall or additional energy generation. To achieve this purpose, the complex problem was divided into a multi-agent structure. Therefore, three kinds of agents, including RDRA, DRP, and IDRA, were addressed. The IDRA evaluates the flexibility potential among the whole production lines of two energy-intensive industries, cement factories, and metal smelting power plants. Moreover, the RDRA integrates the demand response opportunities of the electrical appliances in the household, such as lighting, electric water heaters, TV, refrigerator, and heat pumps. Furthermore, the capacity of ESS-RPV is used to deliver down-regulation to the grid network on short notice. In order to ensure the power system flexibility, the time-oriented demand response program was projected to optimize the total cost of energy, and regulation by allowing the DRP to trade DR opportunities in three successive floors of the electricity market, day-ahead, adjustment and balancing markets. In this method, the DRAs may perhaps trade demand response values in a competitive structure based on the demand bids, instead of subsidizing the demand-side flexibility. In the industrial sector, the key feature of the proposed framework was that the sub-processes with the aptitude to change load demand on long, mid, and short notices were determined. The results presented that the S-VS milling systems and variable voltage plotlines play a critical role in providing immediate regulation to the network. The simulation results presented that the suggestion could protect the future of the network against the increasing RE systems on one side and decrease the energy cost of customers on the other side. Though, the previous is more critical for the Nordic Electricity Market, which is an issue to considerable variation of the RE system. Therefore, it can be interpreted as a win-win game for all market participants.

Eissa MM. (5), studied on the topic of Developing an incentive demand response with a commercial energy management system (CEMS) based on diffusion model, smart meters, and new communication protocol. A primary concern of a utility is to balance power generation with power consumption. The mechanisms of traditional demand response provide commercial/industrial customers with the option to curtail or cut-off electric power from the grid during peak hours. Most customers are willing to participate in such programs, but there may be restrictions that can limit participation in these programs. The limitations of the demand response programs concern the customers' ability to curtail and manage loads. With various renewable resources now starting to become available, the customers can make efforts to help this balance by installing them at their premises. An incentive DR program with two tools is projected in this research to help the customers to participate in the program. The first is the usage of advanced metering infrastructure (AMI) with a two-way communication system that carries important implications for customer service, confidentiality, and consumer protection policies. The aim of the DR program with AMI is that, based on the real-time signals, it can be an effective technique for the utilities and to manage the peak power of the network by managing customer demand with renewable energy sources. Generally, the use of the DR program integrated with AMI meters will be supported by a flexible and reliable ECHONET Lite Specification (ELS) communication protocol. The other tool is that it would inspire consumers to participate and decrease their energy demand at peak times. ECHONET Lite, next-generation industrial and household level protocol system, is designed to integrate many devices and systems. The CEMS based on innovative smart metering and ECHONET Lite protocol can support in getting the balance between the demand and supply at the customers' buildings. CEMS can control the electrical appliances and RE system devices at the consumers' buildings with the foundation that the consumers control the load demand by themselves for balancing and reducing the energy costs. The development of an energy management system is based on a diffusion model for load power balancing. The automatic model of vaporous diffusion is implemented as power consumption for balancing the model between demand and supply. The model gives to get an automatic balancing between the load power and supply power at the customers' buildings. The projected DR with real-time pricing and hourly pricing, offers consumers to select and transparency and promotes energy efficiency. The provided scheme gives tools that can contribute to the customers' buildings to participate in DR programs.

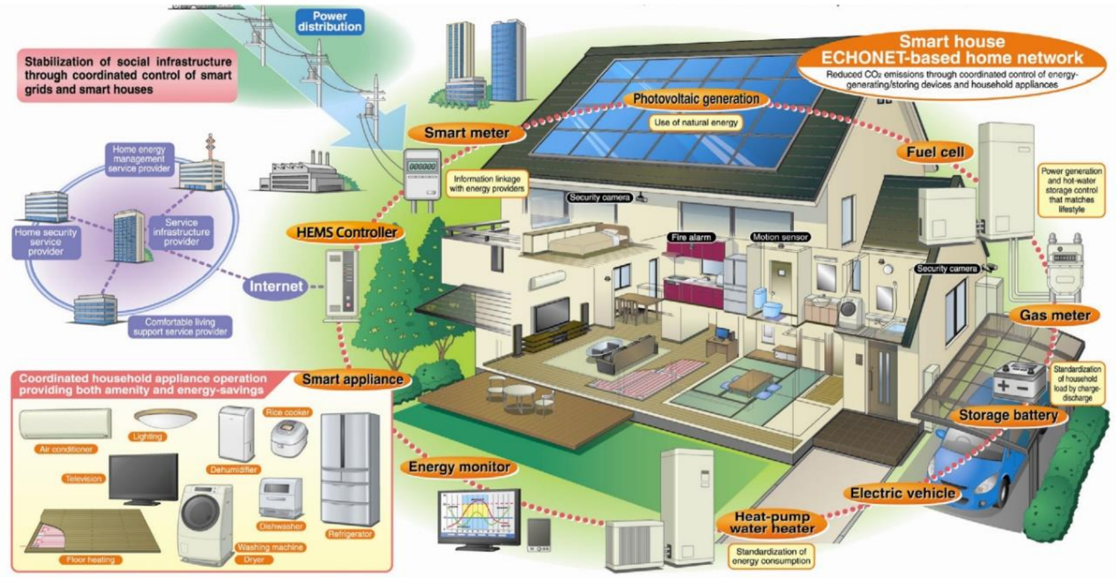

Figure 13 The future use of the ECHONET Lite in managing the appliances at Home

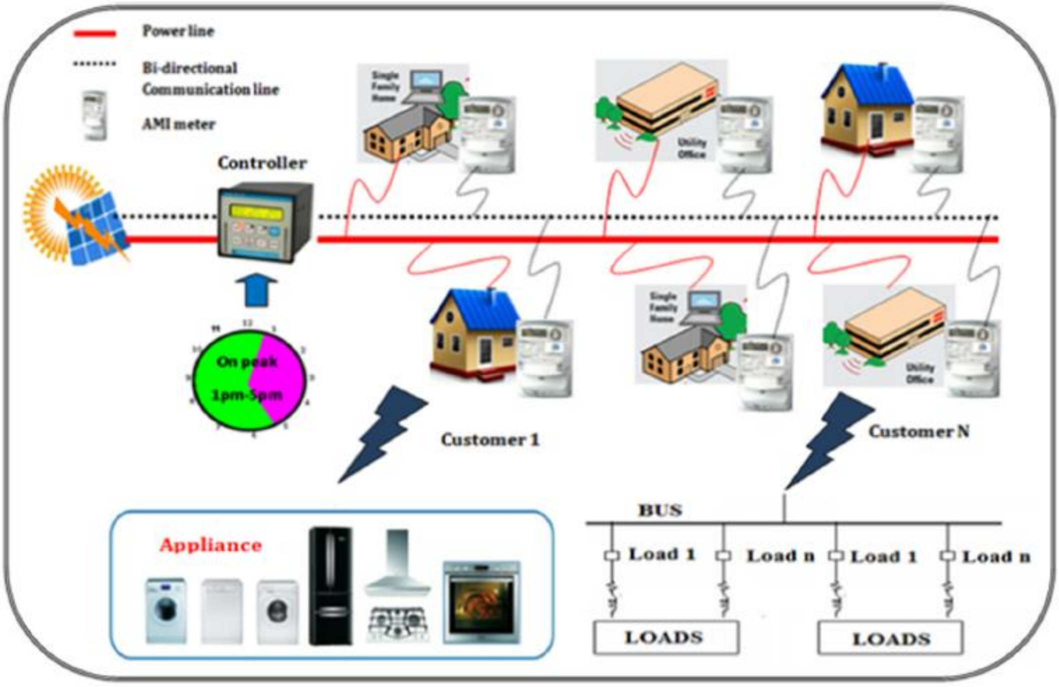

Figure 14 Local control via load redistribution.

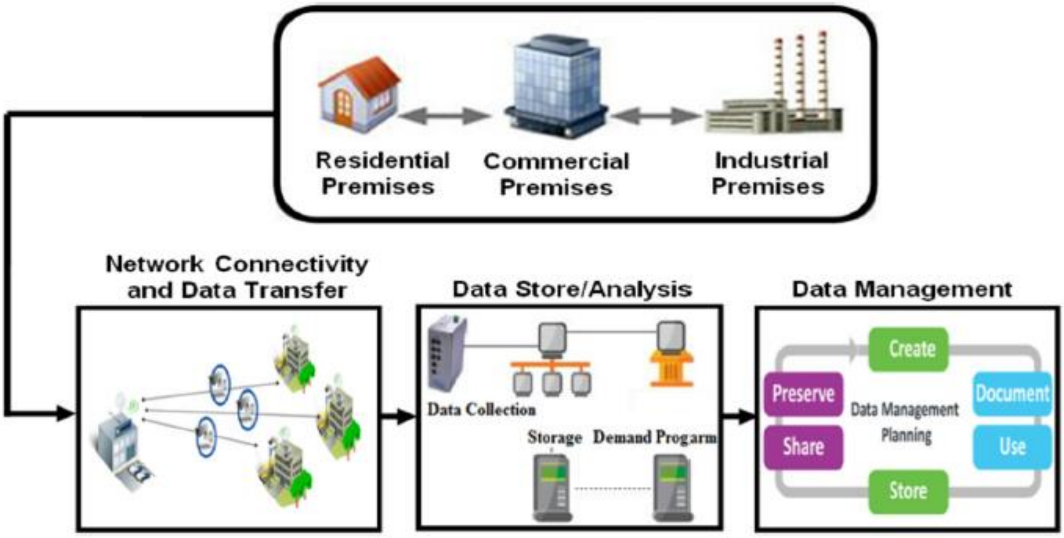

Figure 15 The smart meter data flow

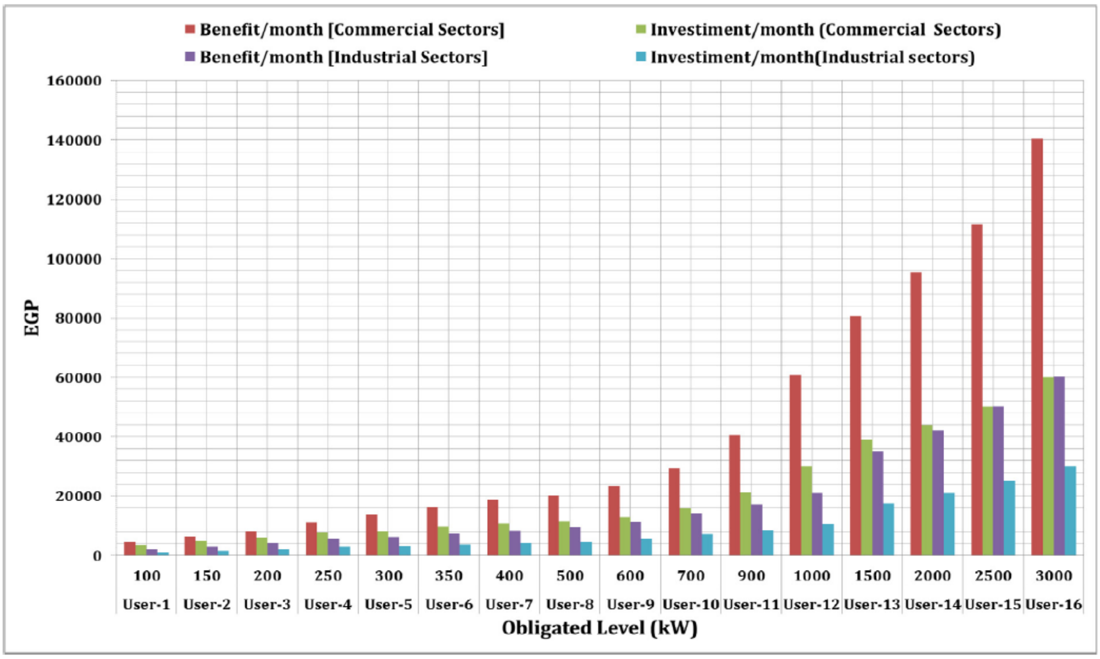

Figure 16 Investment and benefit from participation in the program for two sectors

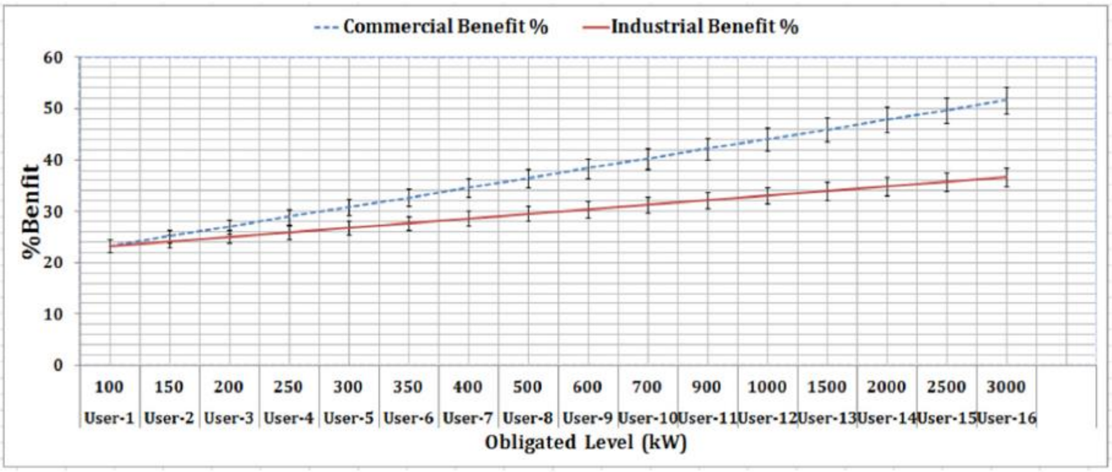

Figure 17 Percentage benefit for both sectors according to the kW obligated quantity in the program

Demand response program for the commercial energy management system (CEMS) that can manage and control the loads and sources at the consumer premises using robust ECHONET Lite protocol and diffusion model is described. At the customer's premises, there are many different loads and renewable resources that can be balanced using CEMS. This allows consumers to act as prosumers by automatically balancing the demand with resources. The paper provided new analytic methods such as the diffusion model for handling balancing in real-time between the loads and sources. New analytic estimation for the energy reduction payment, base power, obligated quantity for the customers who participate in the program is given in detail. The utility has a real-time updating pattern with the actual real-time load and generation at the consumers' premises. CEMS can also use the ECHONET Lite protocol for handling data in two ways; bi-directional information between smart meters and Utility and also between the appliances and resources at the customers' premises. The scenario of ECHONET Lite protocol between the CEMS and smart meters is also discussed. Based on the analysis and results, the paper provided many features for the utility and customers' premises. The program at the utility provided accurate estimation feedback for energy consumption. Also, at the utility side, there is an accurate estimation for the actual kW reduced from the customers. The financial payment is made during peak periods only and not outside the period like traditional demand-side programs. This can enhance the load factor of the grid at the utility side. ECHONET is a next-generation industrial and household level system designed to integrate many devices and systems. Now, there is the need to guarantee a stable supply of power by maintaining power supply and- demand balance between the distribution system and households/ industrial/commercial appliances and devices through customers' premises. CEMS with the unique feature of the communication protocol in managing the appliances/devices and resources at the customers'' premises, provides such features.

Mancarella P. (6), this paper proposes a two-stage development and design technique for the multi-energy system (MES), which contains multiple combined freezing, heating, and power (CCHP) systems connected by the district electrical grid network and district heating and cooling line. In the first objective, the optimum objective is to minimalize the yearly capital and operating costs of the CCHP systems, as well as to gain the optimal type and capacity of the equipment using the system parameters and load profile data. Then, a new modal energy pricing strategy is first planned and considered using the flow-tracing technique. The nodal energy price contains two parts: (i) creating nodal price and (ii) nodal transmission price. In the second stage, reliant on the electrical and heating/cooling pricing, a load aggregator (LA) is implemented to manage the electrical, heating, and cooling loads of the end-users using a combined DR (IDR) program. The aim of the LA is to minimize the annual consumption expenditure of the end-users and apprise the loads for the optimization in the first stage. Also, the IDR program contains electricity-load shifting and flexible electrical load, such as heating/cooling supply. Three cases are showed to establish the effectiveness of the planning and design technique and to present the influence of the nodal energy prices on the IDR program as well as the penetration of PV systems based on a reconstructive MES in China.

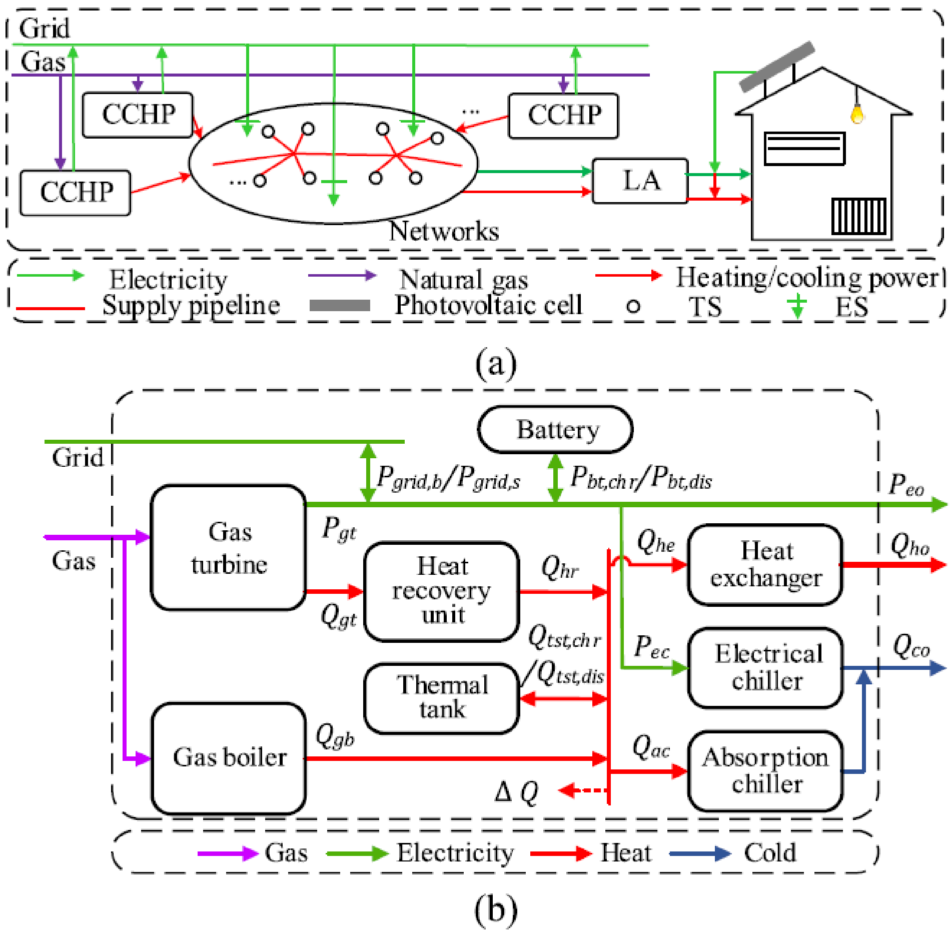

Figure 18 Structures of (a) MES and (b) CCHP systems

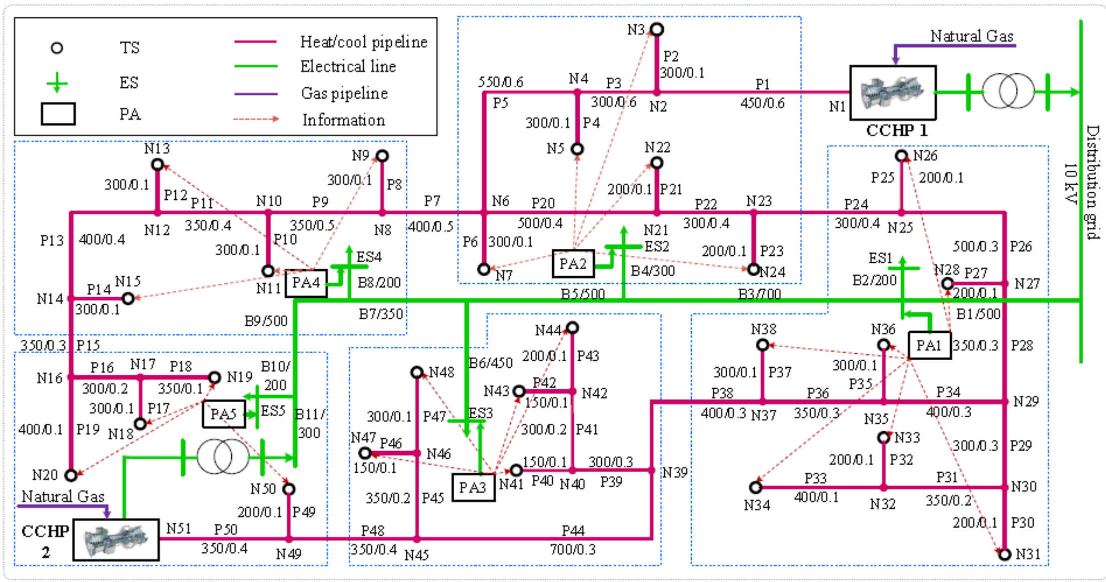

Figure 19 Structure of the MES with DEN and DHCN

Rozali NEM et al. (7), they studied the peak load clipping based on hybrid systems and demand response for industrial customers. The hybrid systems can obtain the energy from various sources such as electricity market, reciprocal agreements, small-scale turbines, wind generation, batteries, solar panel generation, and the demand response program (DeRP) participants. Due to volatilities in the electricity business, the total price of energy delivery for industrial customers cannot be strongminded. In this study, a new optimization method is developed for modeling the indecision of the pool harvest amount. Also, a new process technique of risk-averse proposed and compared with the risk-neutral technique is recommended. In this part, DeRP is used in order to decrease the total price of electric energy for business customers. To show the efficiency, fare comparison is showed between the deterministic approach and the suggested optimization model with and without considering the DeRP. Obtained results present that applying the DeRP, the energy delivery prices are reduced using risk-neutral and risk-averse methods, respectively.

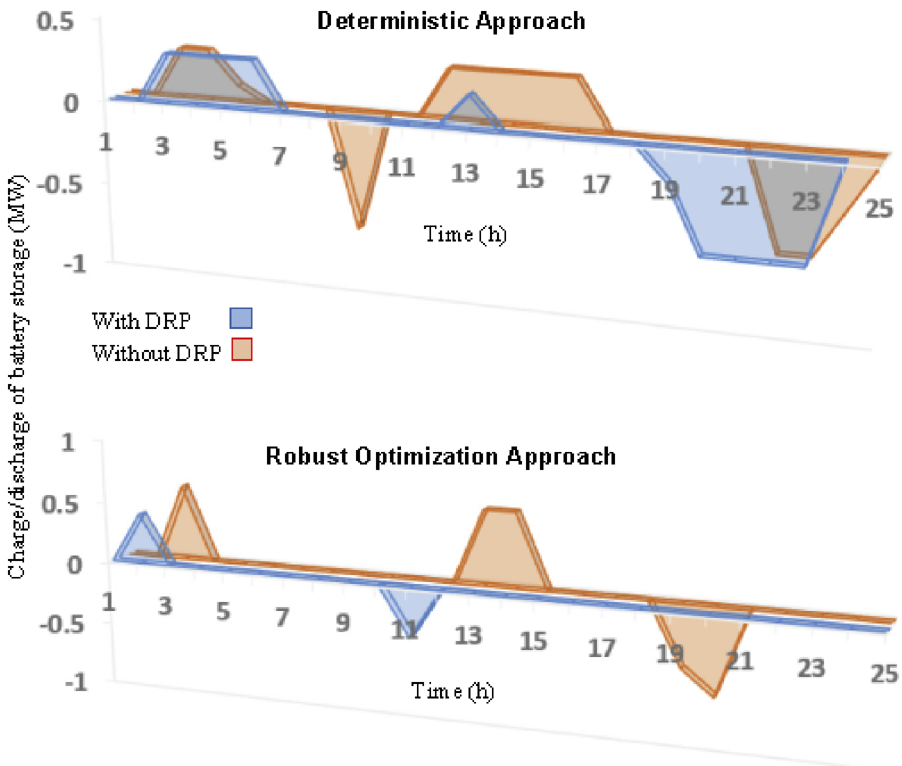

Figure 20 Charge and discharge of the energy storage

A solution for electricity provision problems met by industrial customers with including different energy provision methods such as wind generation, solar panels, batteries, internal generation, electricity market, and reciprocal agreements, is presented. Moreover, the powerful optimization method is suggested to represent price volatility in the electricity market to achieve a more powerful approach compared to the deterministic approach. Also, we utilized DeRP as a solution for decreasing expenses of industrial customers and investigated the effects on their expenses. The yielded outcome suggests that the impact of implementing DeRP on the industrial customers' expenses varies using the powerful optimization and deterministic methods. Hence, industrial customers' expenses are decreased by 8.2% and 6.5% because of utilizing DeRP. Also, with respect to the contrast made in risk-neutral and risk-averse approaches in presence and absence of DeRP, it is possible to observe that with a maximal increase of 10% in an electricity price market, the energy provision prices have risen by 5.8% and 7.7%, respectively that facilitate the steady performance by industrial customers when there is price volatility in the electricity market. Moreover, the outcomes suggest in the case of the volatile electricity market, and the customers will have less motivation to procure energy from the electricity market. Also, because of implementing DeRP and distributing the load to off-peak periods, the load profiles will be smoothened. Hence, the benefits of implementing DeRP are presented by the outcomes, and the desire of the industrial customers is investigated in the volatile electricity market.

Stoll B et al. (8), studied on the topic of the value of demand response in Florida. DR is a comprehensive descriptor for any electric utility or aggregator program that incentivizes or requires loads demand to decrease then modify their load profile in support of the grid network. These programs have been used for many years in the USA in the industrial cycles, where customers are contracted to reduce their load power during emergency periods when unbalancing of demand and supply. More recently, DR programs have been used to shift residential load and commercial power away from peak time. Several electrical load demand may be operated flexibly to deliver grid services such as peaking power, reserves, and load profile shifting. The authors model 14 demand profile of end uses in Florida and investigate their operational influences and overall value for a wide range of high PV penetrations and grid flexibility options for stability. They need DR is able to decrease production costs, decrease the number of low-load hours for customary generators, reduce the starting of gas generators, and reduce limitations.

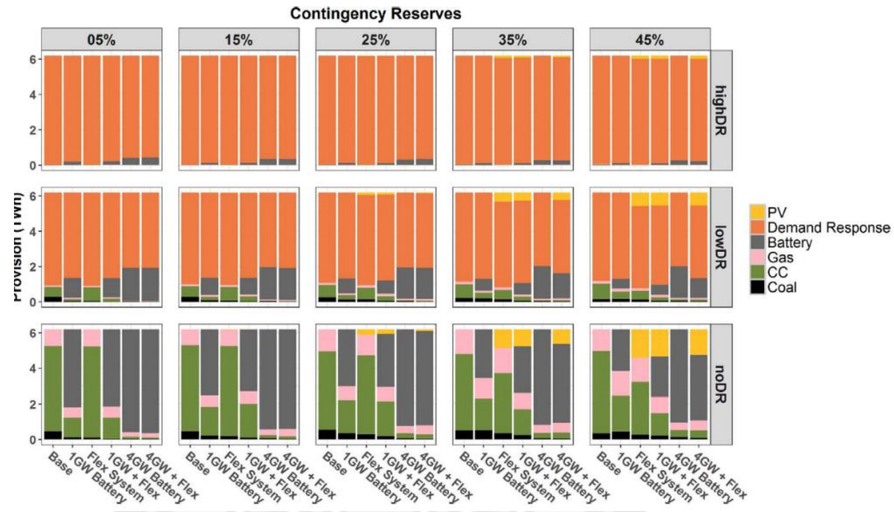

Figure 21 Contingency reserve provision by generator type for each PV penetration

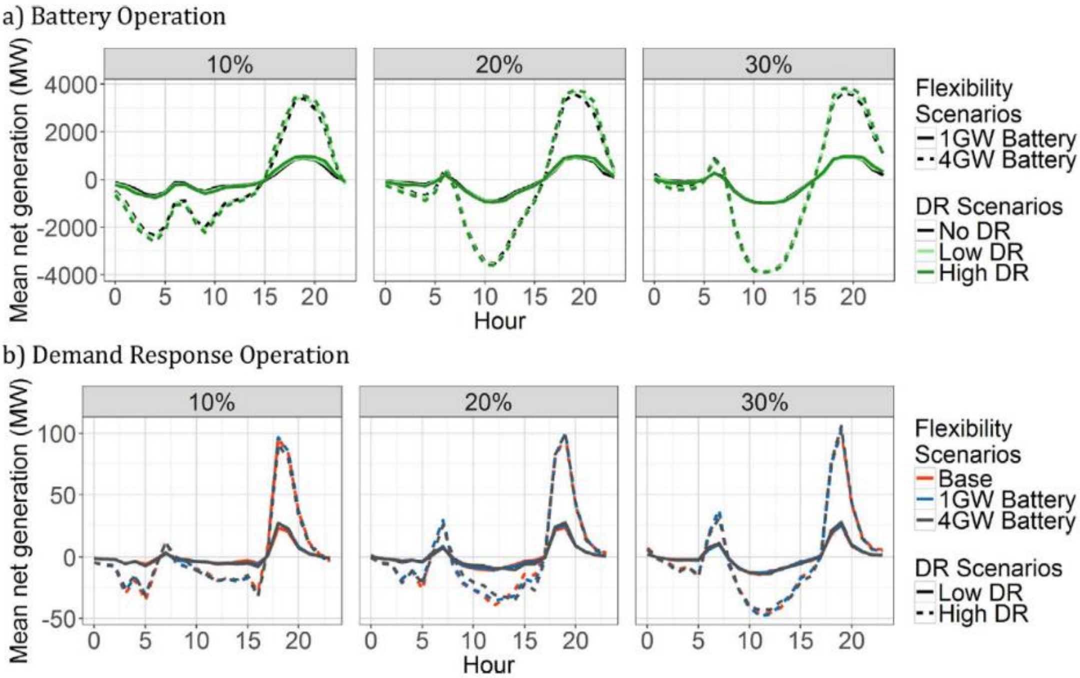

Figure 22 Battery (a) and Demand Response (b) operations on average for each hour

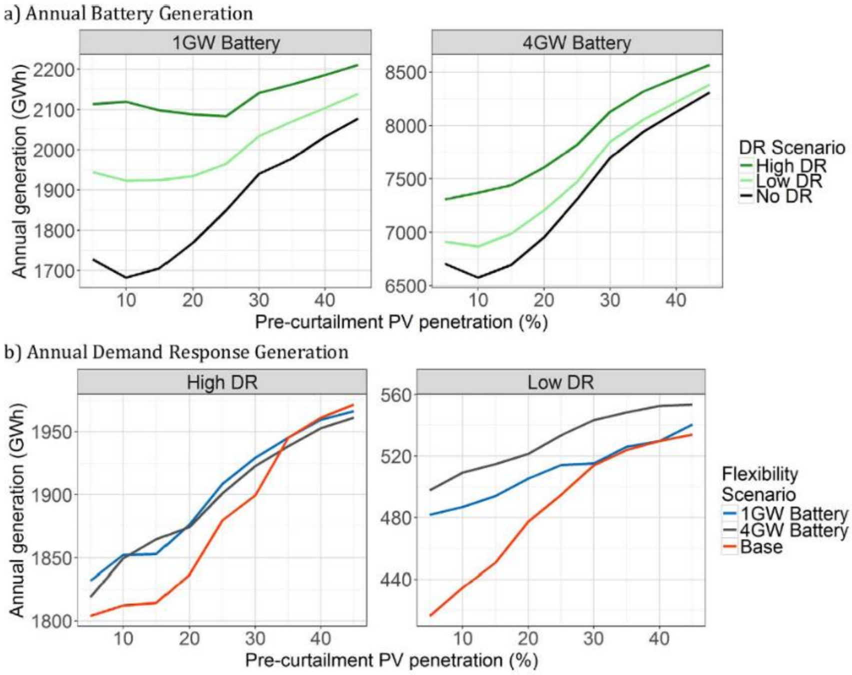

Figure 23 Annual battery Generation

This is also demonstrated by reducing the number of times gas turbines are started, a decline of 20–29% in the Low DR scenario, and 47–61% in the High DR scenario. Demand response reduces the reliance on these units by shifting small amounts of the load for a few hours, which lessens the need for quick-start units and allows baseload generators, such as coal units, to provide that demand. Another important potential role of DR is providing operating reserves. These resources are particularly well suited for providing contingency reserves. We found that in both the Low and High DR scenarios, nearly all contingency reserves can be provided by demand response. While this may be unrealistic due to requirements for the firm capacity to provide some fraction of reserves, it demonstrates the capability of DR to provide this service, even given low penetrations of the resource. However, we found that the current reserves market is shallow and easily satisfied by a variety of low-cost resources such as batteries and PV. Demand response providers looking to reserves for a majority of their revenue should consider this, particularly as batteries and other flexible resources decrease in cost and regulations change to allow variable generators to participate in reserves markets.

Hussain M, & Gao Y. (9), studied of DR in an efficient smart grid environment. The management of the electricity price is currently undergoing drastic changes in its construction and operations as it is transformed from a conventional system into a smart and decentralized system with added contributions from renewable sources. The smart grid emphasizes maintaining interactions with users, including power consumption and dynamic pricing; that, in turn, is achieved through the deployment of various demand-side management programs. By the definition of the U.S. Department of Energy, the smart grid (SG) is an electricity delivery system enhanced with communication facilities and information technologies to enable more efficient and reliable grid operations with improved customer service and a cleaner environment. Demand response takes advantage of two-layer communications and information networks in SGs and makes the grid multi-layer-intelligent by realizing intelligent demand response. This paper conducts an extensive literature review of DR programs and proposes a communication and computation-based DR program (CBDR) for future grid systems. The study further enhances the DR program through the deployment of a customer-friendly and cooperative tariff. The objectives are fourfold: to monitor users' consumption behavior by installing home displays and smart meters connected with the grid; to minimize peak demand by employing an inclined-block tariff (IBT) on power volume distribution; to maintain a responsive communication interaction for data sharing between users and the power grid through the (HAN, WAN, and NAN) networks. Both the smart communications and smart tariff will propagate DR intensively among users and utility providers.

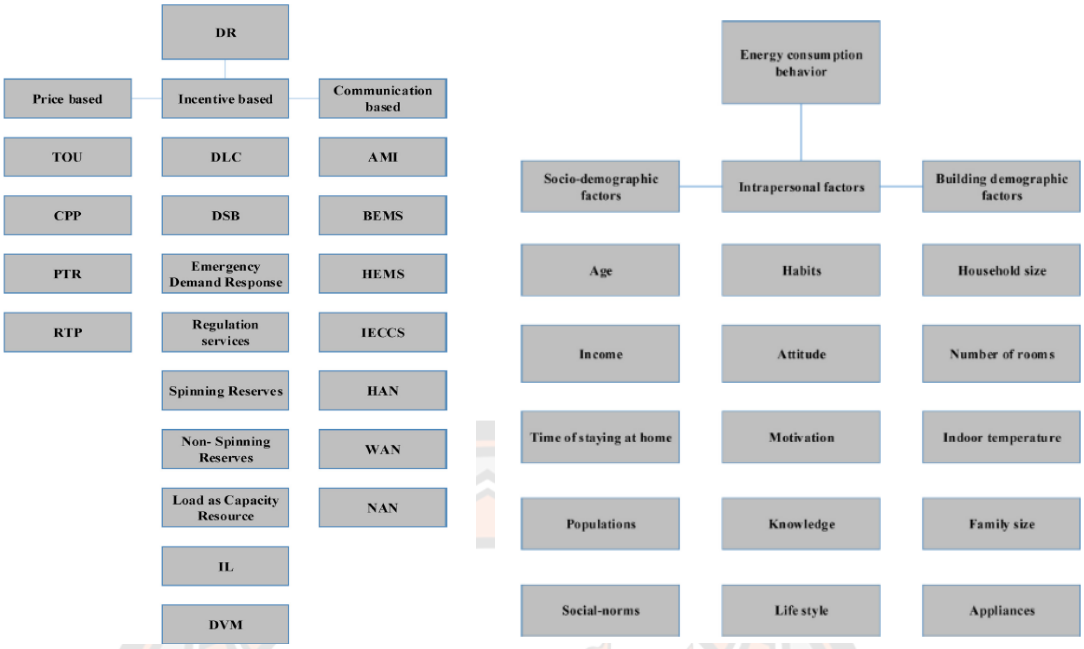

Figure 24 Portrait of consumer consumption behavior

Communication-Based demand response is proposed in this paper to implement demand response successfully in the residential market. An advanced communication network and tariffs are the foundation of demand response that applies to users. Our work recommends IBT tariffs in different price blocks for power volumes that are based on user consumption. Customers actively link with the utility system by making peak reductions and power shifting based on financial incentives. Therefore, it has been observed that social equity can be an active factor in making DR more effective and successful in future smart grid networks. In existing DR programs, customers are given either flat rates or time-varying tariffs. We suggest the IBT scheme to set the price block for every customer and define power limits for consumption in the smart grid. In this scheme, participants already know the defined price limits in every block with a view to ultimately making DR friendly and acceptable.

Fallahi Z, & Smith AD. (10), studied on the topic of economic and emission-saving benefits of utilizing demand response and distributed renewables in microgrids. With the increasing integration of renewable energy resources in power generation, the challenges associated with their variability, such as dispatch ability, grow. In the state of California, increasing penetration of solar electricity in the grid extends the risks of over-generation and significant ramp-up needs during peak hours or when the solar irradiation is not available, as shown in the California Independent System Operator's "duck graph", Figure. 15. The resulting ramping needs are typically met by fossil-fuel-fired generation, which can be expensive, complicated, and inefficient. When thermoelectric power plants have numerous startups, this is also more harmful to the environment than steady operations. Commercial buildings are responsible for 18% of total U.S. emissions, and a building's operational emissions can be categorized into direct and indirect sources. Direct sources of emissions include all combustion at the building site, generally produced by burning natural gas or other fuels for heating, hot water, or kitchen needs. Indirect sources of emissions are not located at the building site and include all emissions associated with the electricity purchases.

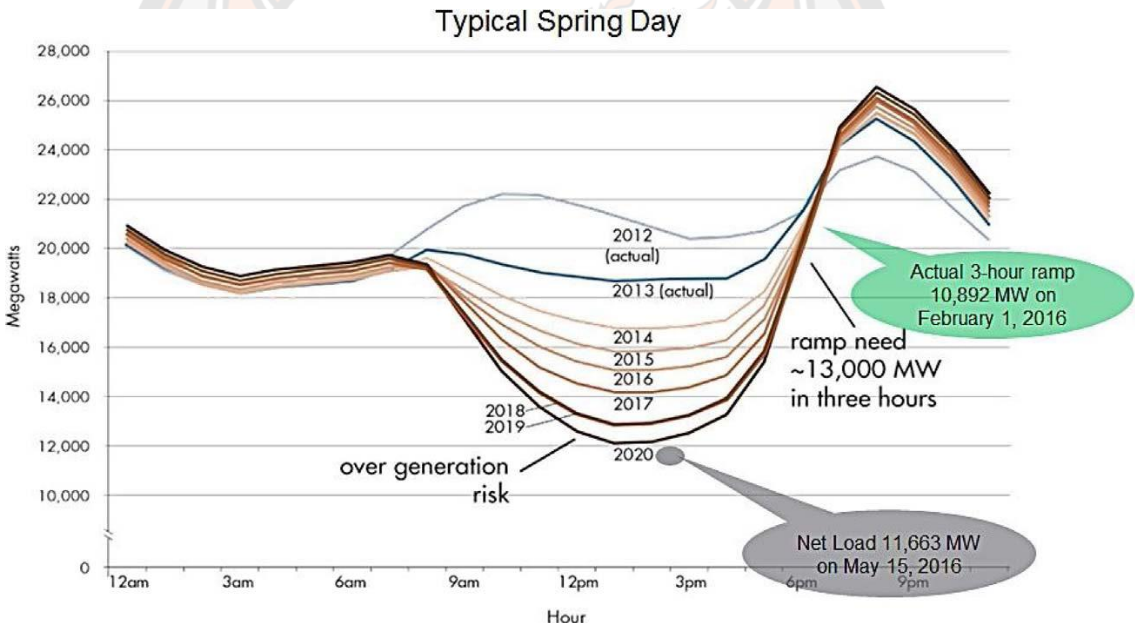

Figure 25 Duck graph representing over generation and ramp-up risks, California ISO

In this work, four commercial building models are simulated to evaluate the potential benefits of a demand response action on building-related emissions. The use of the thermal mass of the building, as a means of energy storage, may be beneficial in load flexibility in the building. This kind of storage and load change due to generation and consumption patterns can be implemented in every commercial building without the need for capital cost. In this section, the methods used for the assessment and implementation of DR are discussed. In this article, we studied the potential of using demand response for electricity purchase reduction and emission reduction in commercial buildings. The buildings have solar PV electricity generation on-site, and with demand response practice, the building automation system (BAS) can be programmed to use more or less electricity. In an HVAC system demand response, the BAS will change the temperature set points to over-cool the thermal mass of the building when excess PV electricity is available. The thermal energy stored in the thermal mass of the building will provide air conditioning during evening hours or when the solar PV is not widely available. This change in the pattern of electricity use by the building results in changes in electricity purchases as well as changes in the indirect emission productions attributed to the building. For a single building, the size and timing of its electrical loads and the available rooftop area limit the potential for producing and self-consuming renewable distributed power. In a small building, assuming the use of the whole rooftop for PV electricity production, the hours of excess electricity are more than the actual occupation of the building during working hours. Therefore, the discussed DR practice does not affect the purchased electricity of the small building. At the same time, as net metering is not always applicable, for a stand-alone small building that is located in an area with high solar irradiation, the optimal area for PV arrays is smaller than the rooftop, in order to minimize the amount of unused electricity. In that case, the effect of DR on the small building will be similar to Figure. 9, with lower electricity purchases in the evening hours compared to the default schedules. However, when combining multiple buildings, it is possible to use the excess electricity generation on-site for the buildings with higher consumption. A stand-alone large office building cannot self-sufficiently produce its electricity consumption. As part of the microgrid, the excess PV electricity generation from other smaller sized buildings can be used for the large office building. Applying the temperature set-point demand response for the micro-grid also yielded a 1.37% reduction in indirect CO2 emissions. Demand response has potential benefits for building owners, both stand-alone and within a microgrid. Additionally, applying demand response in areas with large capacities of solar power production, such as the CAMX eGrid region, can be helpful to the grid. Load increase when solar availability is abundant reduces the risk of over-generation and the need for negative pricing of electricity to maintain grid balance. Also, the reduction of electricity purchases during the evening hours will result in less ramp-up capacity needed for the grid and will lessen the technical difficulties associated with the sudden load changes, demonstrating the benefits of grid-centered demand response for ISOs. Finally, the demand response and other load shifting methods, integrated with renewable resource availability, show that electricity consumption use reduction is not the only possible method for reducing the emission production associated with the electricity purchase.

Asadinejad A et al. (11), studied on the topic of evaluation of residential customer elasticity for incentive-based demand response programs. Introduction Modern economies depend on electricity to ensure comfort, dispense information, and provide entertainment and other conveniences. Providing these services requires a highly capital-intensive industry with significant investments in order to maintain adequate infrastructure. It must also have the ability to expand to meet changing societal needs. At the same time, the deregulation of the electricity market in many developed countries, unstable oil prices, and continuing global warming concerns have put pressure on these investments. The key component to understanding demand response program design is elasticity, which reflects customer reaction to commercial offers. In this work, customer elasticity for Incentive-Based Demand Response (IBDR) programs is estimated using data from two nationwide surveys and integrated with a detailed residential load model. In addition, incentive-based elasticity is evaluated at the individual load power since this is more effective for operations than at an aggregate value for a feeder. The elasticity of residential customers under IBDR is calculated for different appliances. Results show that customer incentive expectations for lighting and washing devices are much lower than those of HVAC. Lighting has the highest elasticity among all devices. However, since HVAC has the highest share in the aggregate load signal, the resultant load reduction of the HVAC thermostat is the largest. Due to the critical role of the HVAC load, especially at peak hours, the HVAC elasticity is calculated for different thermostat settings. Incentive-based elasticity is defined as the ratio of load change to the incentive. The customer’s incentive expectations across all groups are close (based on survey data); therefore, elasticity primarily depends on the possible load change. The load change represents the ratio of the consumption difference before and after the DR to the original energy. Therefore, this value depends on the highest power consumption, i.e., HVAC. The load change will be lower when the HVAC consumes higher energy, i.e., a low-temperature setting in summer and a high setting in winter. As a result, elasticity price is decreased with the average power increase. Grouping thermostat settings are done for different group sizes. Elasticity presents a significant change from average elasticity under different customer groupings.

Minoli D et al. (12), studied about IoT considerations. Internet of Things (IoT) is entering the daily operation of many industry sectors. For example, the concept of a “smart city” is emerging. Smart city systems not only offer improvements in the quality of life of the inhabitants but also significantly improve efficiency regarding asset management. Including intelligent transportation systems (e.g., smart mobility, vehicular automation, and traffic control); smart grids; street lighting management; traffic light management; waste management; environmental monitoring (e.g., sensors on city vehicles to monitor environmental parameters); water management; surveillance/intelligence; smart services. and crowdsensing (where the citizenry at large uses smartphones, wearable, and car-based sensors to collect and forward for aggregation a variety of visual, signal, and environmental data). Although BMSs currently tend to focus primarily on electrical consumption, in the future BMSs (and the smart building IoT) are expected to focus on all energy sources supporting a building, also including natural gas, renewable energy, and so on. Additionally, it should manage other utilities such as water use and perhaps steam. IEAQ capabilities are also important. Sensors and sensor technologies of interest include demand-controlled ventilation, energy recovery ventilators, dedicated outdoor air systems, CO_2 sensors, ultraviolet germicidal irradiation, displacement ventilation, and underfloor air distribution. As mentioned earlier, BMSs have evolved in recent years to support some of these devices and the underlying functions; however, comprehensive multisystem management using one all-inclusive BMS (in a manager-of-managers role) and standardization of data flows, data analysis, and actuation remain an unattained goal.

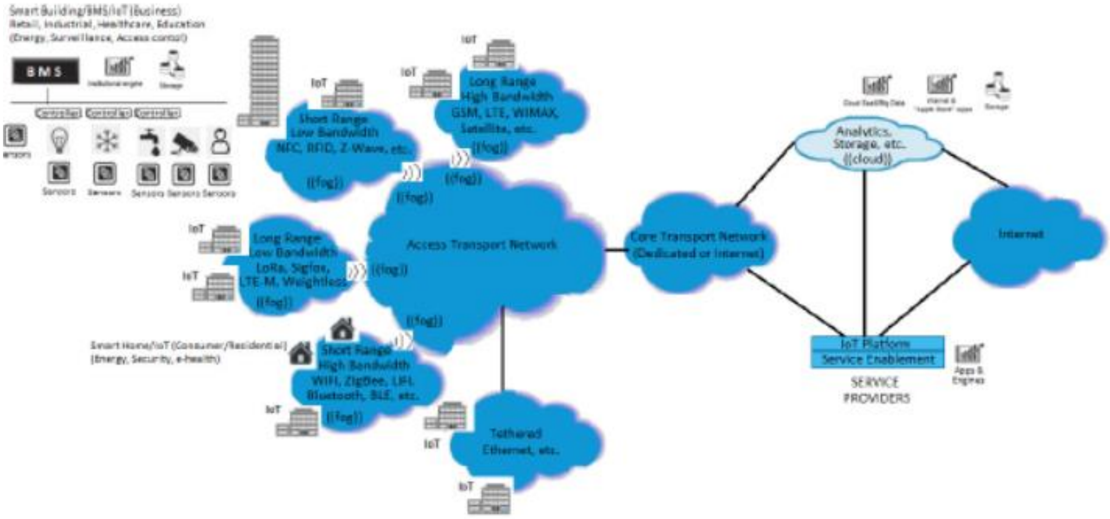

Figure 26 IoT environment showing sensors, BMSs, aggregation networks, and cloud services

Smart buildings based on IoT concepts are expected to evolve rapidly in the next five years. The confluence of IoT, PoE, IP (IPv4 as well as IPv6) is expected to enhance the functionality, capabilities, energy efficiency, and cost-effectiveness of buildings, moving them up the automation continuum to a "smart building" status. In recent years, governments and regulatory agencies around the world have increased their focus on commercial buildings, given the fact that buildings are large consumers of energy. Continued regulation is expected (at least in some parts of the world), including mandates for greenhouse gas emissions targets. Therefore, stakeholders should investigate evolving technologies such a next-generation BMS, PoE, IoT, cloud services, and converged networks to get a better handle on the issue, save expenses on the bottom line, and future-proof their environments and their investments.

Li R et al. (13), they studied on the topic of are building consumers prepared for energy flexible buildings-A large-scale survey in the Netherlands. The demand load flexibility will play a crucial role in demand-side power management for integrating with renewable energy systems into the smart grids. The potential of flexibility load in buildings depends not only on the physical characteristics of a smart building but also on inhabitant behavior in the smart building. Power demand will have to approve advanced technologies and to change their daily energy pattern or procedures if energy load flexibility is to be achieved. The survey consisted of questions about the sociodemographic characteristics of the current users, house type, household composition, current energy use behavior, willingness to use smart technologies, and preparedness to vary energy use behavior. The survey was finished by 835 respondents, of which 785 (94%) were analyzed to have provided a genuine response. Our analysis presented that the concept of smart grids is an unacquainted one, as more than 60% of the defendants had never heard of the smart grids. Though unfamiliarity with smart grids increased with age, and half of the respondents aged 20–29 years old were aware of the concept. Monetary incentives were identified as the most significant motivating factor for the acceptance of the Microgrid technologies. It was also found that people would be most in favor of obtaining smart lighting, dishwashers (65% of the respondents), and refrigerator/freezers (60%). The result analysis shows that people who are willing to use smart technologies are also ready to change their load pattern, and can thus be categorized as possibly flexible building consumers. The assumptions, 11% of the respondents were found to be potentially flexible building users. To encourage people to be prepared for energy flexible building customers, the responsiveness of smart grids will have to be increased, and the acceptance of smart technologies may have to be endorsed by providing incentives such as financial rewards.

Al-Ali AR et al. (14), studied on the topic of Home Energy Management System Using IoT and Big Data Analytics Approach. Increasing cost and demand for energy has led many organizations to find smart ways for monitoring, controlling, and saving energy. The Energy Management System (EMS) can donate towards cutting the costs while still meeting power demand. The emerging technologies of the IoT and Big Data can be applied to better manage energy consumption in residential demand, commercial, and industrial sectors. This paper showed an Energy Management System (EMS) for smart homes. In this system, each home device is interfaced with a data acquisition module that is an IoT object with a unique IP address resulting in a large mesh wireless network of devices. The data gaining System on Chip (SOC) module saves energy demand data from each device of each smart home and transfers the data to a decentralized server for further processing and analysis. This information from all residential areas accumulates in the utility's server as Big Data. The proposed EMS utilizes off-the-shelf Business Intelligence (BI) and Big Data analytics software packages to manage energy consumption better and to meet consumer demand. Since air conditioning contributes to 60% of electricity consumption in Arab Gulf countries, HVAC (Heating, Ventilation and Air Conditioning) Units have been taken as a case study to validate the proposed system. A prototype was built and tested in the lab to mimic small residential area HVAC systems.

Yoo CH et al. (15), presented the smart control of BESS and independent energy management pattern of MGs depending on the ideological multi-agent systems. The author divided such intelligent control patterns into two layers of decision-making processes. The planning of optimization in individual Microgrid identities was managed by the bottom layer, such as loads BESSs, and backup generators. On the other hand, the central Microgrid coordinator (MGCC) cooperates multiple energy sources resulting in the overall Microgrid are able to be paired with load decreasing requested by the grid practitioners. The author's research is referred to as "Korea Power Exchange's Intelligent Demand Response Program," in which the grid operators desired rapid load reduction within sometimes. However, direct power interference leads to customers' benefits losses suffering and costly. However, the author suggested that the optimization of distributed energy resources tends to decrease financial losses and load reduction, respectively, based on using multiple intelligent agents. In addition, the author presented the methodology that is referred to as the Intelligent DR program of the Korea Power Exchange (KPX), which is an emergency demand response (EDR) program. Such programs will operate smart management distributed energy resources for optimization of the overall financial outcomes of the Microgrids and for adjustment of conflict possibility between the Microgrid identity and applying those to IDRP when referring to the changes in Microgrid environments. The author also compared those with typical loads especially via ADR, which lead to Microgrids has more efficiency as participants in the DR program. However, the limitation consideration of BESS is based on between the state-of-charge (SOC) and the size of charging or discharging currents of the battery uniformly. The agents are planned to flexibly communicate to the other managers and the MGCC via the CNP and then finally find an explanation of each unit corresponding to a certain EDR request for peak shaving and clipping. More efficient smart algorithms for optimization and coordination will be developed for the multi-agents in future research.

Minchala-Avila LI et al. (16) reviewed the techniques of optimal control referred to the energy management system and control of Microgrids. Furthermore, the author developed the optimization of the energy management system (EMS) and also used the optimization techniques to solve the optimal control problem (OPC) relating to the reliability of Microgrid operations. The communication between the layer to the upper layer of a distributed control in telecommunication infrastructures lead to the successful optimization in Microgrids operation, which are called Microgrid central controller (MGCC). The optimal Microgrid techniques are classified according to the objective function for optimal controlling Microgrid, which is consisted of optimal power flow, load shedding, economic dispatch, demand-side management, carbon dioxide emissions reduction, predictive optimization, MILP, non-classic optimization techniques. However, the author found that the fundamental requirement of Microgrid control is to assure balancing between demand load and power generation sources to solve OPC in order to avoid instability problems in Microgrids operations. MPC would be very performance methodology and is also attractive to manipulating Microgrids due to its ability to control based on future behaviors of the system in the predictive perspective.

Kabalci Y. (17), studies on the topic of a review of smart meters and the communication of Smart Grid. The Smart Grid can describe the advantages of the control system and communication integrated into the typical grid in the 21st century. The Smart Grid framework is planned to integrate into masses of high speed, bidirectional information components to institute an interactive metering system and power management. A demonstration of the LAN structure of Smart Grid is shown in Figure 27.

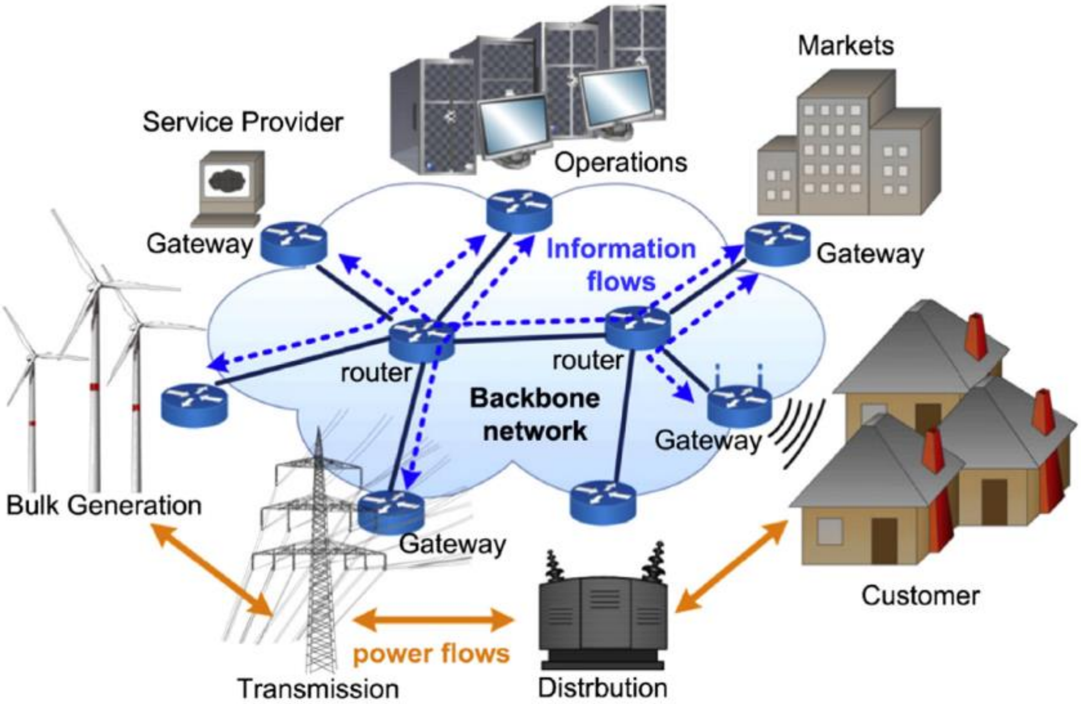

Figure 27 Local area network structure in Smart grid

Representation of local distribution network structure in the Smart Grid, the communication system of the SG is well defined by IEEE 2030-2011 standard that is essential to understand SG infrastructures in a hierarchical arrangement and SG applications. The standards, data rates, advantages/disadvantages of wireless and wireline communication technologies. This research studies concentrated on the SG communication methods and smart metering and for considering the related technologies, challenges, and applications. The investigation consists of four main sections; the first is measurement and metering; second is the SG and intelligent energy infrastructure; the third is cybersecurity on the smart grid communication technologies that used in the smart grid. Outline and future research are introduced into several subsections. The topics concerning the Microgrid system, EV, storage system, and DG integrations, are reviewed regarding SG interactions. The smart infrastructures of the Smart Grid are described in three aspects of the system, distributed generation, distribution and transmission, customers, and utilities. The intelligent measurement and monitoring system are referred to as a control system for energy power management. The essential candidate is the development of a computational model confirming on-power demand facilities, and shared generation resources via the internet. EMS in SG can be evaluated by considering cloud applications. Also, prepare more memory and storage ability for energy management systems. This computing is used on the topic of communication management systems of the smart grid. For instance, big data acquired from SMs can be accomplished by cloud computing. Also, it offers the advantages of better cybersecurity features.

Papantoniou S et al. (18), studied about demand-side management on the topic of building optimization and control algorithms implemented in existing BEMS using a web-based energy management and control system. The purposes of this study are to consider a building optimization and control (BOC) algorithm, is implemented in the building energy management system (BEMS) of the Saint George Hospital, Greece. A control algorithm comprises predicted models for indoor and outdoor ambient temperature by using neural networks, multi-step optimization using genetic algorithms, and real-time control using Fuzzy logic techniques. The research methodology can be divided into three phases. The first is the development phase, the BOC control algorithm was designed in the MatlabTM environment, the second is setting the available inputs, then selected outputs, and the third is subsystems are accomplished based on the available data. The excellent phase: Through the fine-tuning phase, the BOC control algorithm is equipped with a verified TRNSYS model that is evaluating the system performance by using a dynamic model. The implementation and installation: the BOC is integrated into the typical BEMS of the Saint George hospital in Chania, through a specific Web-EMCS platform, explained in the section. The BOC output and input parameters are integrated into sensors and actuators, respectively.

Khan AR et al. (19), studied the topic of Load forecasting, dynamic pricing and DSM in Smart Grid. DSM is an essential tool, which is used to control the stability and reliability of the system. The DSM has been overlooked due to the complex dynamics of demand, consumer behaviors, and lack of computational capabilities. Information technologies (IT) are essential for system communication and control. The advantages of the Smart Grid can be shown as follows, system efficiency, reduce the peak, minimizing the cost of energy production and integrate with the RE system. Other objectives of the Smart Grid are illustrated in Figure 28.

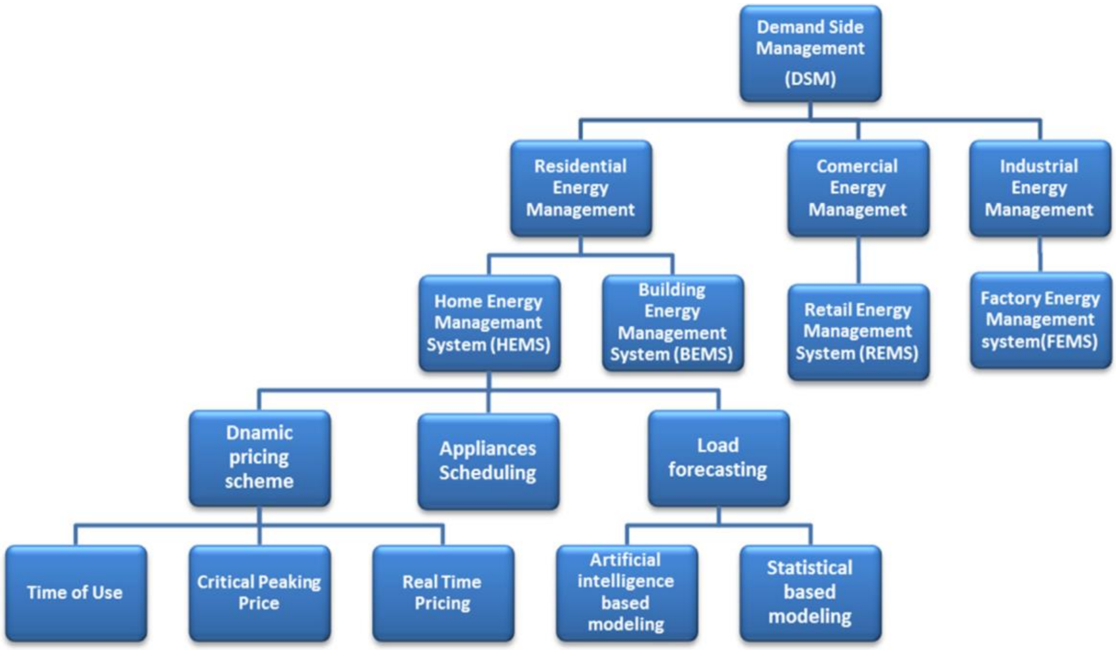

Figure 28 Demand respond concept

The summary of the literature review

After reviewed many articles, I found that energy management at both sides (demand and supply) is very important for the future grid. Demand response is one of the key factors that enable to management the load follows any cases or evens of the network. The building energy management is developed for controlling the load under two types of DR programs. The first DR program is a load response, which is for the stability of the grid. This program, a load reduction, is called by a utility company, with little pleasure in agreement on the part of the electricity demand. Utilities that may call for a load response or DR include autonomous system (grid) operators, load management entities, and utility distribution businesses. The second program is dynamic pricing, which is for the load shape management such as controlling demand for flattening Duck Curve, peak clipping by decreasing the load, etc. The technology for building energy management have been developed for many years in many countries, especially in developed countries, each technology has deference advantages and disadvantages, and some technology is the high price. The BEMS components can be divided into two parts (Hardware and Software). The hardware has mainly controlled the load by on/off and increase/decrease power demand for electrical appliances, and the software is mainly focused on communication, decision processing, command, and reporting. The advanced BEMS, hardware, and software work together properly. According to the literature above, this research focused on the development of the automated building energy management system using IoT called aBEMS-IoT. Not only develop energy management technology, but this research studied the impact of automated demand response for the emergency case and for flattening the Duck curve. The result of this research gave the achievement of suitable BEMS technology, and the price is not so high, hardware and software can be produced in Thailand.

CHAPTER III

METHODOLOGY

Research methodology

The study and development of an Energy Management System for a Group of Smart Buildings with the Internet of Thing for Supporting the Automated Demand Response, this research will develop an automated building energy management system using IoT (aBEMS-IoT) for flattening the Duck Curve under the demand response (DR). The aBEMS-IoT consists of two parts as follows. The first is the control system (Hardware) which enable to control the load On/Off, increase/decrease the power consumption of the load. The second is a data processing and monitoring system (Firmware), which is analyzing the data from both sides load aggregator and customers; then, after data analysis sends the signal to the control devices for the future process. The performance of the aBEMS-IoT will be investigated, and the utility and customer benefits will be evaluated. The complete research methodology is explained in six steps as follows.

1. A literature review of the BEMS with IOT
2. Design and development of the aBEMS-IoT for the smart building
3. Performance test of the aBEMS-IoT in the implemented building under the assumed DR program
4. Investigation the impact of utility in case of using aBEMS-IoT under the assumed DR program
5. Analysis and conclusion

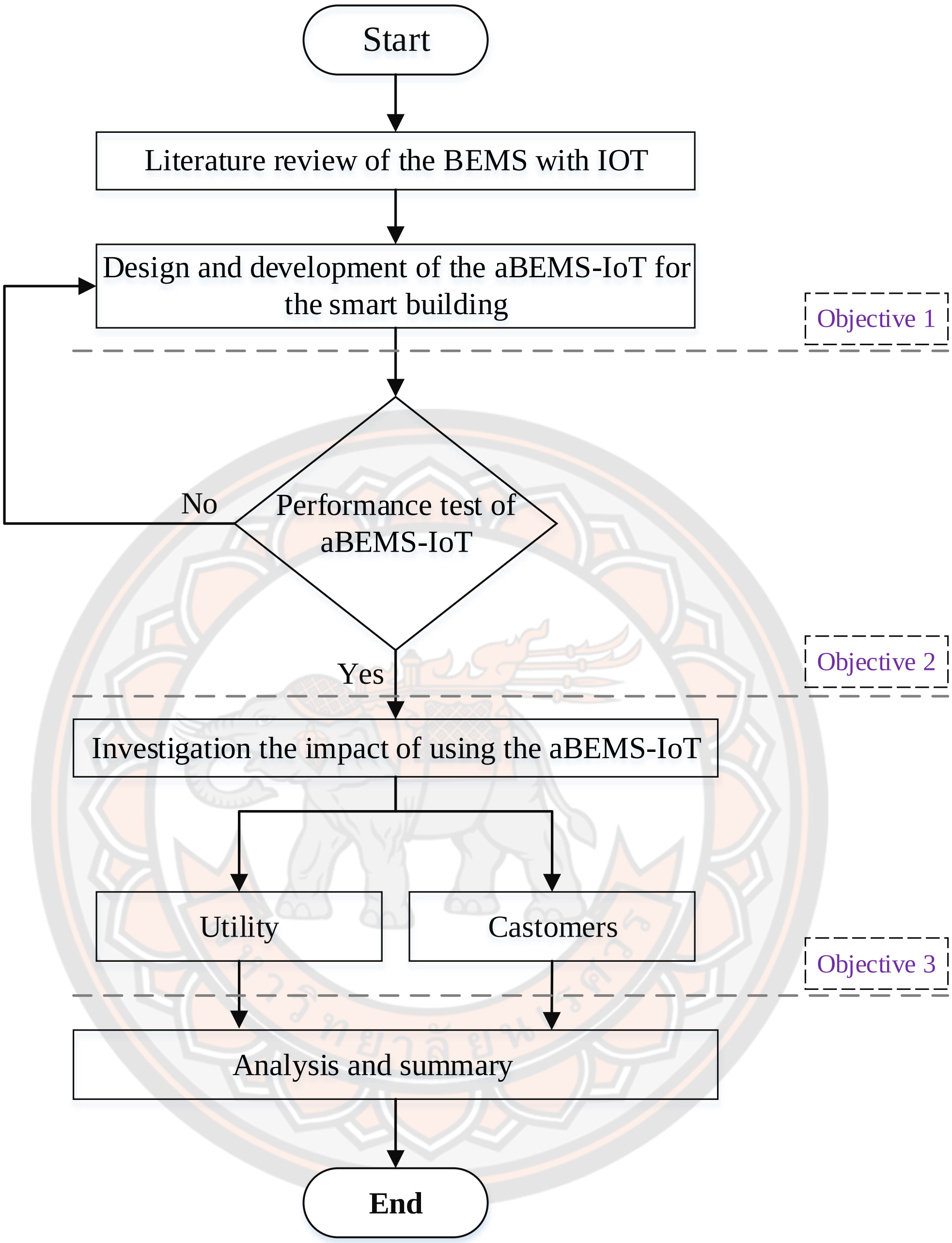

Figure 29 Flowchart of dissertation methodology

Figure 29 shows the research methodology, which consists of six steps, all steps will be described as bellow.

STEP 1: A Literature review of the BEMS with IOT

This part of the research focuses on the review of published articles, in particular, building energy management systems under DR programs. Many of the published articles are reviewed and summarized for comprehensive knowledge to finish this research

STEP 2: Design and development of the aBEMS-IoT for the smart building

The automated building energy management system using IoT (aBEMS-IoT) will be developed for supporting the DR program. The automated demand response (ADR) or load management is an automatic response to the requirement of an aggregator or an emergency situation. The concept of the aBEMS-IoT can be divided into four levels; the first is sensing devices and load, the second is a control level, which controls the purposive load, the third is operation level and the management level. The detail of a BEMS-IoT can be presented in Figure 30.

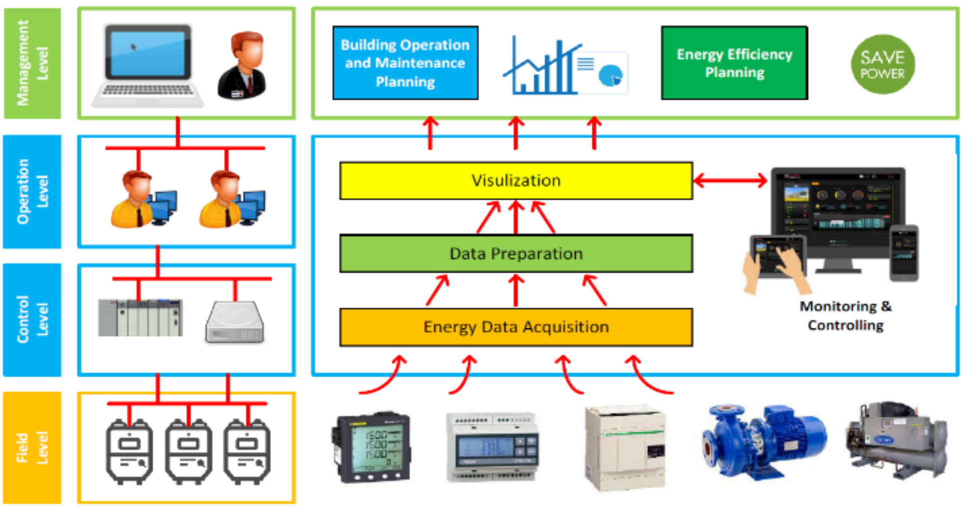

Figure 30 The concept of aBEMS-IoT

The concept of the aBEMS-IoT is to manage the load in the building by Edge analytics and Control, its sending and receiving the signal through the IoT Gateways. The communication between the IoT Gateways and load can be the wireless, cable, or using both of them. The aBEMS-IoT consists of three main parts; the first is controlling devices (Hardware), and the second is a data processing and monitoring system (Software). The detail of the aBEMS-IoT and components are described below.

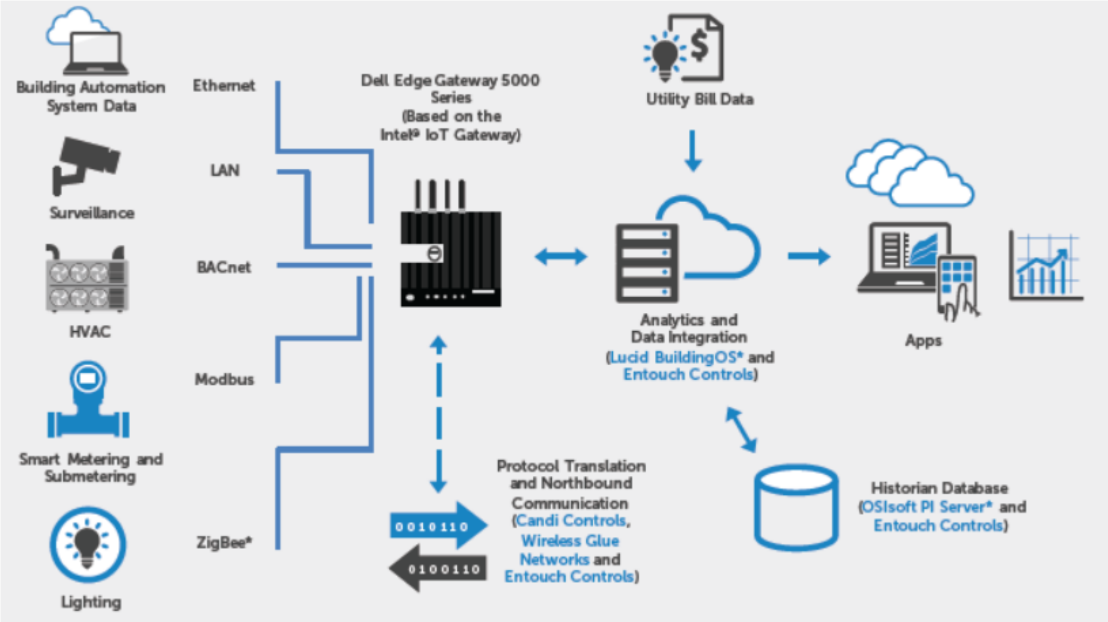

Figure 31 The aBEMS-IoT

The aBEMS-IoT components can be classified into three main parts as shown in Figure 31, the first is controlling devices (Hardware), and the second is a data processing and monitoring system (Software) and The third is the communication. The details of all components can be described as following.

The Control System (Hardware)

The control system was developed in this research, and it is hardware for controlling and managing the load consumption in the building. The control system (hardware), which enables to control the load On/Off, increases/decreases the power consumption or the target load. The loads are controlled by the aBEMS-IoT consisting of the air conditioner, lighting, and plug for electric appliances. The main components of this part consist of MicroController, automatic on/off switch/breaker, and the controller for the air conditioner system. The control system can control on/off switch or breaker, and it enables to decrease and increase power in the air conditioner system. The control system for the aBEMS-IoT is shown in Figure 32.

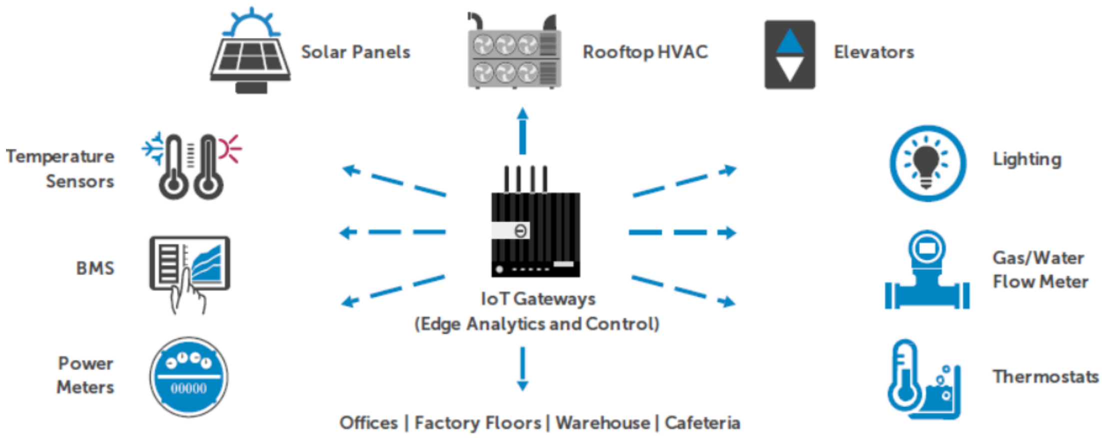

Figure 32 The control system (hardware) of the aBEMS-IoT

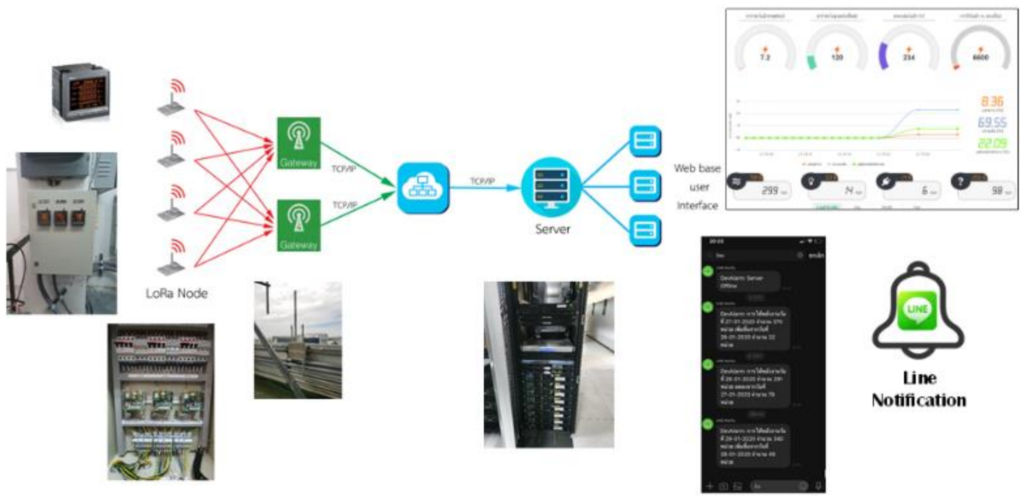

Figure 33 The control system (hardware) of the aBEMS-IoT

The critical part of an aBEMS-IoT control system is a MicroController, which is used for receiving and sending the command from the analytic part to the operation. The electrical power appliances are integrated with the automatic operation devices for working under the supervision of a control system. The control system can communicate with smart devices, power meters, sensors, all of the devices are working together automatically. The intelligent appliance devices such as air conditioners, lighting can be directly controlled. But some of the electrical appliances without automatic devices, it is needed to modify in the part of automation. The example of a control system of aBEMS-IoT is presented in the Figure 34.

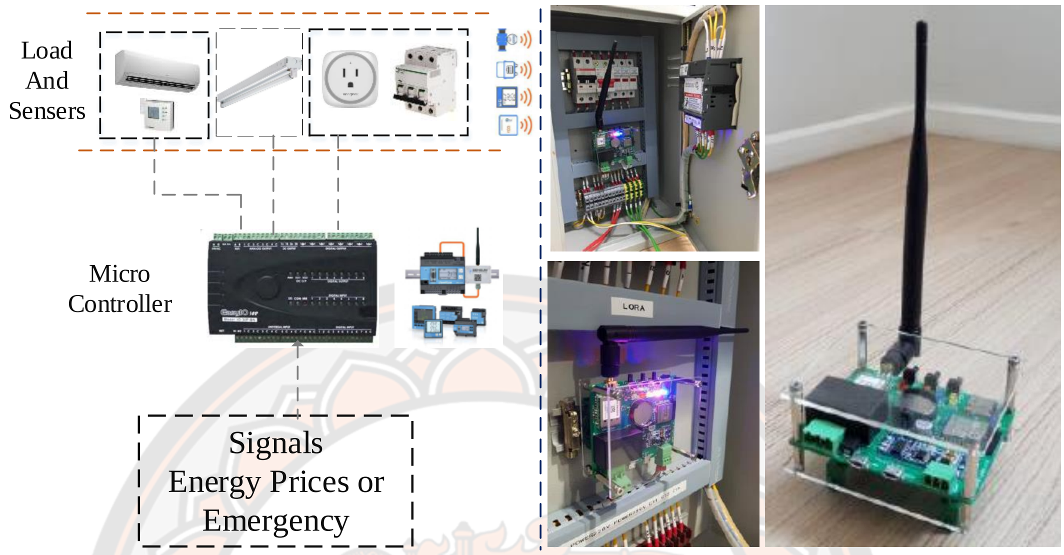

Figure 34 An example of the control system (hardware) of the aBEMS-IoT

The data processing and monitoring system (Software)

The firmware will be developed for energy management in the smart building under the demand response program. This firmware can automatically control the load following the requirements of users or load aggregators. These parts will consist of energy monitoring and data analytics for smart demand response to any situation and requirements. This firmware will control air conditioners, lighting, plug, and beakers via the internet. An edge gateway can connect smaller mesh sensor networks and non-Ethernet/IP-based devices (e.g., serial BACnet* and Modbus*) to an IT network, data center, or cloud. Gateways support hybrid configurations of wired and wireless sensor connections. For example, a gateway measuring power with a wired current clamp at the main panel can also collect data from nearby wireless mesh sensors measuring voltage and current. Data analytics can be centralized in a data center or cloud, decentralized in edge devices (e.g., gateways), or a combination of the two. Centralized data analytics is relatively easy to implement and maintain since the software runs in one place; however, this approach could require a significant amount of network bandwidth to carry as much as a thousand data points per second. Using a cellular network to send large amounts of building data to the cloud could be rather costly. Backhauling all of this data to a complete centralized analytics structure also requires a substantial amount of storage in the location where it is most expensive. The gateway communication and data analytics of the aBEMS-IoT is shown in Figure 35.

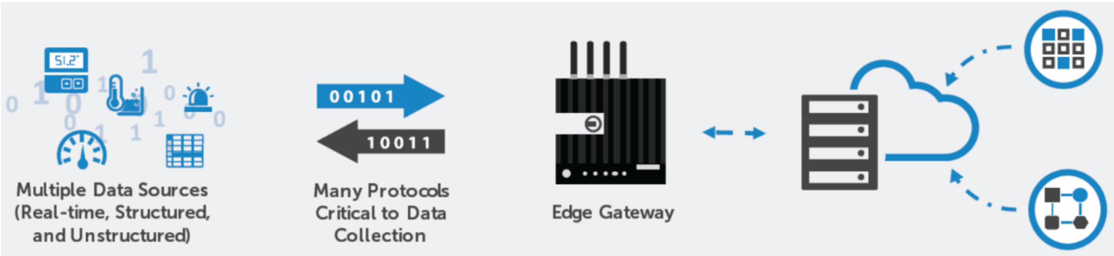

Figure 35 the concept of data processing and gateway

The monitoring of this firmware can be accessed via the mobile, dashboard, and other internet devices. The concept of data processing and monitoring systems of the aBEMS-IoT is shown in Figure 36.

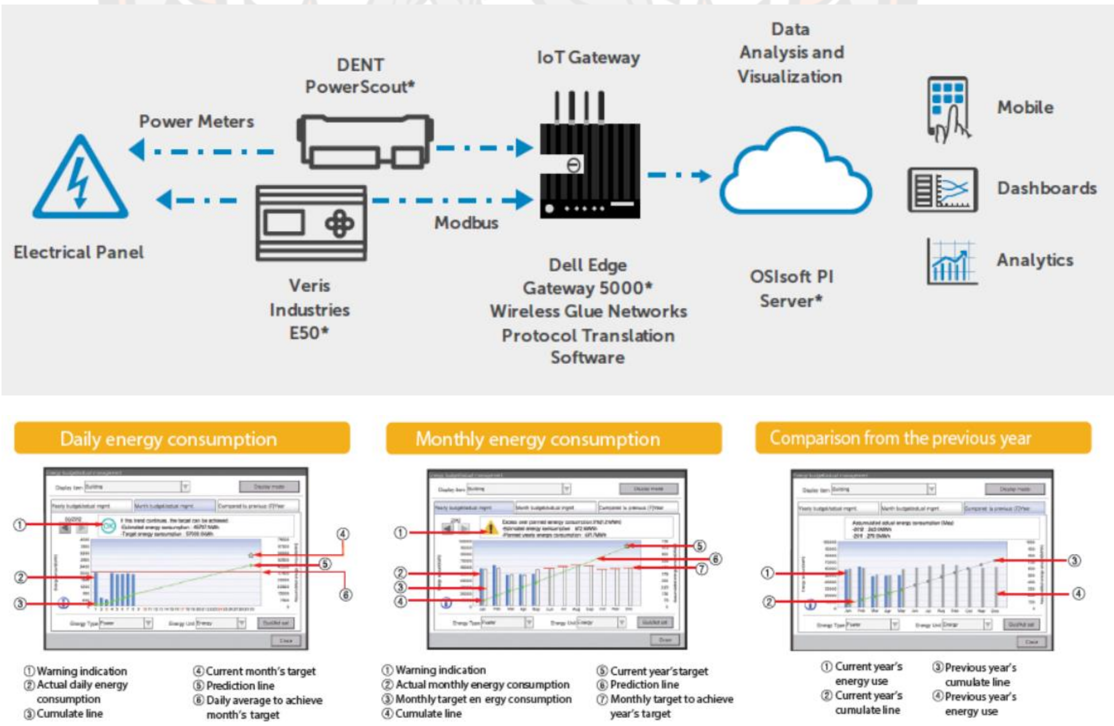

Figure 36 The data processing and monitoring system (Software) of aBEMS-IoT

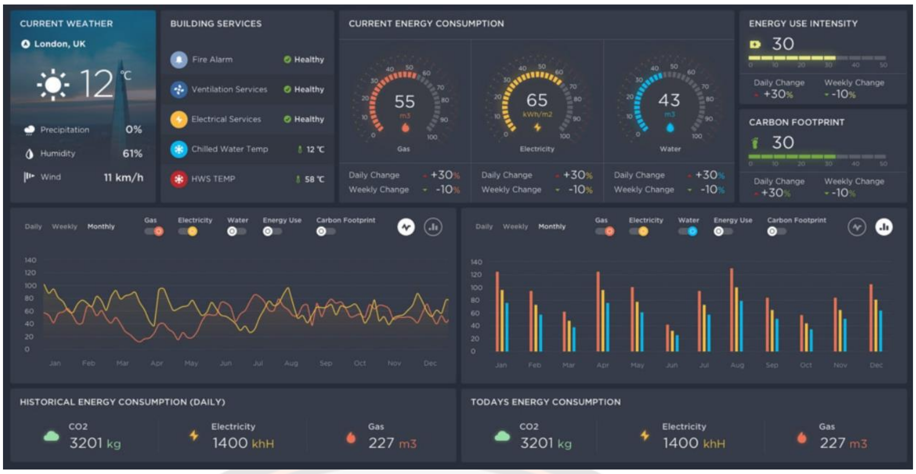

Figure 37 The monitoring system of the aBEMS-IoT

The communication of the aBEMS-IoT

The communication of the aBEMS-IoT can use both cable or wireless that depends on the working area of the building. The communication via the wireless is popular because easy to install, and it doesn't need to wiring the cable. For the wireless solution, the aBEMS-IoT uses LoRaWan, which is a low power, wide-area networking protocol. The wireless communication takes advantage of the long-range characteristics, allowing a single-hoplink between the end-device and one or many gateways. All modes are capable of bi-directional communication, end-to-end security, mobility, and localization. The wireless solution of aBEMS-IoT is shown in Figure 38.

Figure 38 The wireless solution of the aBEMS-IoT

Figure 39 The implementation of an example of the aBEMS-IoT in the actual building

The aBEMS has been implemented in the purposive building for testing the technical performance for controlling the target load under the demand response program. Some example of the building integrated with the aBEMS-IoT is in the hospital and the Post Engineer Department.

STEP 3: Performance test of the aBEMS-IoT in the implemented building under the assumed DR program

After aBEMS-IoT is developed and implemented in the commercial building, this building becomes a smart building. The performance of the aBEMS-IoT will be tested under the assumed DR program. The response time and firmware stability will be investigated. The working principle will also be analyzed under the assumption of demand response, and this will be referenced from other countries where have been using. The performance test is to find the capability of the aBEMS-IoT, there consists of two parts. The first part is the development of the aBEMS-IOT test, which is tested in laboratory so-called laboratory tests and the actual implementation test of the aBEMS-IoT. The second is the simulation of the impact of demand response using aBEMS-IoT to flatten the duck curve. The detail of the two parts is described as below.

The laboratory tests of the aBEMS-IoT

This test is a capability test of the aBEMS-IoT, which is taking place in the laboratory. The laboratory test is a controlling test in the laboratory for finding the response time (on and offload). The load in this test consists of baseload, which is about 1,000 W and the target load for controlling is about 1,000 W, which consists of load 1, load 2, load 3, load 4, and load 5. The aBEMS-IoT operates following the control signal from the assumed DR program (As shown in chapter 4) to control the on or off-target load. The important parameters of this test are shown below.

The response time is the whole process time from receiving the requirement signal until load management is done. This value will give the performance of the aBEMS-IoT then it can be classified into a suitable type of DR.

Firmware Stability, this test just identifies the errors of the developed firmware for aBEMS-IoT during the receiving and sending a signal of the process of energy management.

Working principle, the aBEMS-IoT working principle will be analyzed and explained for concrete details.

The simulation of the impact of demand response using aBEMS-IoT to flatten the duck curve

This part focused on demand-side management using aBEMS-IoT for flattening the duck curve and maintaining the power quality in the 22 kV distribution network. The increasing of RE systems connected to the 22 kV distribution systems has some negative impacts on the network, especially voltage rise in the daytime when a high amount of active power is injected into the grid. And the voltage drop in the night time during the peak load. These behaviors also create the duck curve. To verify the operation of the group of smart buildings integrated with aBEMS-IoT for flattening the duck curve and maintaining the power quality. The typical 22 kV distribution system in Thailand (Tambon Huai Bong, Nakhonratchasima province) was modified to the test distribution system connected with a BEMS-IoT (groups of the smart building) as shown in Figure 40. The group of the smart building was assumed to use aBEMS-IoT for maintaining the grid voltage in the distribution system. The grid voltage profile in the 22 kV distribution test system was simulated by the Digsilent Power Factory Software (license to Naresuan University)

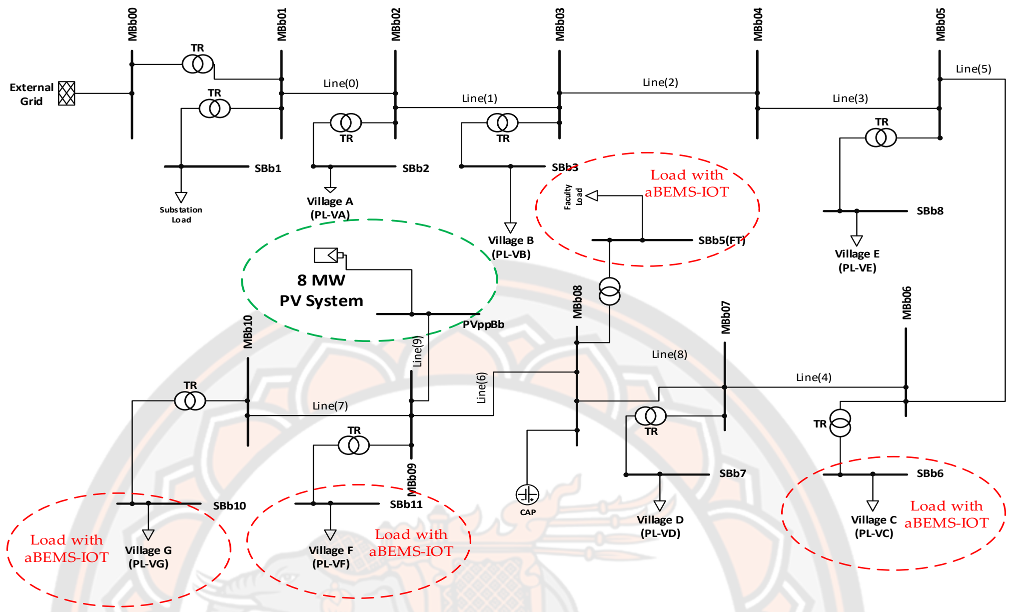

Figure 40 The 22 kV distribution test system

Table 1 The main components and parameters within the 22 kV distribution test system

Components	Connection at Busbars	Ranges	Peak Load (MW)
Total Load (MW)			6 MW
Substation load	MBB001	At substation	0.08 MW
Vill. A (MW)	MBB002	From MBB001 to MBB02 (1.5 km)	0.5 MW
Vill. B (MW)	MBB003	From MBB002 to MBB03 (2.5 km)	0.5 MW
Free busbar	MBB004	From MBB003 to MBB04 (4.0 km)	0.5 MW
Vill. E (MW)	MBB005	From MBB004 to MBB05 (4.0 km)	0.4 MW
Vill. C (MW)	MBB006	From MBB005 to MBB06 (3.0 km)	0.5 MW
Vill. D (MW)	MBB007	From MBB006 to MBB07 (5.0 km)	0.8 MW
Factory Load, PL(FT) (MW)	MBB008	From MBB007 to MBB08 (1.0 km)	1.9 MW
Vill. F (MW)	MBB009	From MBB008 to MBB09 (6.0 km)	0.5 MW
Vill. G (MW)	MBB0010	From MBB009 to MBB010 (1.0 km)	0.5 MW

The 22 kV distribution test system has the power quality problems on the grid fluctuation because of the unbalance of supply and demand that is existing in the northeast of Thailand. This feeder is connected with an 8 MW PV system, and the peak load of the feeder is about 6 MW, sometimes the load demand was only 1.5 MW, this even may create the voltage rise when high power production from the PV system.

The assumption of the DR program and working principle for aBEMS-IoT

The assumed DR programs would be used in this research is the Ancillary Services Demand Response Program (ASDRP). According to the DR programs, the aBEMS-IoT will operate under these DR programs for two purposes, the first is for maintaining the grid stability by keeping the power quality (Grid Voltage) in the acceptable range, and the second is the load profile management for flattening the Duck Curve.

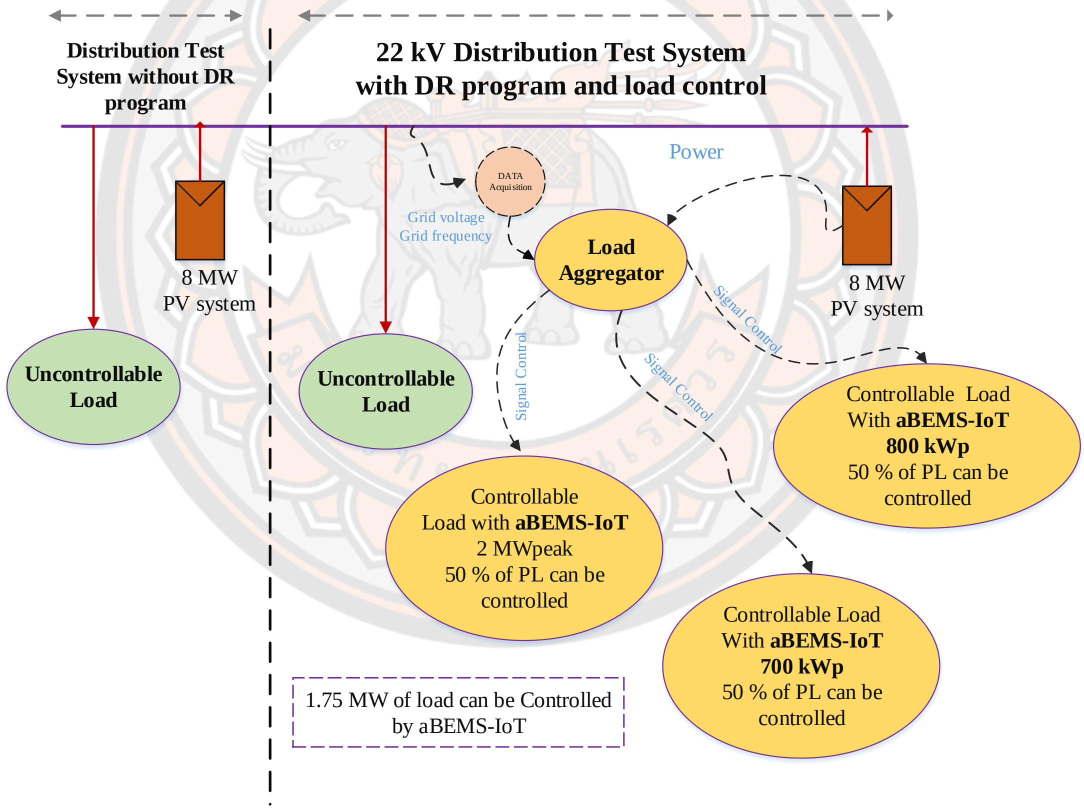

Figure 41 The assumed DR program

The assumed DR program for simulation the impact of the demand-side management in the 22 kV test feeder system in case of an unbalance between supply and demand. The aBEMS-IoT was modeled for three groups, which were classified by peak power of the load, 2 MWp, 700 kWp, and 800 kWp, 50 % of them can be managed by the aBEMS-IoT for managing the target load. The Algorithm for controlling the load of the aBEMS-IoT at the test system can be shown in Figure 42.

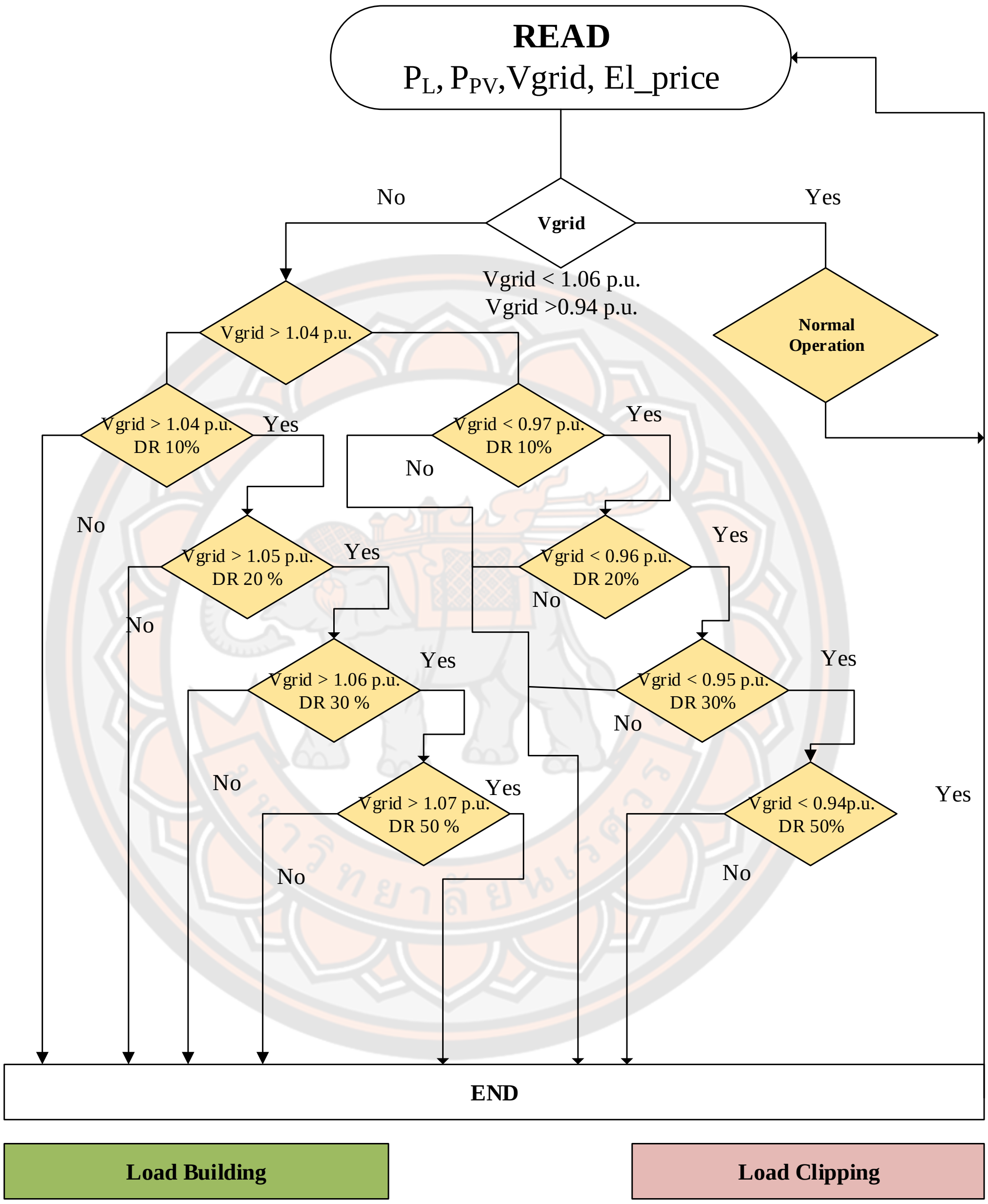

Figure 42 The Algorithm of the aBEMS-IoT

Figure 42 presented the algorithm of the aBEMS-IoT for flattening the duck curve and stabilizing the power quality. The power quality mentioned in this research means grid voltage. The desired range of the grid voltage is 0.94 p.u. -1.06 p.u., which is better than the PEA requirement (0.9 p.u. -1.1 p.u). According to the algorithm, the load of smart buildings is managed by aBEMS-IoT by two entities, the first is load clipping, and the second is load building. In the case of load building, when the load aggregator sends the control signal to the aBEMS-IoT then it is analyzed to control the target load. During the daytime, when high PV production, the active power was supplied to the grid network, during this time may affect to increase the grid voltage. For maintaining the power quality of the grid network, the load aggregator sends the signal control to the aBEMS-IoT for load building, increasing the demand power for balancing demand and supply. On the other hand, during the evening time when power consumption is high. The grid voltage is decreasing because the demand is higher than supply. These process affects the grid voltage decreasing. Then, to maintain the grid voltage, the load aggregator sends the signal to the customers who used aBEMS-IoT integrated into the building for stabilizing the grid voltage by load clipping, decreasing the load demand. After the power quality of the grid is maintained by the DR program, the simulation result can be explained, as shown below.

The electrical parameters and other concerning parameters for the customer and utility will be recorded for evaluation. The data concerning the technical performance of the aBEMS-IoT is shown in the table 2.

Table 2 Parameters concerned the aBEMS-IoT performance

Parameters concerned the aBEMS-IoT performance	**Unit**
Grid voltage	V
Current of Load	A
Active Power of load	W
Reactive power of Load	VA
Ambient temperature	^{o} C
Humidity	%

Table 3 Parameters concerned the DR Program

Parameters concerned the DR program	**Unit**
Price of electricity	THB/kWh
Emergency Time	hour
Load power for profile management	kW
Time response	s
DR Energy management	kWh
Customer income (Under DR Program)	THB

STEP 4: Investigation the impact of utility and customer in case of using aBEMS-IoT under the assumed DR program

This part will study the impact of automated demand response by using the aBEMS-IoT under the hypothesis of the DR program. The DR program will be assumed to use in this research by referring to other countries that are already used. The assumed DR programs would be used in this research, can be classified into two groups, the first is called Emergency Demand Response Program (EDRP) and the second is Ancillary Sevices Demand Response Program (ASDRP). The DR Programs can be shown in Figure 43.

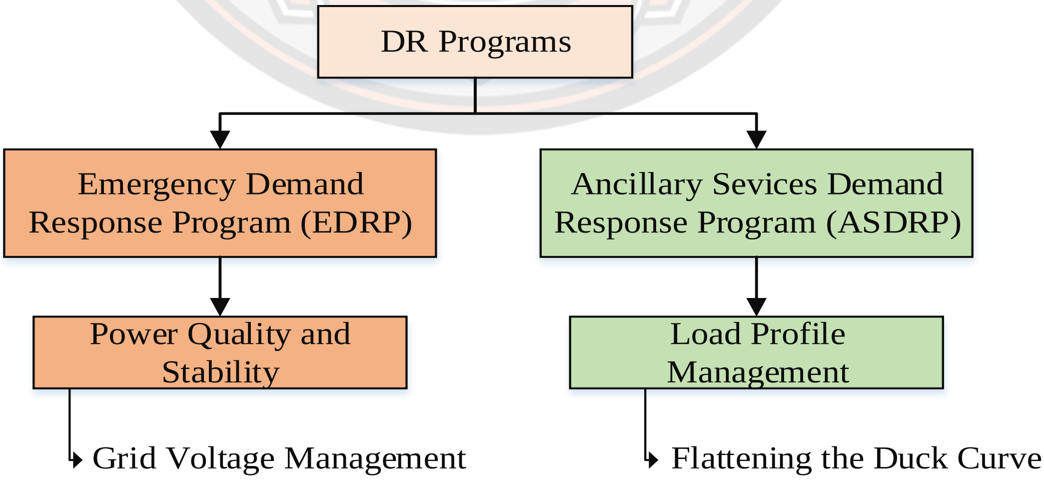

Figure 43 The assumption of DR programs

According to the DR programs, the aBEMS-IoT will operate under these DR programs for two purposes, the first is for maintaining the grid stability by keeping the power quality (Grid Voltage) in the acceptable range, and the second is the load profile management for flattening the Duck Curve. The benefits of both utility and customers will be investigated as follow. The utility benefit is concentrated on the grid voltage stability by demand response during the emergency case, and the customer benefit is concentrated on the saving money or income under both DR program (EDRP and ASDRP). The investigation will use Digsilent Power Factory software or other suitable software such as Power World or Homer for simulation of the aBEMS-IoT operation under the EDRP and ASDRP.

STEP 5: Analysis and conclusion

After all the research steps are done, all data concerning the aBEMS-IoT will be analyzed and concluded to follow the objectives of this research. Technical and economic data will be summarized and it also will give more detail about the future research area according to the development of the aBEMS-IoT.

CHAPTER IV

RESULTS ANALYSIS AND DISCUSSION

This section will describe the research results, which follow the methodology in Chapter 3. The results and discussion will follow two steps: the first is the development of an Automated Building Energy Management System with the Internet of Thing (IoT) (aBEMS-IoT), and the second is the implementation of the aBEMS-IoT in the buildings. All the results and discussion detail are described as presented below.

The development of the aBEMS-IoT

The automated building energy management system using IoT (aBEMS-IoT) was developed for supporting the DR program, and it was tested to find a capability. The capability test of the aBEMS-IoT consisted of two parts; the fist is a laboratory test and the second is an actual system test. The laboratory test is a controlling test in the laboratory for finding the response time (on and offload). An actual system test is a test of the building that is integrated with aBEMS-IoT, and it is tested under the assumed DR program. The response time and firmware stability are investigated. The working principle is also be analyzed under the assumption of demand response. The demand response program in this research was assumed as the signal for testing the aBEMS-IoT. The signal is the electricity prices, which can be classified into low, fair and high as shown in Figure 44.

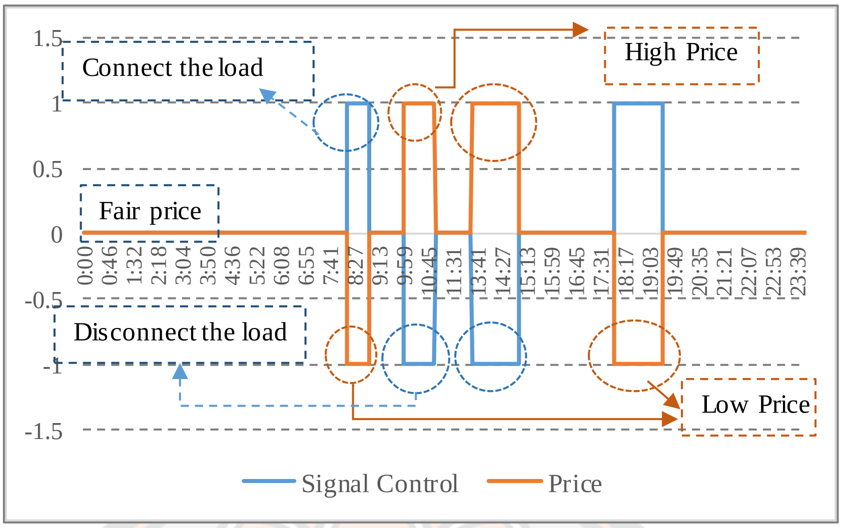

Figure 44 The assumed electricity price and signal control of the DR program for this research only

The Figure 44 presented that the assumed DR program for testing aBEMS-IoT in case of an actual system test. The price stands for electricity price which consisted of Fair price, low Price, and High price. The signal control is the signal which controls the load from the control device thought the IoT gateway. The value -1 of the price is low price, 0 is fair and 1 is the high price but the signal control is opposite, - 1 is a disconnect the load (load clipping), 0 is standby and 1 is a connect the load (load building). The algorithm of the aBEMS-IoT can be presented in Table 4.

Table 4 The basic algorithm of the aBEMS-IoT

Even	Price	Signal Control	aBEMS-IoT operation
1	-1	1	aBEMS-IoT connect the load which consist of air conditioner, motors and lighting (called load building)
2	1	-1	aBEMS-IoT disconnect the load which consist of air conditioner, motors, and lighting (called load building)
3	0	0	aBEMS-IoT is standby

The result of a laboratory test

The aBEMS-IoT was tested in the laboratory for finding the response time when it controlled the load. The control signal sent from the control device through the IoT gateway to the end device for switching on and off (open and close contact). When the target loads were controlled following the signal control then load power can be managed for balancing supply and demand. The result of a laboratory test is shown in Figure 45.

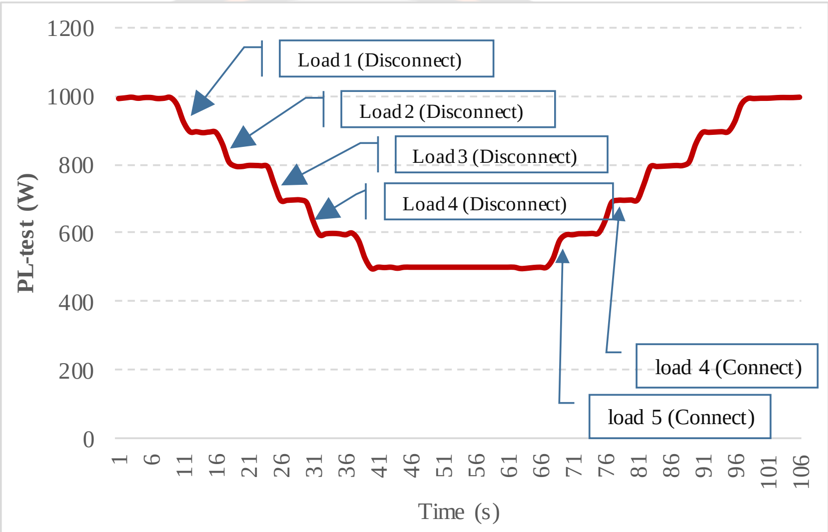

Figure 45 The result of a laboratory test for controlling the load of aBEMS-IoT

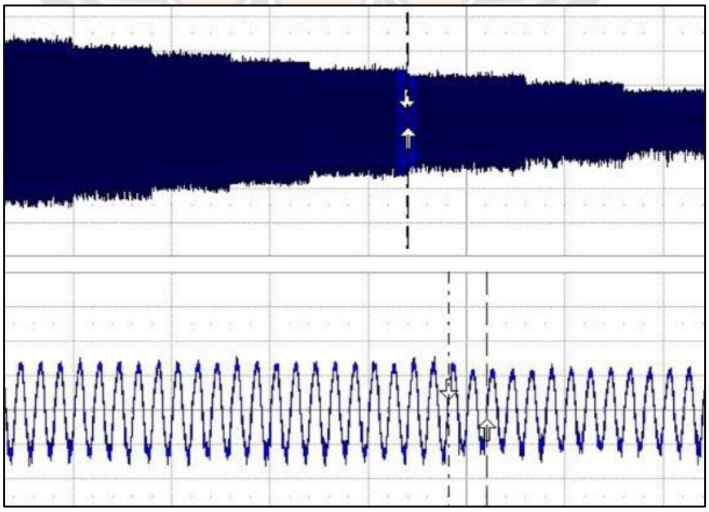

Figure 46 The response time for controlling the load measured by the oscilloscope

The Figure 46, presented the load management of the aBEMS-IoT in the laboratory test, the test loads consisted of baseload, load 1, load 2, load 3, load 4 and load 5. The total capacity of the test load is about 1,000 W. This test is controlled the test load for five-steps on load clipping and load building management. In the case of load clipping, the target load is controlled by the aBEMS-IoT for decreasing the load demand by turn off Load 1, load 2, load 3, load 4 and load 5. On the other hand, in case of the load building, load 1, load 2, load 3, load 4 and load 5, there are controlled by the aBEMS-IoT to turn on the load. The average response time for controlling the test load about 650 ms, this value is very fast for load management and can maintain the balance of supply and demand. This test can control the test load about 50 % of the total capacity which means the baseload was about 50 %, which could not control. This test showed the capability of the aBEMS-IoT which is able to control the target load as any situation.

The result of the actual aBEMS-IoT system test

An actual system test is a test of the building that is integrated with the aBEMS-IoT, and it has been implemented in the Post Engineer Department. This case was tested under the demand response program as mentioned above, the original load profile of the buildings without the demand-side management is shown as Figure 47.

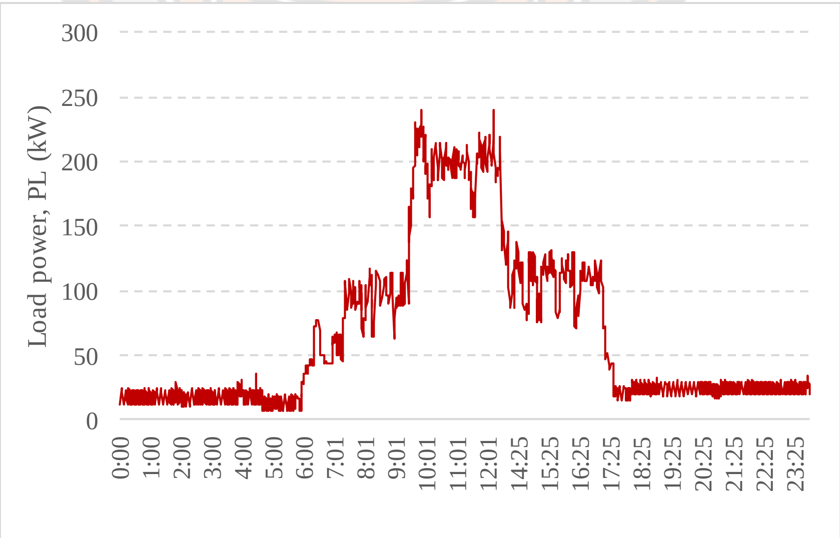

Figure 47 the original load profile of the tested buildings

The peak load was about 240 kW from 9.10 a.m. – 14.15 p.m.. The load power was fluctuation because 65 % of the load demand is an air conditioner; the rest is office devices, and lighting. After implemented aBEMS-IoT, these buildings became the smart buildings, which are fully controlled and monitored by the aBEMS-IoT, more than 60 % of electrical devices are controlled by mobile applications via an internet access system. The buildings integrated with the aBEMS-IoT were tested for controlling the target load under the assumed a DR program, as presented in figure 48.

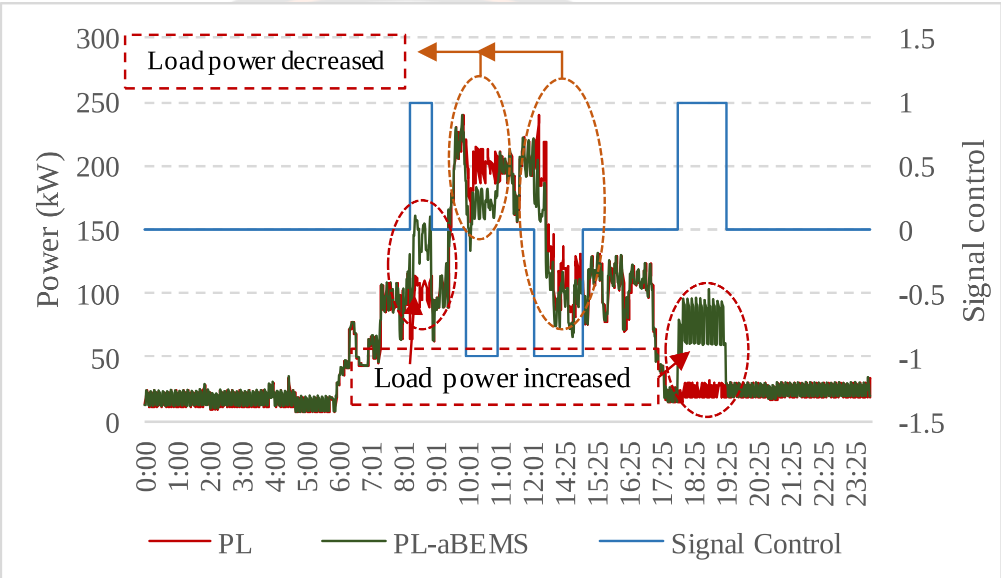

Figure 48 The relationship between load profile and signal control

The operation of the aBEMS-IoT was only followed by the assumed DR program to perform the technical performance and to manage the load in the actual buildings. The target loads were managed following the signal control, as presented in the figure 48. Considering, when the signal equaled to 1 the loads, air conditioners about 16 units and lighting lamp 40 bulbs were controlled for load building (connect the load), this process affected to increase the load power about 50 kW. On the other hand, when the signal control became -1, the load air conditioners (14 units) and lighting bulbs (10 units) were managed for load clipping (disconnect the load), it directly decreased the power demand about 35 kW. From the results can be concluded that aBEMS-IoT can manage the loads, able to increase the power consumption when signal control equal to

1 and to decrease the load demand when signal control -1 as clearly presented in Figure 49.

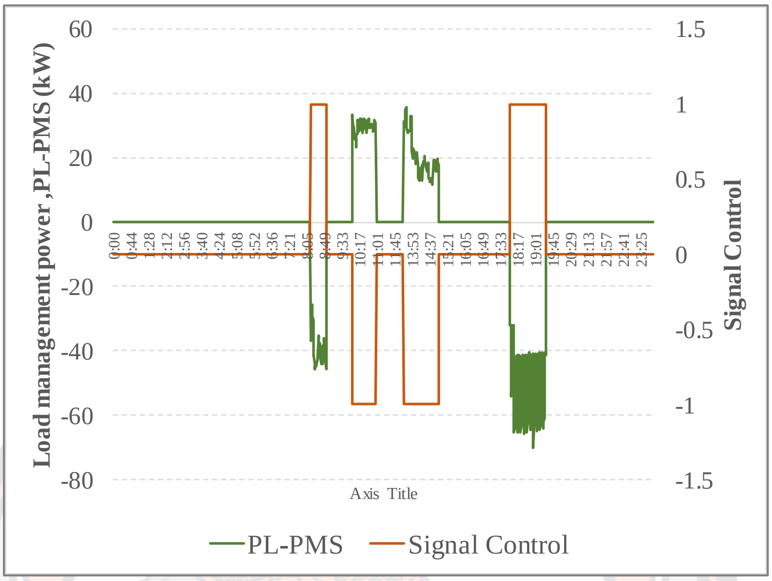

Figure 49 The demand power which was controlled by aBEMS-IoT and signal control

The load power in the buildings that integrated with the aBEMS-IoT could be managed following the signal control. This signal control in the actual demand response program may come from the load aggregator or grid operator. The aBEMS-IoT operates following the signal control, which may be the signal for electricity price or can be the signal for the emergency. In the case of price, this signal can be the price of electricity, which reserves the customers who have the ability to manage the load. In case of emergency signal, the BEMS of the customers who involve in the DR program can manage load for the power quality and stability of the grid by managing the load for balancing the demand. The aBEMS-IoT is developed for supporting any demand response scenarios and can control the load with effective response time, which presented in Figure 49. when the signal comes, the aBEMS-IoT can immediately manage the load. This kind of technology for control the demand side or demand-side management will be mutual in the near future because the electricity consumption of the country is growing rapidly, but the generation is limited due to fossil supply and environmental problems. The aBEMS-IoT is the solution for the stabilize grid and can also be an important part of Microgrid and Smart grid in the near coming future.

Impact of the demand response using the aBEMS-IoT to flatten the duck curve

The study and development of an Energy Management System for a Group of Smart Buildings with the Internet of Thing for Supporting the Automated Demand Response, this research developed an automated building energy management system using IoT (aBEMS-IoT) for flattening the Duck Curve under the demand response (DR). The performance of the aBEMS-IoT will be investigated, and the utility and customer benefits will be evaluated. The complete research methodology is explained in four steps as follows. The first developed of the aBEMS-IoT for the smart building, the second is capability test of the aBEMS-IoT in the implemented building under the assumed DR program; the third is investigating the impact of utility for flattening the duck curve, and the fourth is analysis and conclusion. The detail of the research can be described as below.

The simulation of the aBEMS-IoT for flattening the duck curve

Here are the results for the simulations that were simulated, the first simulating a typical 22 kV test distribution system and the second simulating smart building integrated with aBEMS-IoT, also connected to a 22 kV distribution test system. Generally, the grid voltage in the profile of the 22 kV test distribution system in each study busbars was fluctuated by unbalance of supply and demand. Basically, the overvoltage because voltage source is from the location of the load, and it injected the electrical power to the grid. The voltage drop occurred in the distribution system because the electric current travels through passive elements (such as wires, conductors, the load itself, etc.) that create resistance dragging on the voltage and decreasing. Figure 50 shows voltage profiles for ten busbars of the typical 22 kV distribution test system.

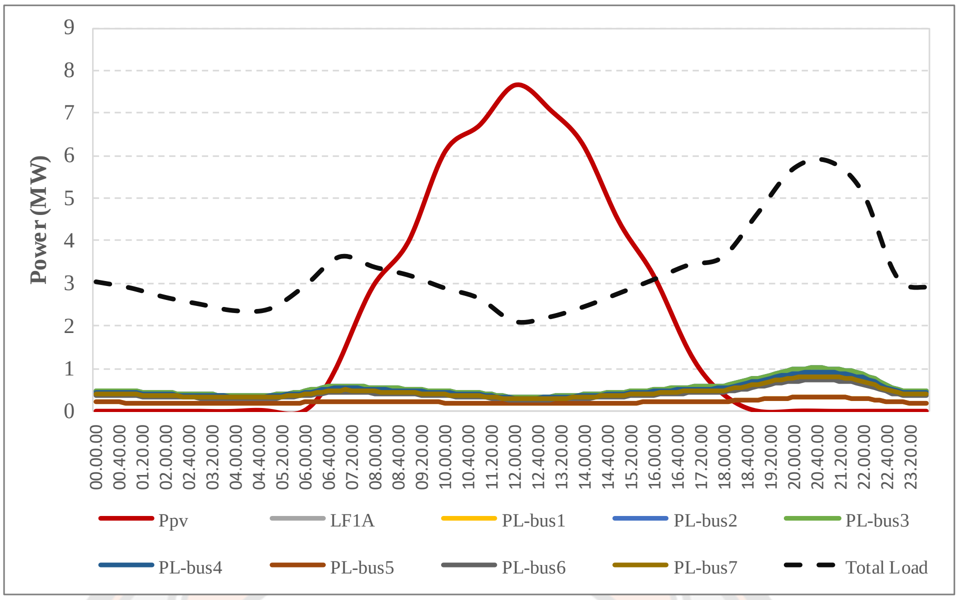

Figure 50 the typical 22 kV distribution system

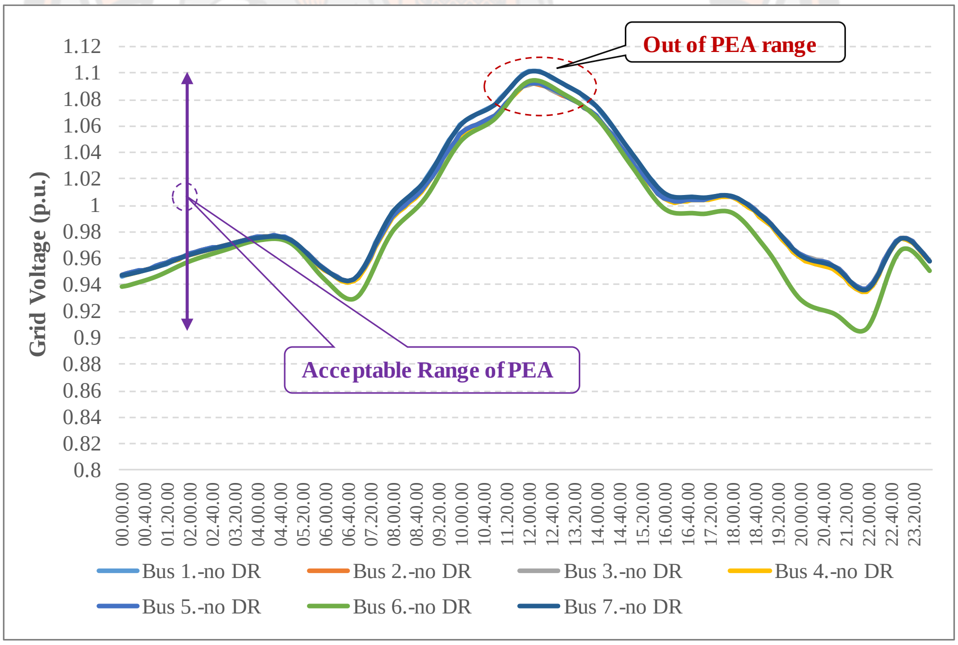

Figure 51 The voltage profile of the 22 kV typical 22 kV distribution system

The voltage profile in the typical 22 kV distribution system without the demand response program was fluctuation, which depends on the demand power and supply power from the PV system. During the day time grid voltage was increasing because the active power is injected to the grid, considering the grid voltage value at the study busbar 5 was 1.101 p.u., which is higher than the limitation of Thailand requirement. This case may affect the power outage because of the control switch is disconnected. On the other hand, during evening time when high load demand, the grid voltage was decreased, considering at bus 7 grid voltage was 0.91 p.u., which was nearly lower than the lower limit of Thailand requirement. The grid voltage fluctuation problem mentioned above will be solved by load management, as described in detail below.

The result of the typical 22 kV test distribution system integrated with the aBEMS-IoT

According to the power quality problems of grid voltage fluctuation, this research found the solution to solve this problem by balancing supply and demand. The assumption of this research is in the 22 kV distribution test system connected to the groups of the smart building, which were integrated with aBEMS-IoTs. Here has the Load Aggregator for controlling the load when the grid operator needs. The concept is that when the power quality has been changed to the point that needs to maintain, then the grid operator sends the command to the load aggregator for controlling the controllable load, which is managed by aBEMS-IoT. The algorithm is that when the grid voltage has been changed to the point of control, under and over voltage, the load aggregator sends the signal control to the customer in this distribution system for load building or load clipping to balance the supply and demand. As mentioned above, then the aBEMS-IoT operates for stabilizing the grid voltage, which is controlled by the grid operator or load aggregator following the algorithm as shown in Figure 52.

The dynamic load flow simulation was done following the topology described above. The result of the simulation by Digsilent power factory software of the 22 kV distribution system with aBEMS-IoT can be shown in Figure 53.

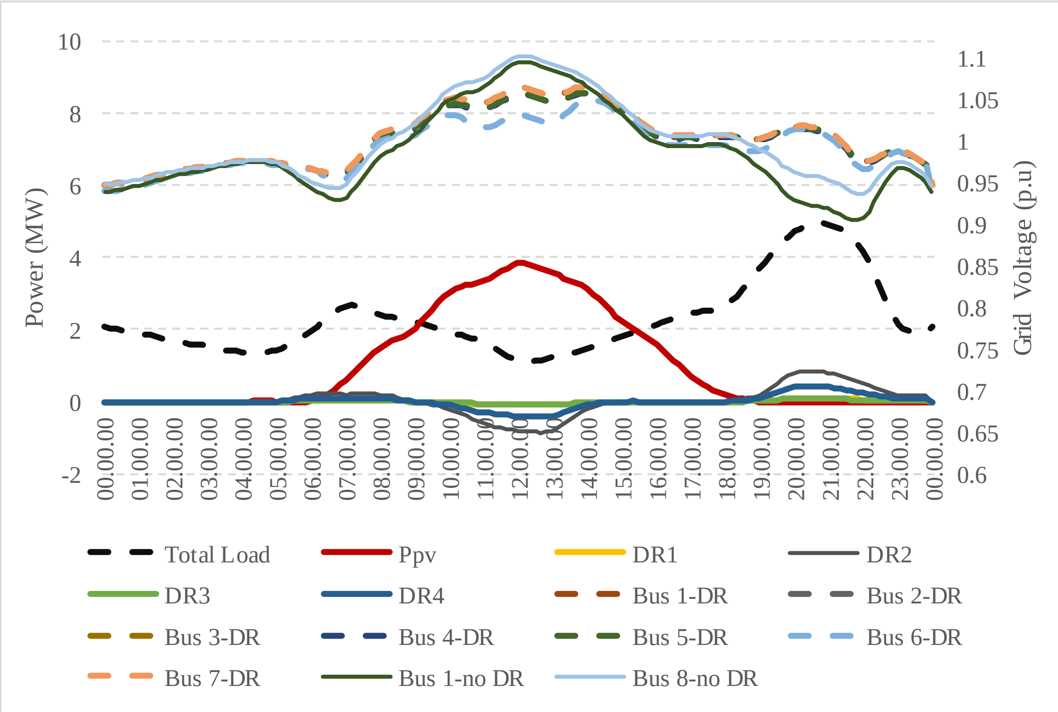

Figure 52 The grid voltage of the 22 kV test system which operated with the DR program for load management by aBEMS-IoT

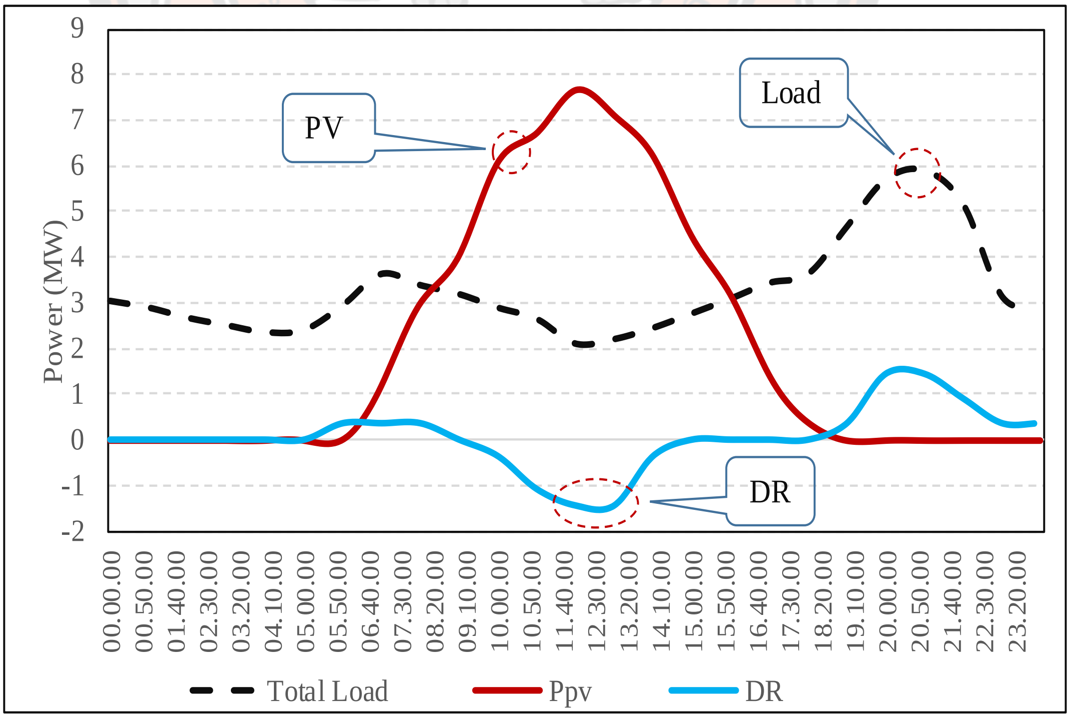

Figure 53 The total DR power in the 22 kV test system

Figure 52 and Figure 53 indicated that the power quality of all busbars in the test distribution system that integrated with the aBEMS-IoT was getting better in the case of comparing to the typical distribution network. Considering, during the daytime (11.00 p.u. -13.00 p.u.) the grid voltage was decreased from 1.01 p.u. to 1.08 p.u; because the aBEMS-IoT turned on the controllable load to increase the power demand. Considering the DR Power (DR) during this time, the value is negative. It means that the system charged electricity to the battery storage for increasing the load. Then, the load increased; this process makes the balance between supply and demand. On the other hand, when the peak load occurred during the peak demand at 6.00 p.m. – 10.00 p.m, the grid voltage dropped in case of high load consumption. To stabilize the grid voltage, the aBEMS-IoT commanded to decrease the controllable load by a switch-off or disconnect the not critical load. Considering this time, the DR power (DR) was positive, which means the electricity power was injected form the battery to the grid. This process could make the grid voltage increased because of load decreased, then supply and demand more balance. The result of this part could be concluded that to stabilize the power quality by demand-side management equipped with the aBEMS-IoT, it directly affects to supply and demand power in the distribution system. When the load power ramps up or ramps down, the ramp rate is not steep then, the demand-side management by DR program with the aBEMS-IoT can be flattened the duck curve as shown in Figure 54

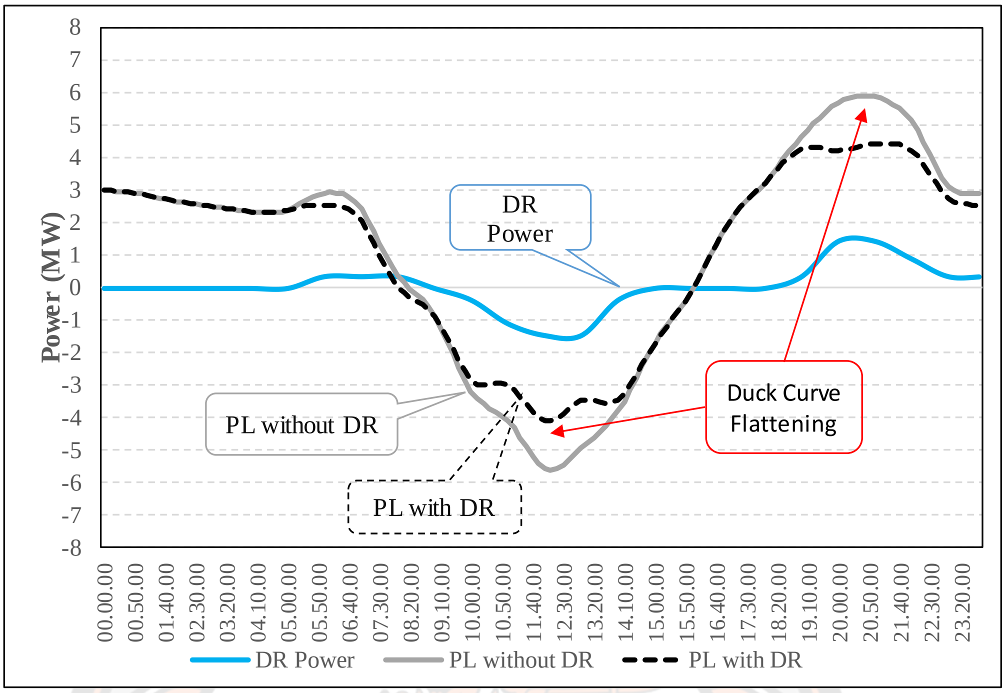

Figure 54 Flattening the duck curve by aBEMS-IoT

Figure 54 presented the load profile in the case of a distribution system operated with the demand response by aBEMS-IoT (PL with DR) and an original distribution system operated without the demand response (PL without DR). During day time at 9.00 AM to 2.00 PM, the load profile with DR (PL without DR) was increased by aBEMS-IoT. On the other hand, during the evening time, the load profile with DR (PL with DR) was decreased by disconnecting the load. It affected to peak load decreasing. As per the results can be concluded that the load profile in the distribution system enables the management of load shave, load building, and clipping for flattening the duck curve.

The comparison between the two simulation cases

The comparison of dynamic load flow simulation of two cases, the typical 22 kV distribution system and the 22 kV distribution integrated with aBEMS-IoT can be shown in Figure 55.

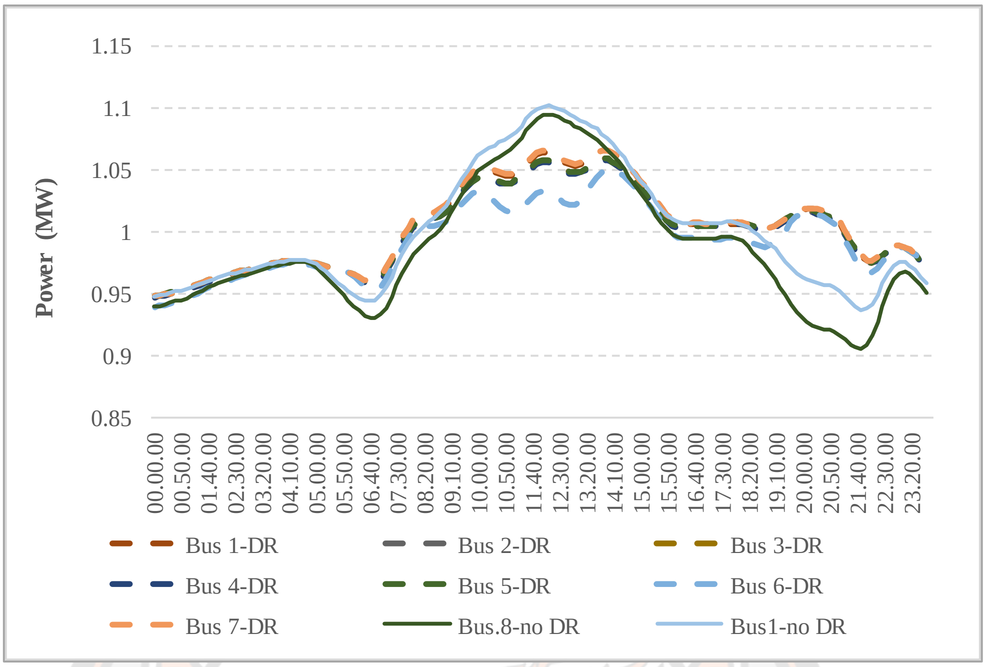

Figure 55 the grid voltage comparison

The grid voltage profile with the demand side management can stabilize the power quality of the 22 kV test system. Then load aggregator or the organization that collecting the customer with the controllable load is necessary for the near future. Because the power demand has been increased every year, but the power plant is limited. To build the fossil power plant is very difficult, not only the limitation of fossil but also environmental problems. Therefore, demand response is one of the essential topics for the coming Smart Grid.

Conclusion of this part

This paper discussed the concept of demand-side management by an automated building energy management system using IoT (aBEMS-IoT) under the Demand Response program for maintaining the power quality in the distribution system. The simulated and analyzed results indicated that the aBEMS-IoT could be managed the controllable load following any situations such as to stabilize the grid voltage as commanded by load aggregator or grid operator. The load flow dynamic simulations were done with two cases, and it can be concluded that in the case of the typical 22 kV distribution system some time the grid voltage may fluctuate out of the acceptable range of the PEA requirement, this may affect the power outage. On the other hand, the typical 22 kV distribution system with demand-side management by the aBEMS-IoT operated under the Demand response program could maintain the grid voltage into the acceptable range of the Thailand requirement. Finally, demand-side technology such as the aBEMS-IoT is important for the coming to the SmarGrid because building fossil fuel power plants is difficult due to the limitation of fossil fuel and environmental problems.

CHAPTER V

CONCLUSION

Conclusion

An Automated Building Energy Management System with the Internet of Thing (IoT)so-called aBEMS-IoT was developed for the reservation of the DR program to stabilize the power quality and stability of the grid network. The aBEMS-IoT consisted of three main parts, the first is the hardware part, which consisted of controlling devices, IoT gateway communication devices, data analytic devices. The second is the software, and the third is the communication part, which able to use both communication cable or wireless solution. The analyzed results of the test indicated that aBEMS-IoT could effectively manage the load following assumed the DR program. The response time from receiving the signal to end process was about 650 ms. This value is lower than 1 second, which is a very fast process. The aBEMS was able to connect (load building) and to disconnect (Load clipping) the load following assumed DR program for balancing supply and demand. This is a solution for Smart Grid or Microgrid, which will take the grid stability, power quality, resiliency, and finally, reliability.

This part presents the load flow dynamic simulation of the demand side management by using the aBEMS-IoT under the assumed Demand Response program for stabilizing power quality and flattening the duck curve. The result of the research indicated that the aBEMS-IoT was able to operate following the control signal of load aggregator for maintaining the power quality and flattening the duck curve. During the daytime, when overvoltage occurred, the controllable load was building to increase power demand for stabilizing the grid voltage as controlled by load aggregator. On the other hand, in the evening time, the peak load was clipped by the aBEMS-IoT for decreasing the load demand.

Finally, the demand-side technology, such as aBEMS-IoT is able to maintain the power quality in the acceptable range and also to flatten the duck curve. Demand response and demand-side management technology will be key parameters for the reliability and stability grid

Recommendation

1. Further study should be done on the applying of the aBEMS-IoT to the actual buildings at the testbed or weak grid network to find out more benefits.

2. The utilization of the aBEMS-IoT for maintaining grid voltage and grid stability should be investigated more for the actual use.

3. The algorithm for controlling the demand side management technology in the groups of smart buildings for maintaining grid voltage should be studied and investigated more in detail.

4. The finance and the economics of the aBEMS-IoT for both side, utility and customers, should be investigated more.

5. The impact of demand response for balancing demand and supply should be studied because it is important for the future grid.

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APPENDIX

APPENDIX A ACCEPTED SCOPUS JOURNAL

GMSARN Int. Conf. on Energy, Environment, and Development in GMS, 28-30 November 2019

Impact of Demand Response using aBEMS-IoT to flatten the duck curve in case of high penetration of RE systems on the 22 kV distribution Network

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This article presents the load flow dynamic simulation of the demand side management by using the aBEMS-IoT under the assumed Demand Response program for stabilizing power quality and flattening the duck curve. The simulation can be classified into two cases; the first was a typical 22 kV distribution test system and the second was a 22 kV distribution test system with demand-side management by aBEMS-IoT. The aBEMS-IoT operated under the algorithm and assumed DR program for stabilizing the grid network, which was controlled by the load aggregator. The result of the research indicated that the aBEMS-IoT was able to operate following the control signal of load aggregator for maintaining the power quality and maintaining the duck curve. During the daytime when overvoltage occurred, the controllable load was building to increase power demand for stabilizing the grid voltage as controlled by load aggregator. On the other hand, in evening time the peak load was clipped by the aBEMS-IoT for decreasing the load demand. Finally, the demand-side technology such as aBEMS-IoT is able to maintain the power quality in the acceptable range and also to flatten the duck curve. Demand response and demand-side management technology will be key parameters for the reliability and stability grid.

***Keywords*— Demand-side management, Demand Response, Load aggregator, Building Energy Management (BEMS)**

1. INTRODUCTION

Energy crisis and climate change are two different topics but closely related. The energy demand is rising every day due to the population and economy grow, but the depletion of fossil fuel is increasing evidently [1] – [2]. Due to the limitation of Fossil fuel, many countries promote a lot of renewable energy such as adder and feed-in tariff programs for increasing the capacity of RE systems [3] – [4]. In the case of high power production in the daytime and low generation in the evening time, this creates the duck curve. Duck curve problem occurs in the countries that generate much electricity from RE systems, especially solar energy because solar power plant can produce electricity only in the daytime when having solar irradiation.

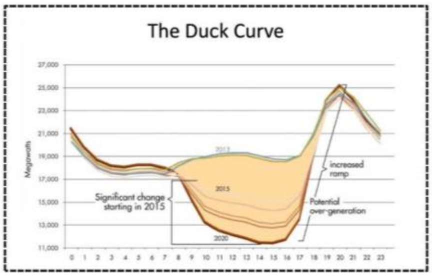

Fig.1. The Duck curve

The solution to flatten the duck curve is balancing between supply and demand. Demand-side management is one of the solutions to balance demand and supply using Demand Response (DR) concept [5] – [9], and it is significant for the future grid. Demand Response (DR) is significant for the future grid, also known as demand-side management [10] – [12]. DR refers to a change in load usage by the user from their normal load consumption pattern in response to changes in incentive payments, the price of electricity or available power quality in the network to achieve the DR concept, need the energy management system (EMS) [13] – [15], which can manage the load at the user side. The main DSM techniques are valley filling, load shifting, peak clipping, load building and load conservation as shown in Figure 2. The objective of DR can be classified into two groups; the first is for maintaining the power quality in the network and the second is for the economy of operation [16]. The programs of DR depend on the number of customers, load types such as residential, commercial, and industrial. The benefits from the DR program also depend on the level of customer's reaction or satisfaction with the applied program, etc [17] – [18]. However, benefits from applying are on both sides of customers and utility. Many utilities apply DR programs for controlling the power quality, stability and reliability of the grid instead of build fossil power plant.

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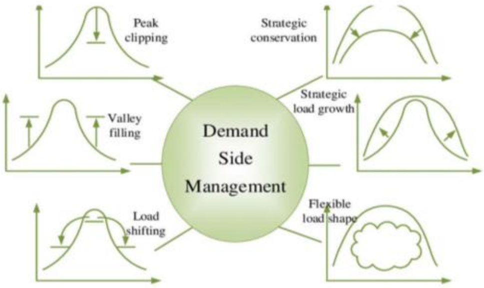

Fig.2. Demand-side management

The main DSM techniques are valley filling, load shifting, peak clipping, load building and load conservation as shown in Figure(2). The objective of DR can be classified into two groups; the first is for maintaining the power quality in the network and the second is for the economy of operation. The programs of DR depend on the number of customers, load types such as residential, commercial, and industrial. The benefits from the DR program also depend on the level of customer's reaction or satisfaction with the applied program, etc. However, benefits from applying are on both sides of customers and utility. Many utilities apply DR programs for controlling the power quality, stability and reliability of the grid instead of build fossil power plant. According mentioned above, Hene, the automated building energy management system using IoT (aBEMS-IoT) is developed for demand-side management and also supports the automated demand response [19] – [20]. The aBEMS-IoT consists of two parts as follows. The first is controlling devices (hardware) which enable to control the load On/Off, increase/decrease the power consumption of the load. The second (software) is a data processing system which is analyzing the data from both sides load aggregator and customers then after data analysis sends the signal to the control devices for the future process. This part includes the monitoring system which is the summary results of the process for the aggregator and customers. aBEMS-IoT enables to control of the load following the DR concept such as peak clipping, valley filling, load shifting, flexible load shape, stratic load growth. The objective of DR can be classified into two groups; the first is for maintaining the power quality in the network, and the second is for the economy of operation.

2. Research Methodology

The study and development of an Energy Management System for a Group of Smart Buildings with the Internet of Thing for Supporting the Automated Demand Response [21] – [23], this research developed an automated building energy management system using IoT (aBEMS-IoT) for flattening the Duck Curve under the demand response (DR). The performance of the aBEMS-IoT will be investigated and the utility and customer benefits will be evaluated. The complete research methodology is explained in four steps as follows. The first developed of the aBEMS-IoT for the smart building, the second is capability test of the aBEMS-IoT in the implemented building under the assumed DR program, the third is investigating the impact of utility for flattening the duck curve, and the fourth is analysis and conclusion. The detail of the research can be described as below.

2.2 The development of aBEMS-IoT

The automated building energy management system using IoT (aBEMS-IoT) was developed for supporting the DR program. The automated demand response (ADR) or load management is an automatic response to the requirement of an aggregator or an emergency. The concept of aBEMS-IoT is to manage the load in the building by Edge analytics and Control, its sending and receiving the signal through the IoT Gateways. The communication between the IoT Gateways and load can be the wireless, cable, or using both of them. The aBEMS-IoT components can be classified into three main parts; the first is controlling devices (Hardware), and the second is data processing and monitoring system (Software) and The third is communication. The control system (hardware) which enable to control the load On/Off, increase/decrease the power consumption of the load. The loads which are controlled by aBEMS-IoT consisting of the air conditioner, lighting, and plug for electric appliances.

Fig.3. The control system (hardware) of aBEMS-IoT

The communication of aBEMS-IoT can use both cable or wireless that depends on the working area of the building. The communication via the wireless is popular because easy to install and it doesn't need to wiring the cable. For the wireless solution, aBEMS-IoT uses LoRaWan which is a low power, wide-area networking protocol. The wireless communication takes advantage of the long-range characteristics, allowing a single-hoplink between the end-device and one or many gateways. All modes are capable of bi-directional communication, end-to-end security, mobility, and localization.

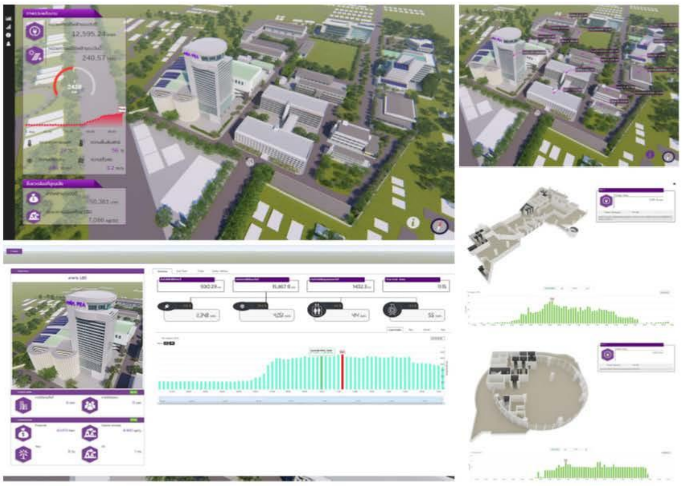

Fig.4. The examples of the buildings which is integrated with aBEMS-IoT

2.2 The simulation of aBEMS-IoT for flattening the duck curve

This research focused on demand-side management using aBEMS-IoT for flattening the duck curve and maintaining the power quality in the 22 kV distribution network. The increasing of RE systems connected to the 22 kV distribution systems has some negative impacts on the network, especially voltage rise in the daytime when a high amount of active power is injected into the grid. And the voltage drop in the night time during the peak load. These behaviors also create the duck curve. To verify the operation of the group of smart buildings integrated with aBEMS-IoT for flattening the duck curve and maintaining the power quality. The typical 22 kV distribution system in Thailand will be modified to the test distribution system connected with aBEMS-IoT (groups of the smart building) as shown in figure(5).

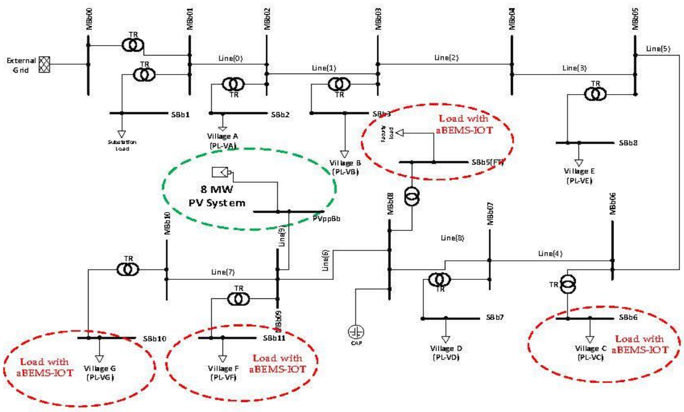

Fig.5. The 22 kV distribution test system

Table 1. The main components and parameters within the 22 kV distribution test system.

Components	Connection at Busbars	Ranges	Peak Load (MW)
Total Load (MW)	-		6 MW
Substation load	MBB01	At substation	0.08 MW
Vill. A (MW)	MBB02	From MBB01 to MBB02 (1.5 km)	0.5 MW
Vill. B (MW)	MBB03	From MBB02 to MBB03 (2.5 km)	0.5 MW
Free busbar	MBB04	From MBB03 to MBB04 (4.0 km)	0.5 MW
Vill. E (MW)	MBB05	From MBB04 to MBB05 (4.0 km)	0.4 MW
Vill. C (MW)	MBB06	From MBB05 to MBB06 (3.0 km)	0.5 MW
Vill. D (MW)	MBB07	From MBB06 to MBB07 (5.0 km)	0.8 MW
Factory Load, PL(FT) (MW)	MBB08	From MBB07 to MBB08 (1.0 km)	1.9 MW
Vill. F (MW)	MBB09	From MBB08 to MBB09 (6.0 km)	0.5 MW
Vill. G (MW)	MBB10	From MBB09 to MBB10 (1.0 km)	0.5 MW

The 22 kV distribution test system has the power quality problems on the grid fluctuation because of the unbalance of supply and demand that is existing in the northeast of Thailand. This feeder is connected with an 8 MW PV system, and the peak load of the feeder is about 6 MW, sometimes the load demand was only 1.5 MW, this even may create the voltage rise when high power production from the PV system. The detail of the main components within the 22 kV distribution test system cab be shown in Table.

2.3 The assumption of the DR program and working principle for aBEMS-IoT

The assumed DR programs would be used in this research is the Ancillary Sevices Demand Response Program (ASDRP). According to the DR programs, the aBEMS-IoT will operate under these DR programs for two purposes, the first is for maintaining the grid stability by keeping the power quality (Grid Voltage) in the acceptable range, and the second is the load profile management for flattening the Duck Curve.

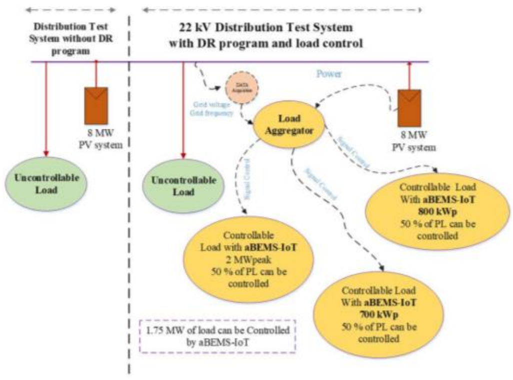

Fig.6. The assumed DR program

The assumed DR program for simulation the impact of the demand-side management in the 22 kV test feeder system in case of an unbalance between supply and demand. The aBEMS-IoT was modeled for three groups which were classified by peak power of the load, 2 MWp, 700 kWp and 800 kWp, 50 % of them can be managed by the aBEMS-IoT for managing the target load. The Algorithm for controlling the load of aBEMS-IoT at the test system can be shown as Figure(6).

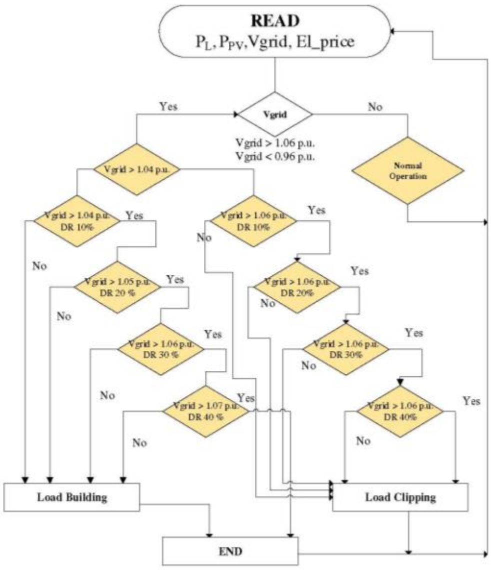

Fig.7. The Algorithm of the aBEMS-IoT

Figure(7) presented the algorithm of aBEMS-IoT for flattening the duck curve and stabilizing the power quality. The load of smart buildings is managed by aBEMS-IoT by two entities, the first is load clipping and the second is load building. In the case of load building, when the load aggregator sends the control signal to aBEMS-IoT then it is analyzed to control the target load. during the daytime when high PV production, the active power was supplied to the grid network, during this time may affect to increase the grid voltage. To maintain the power quality of grid network, Load aggregator sends the signal control to aBEMS-IoT for load building, increasing the demand power for balancing demand and supply. On the other hand, during the evening time when high power consumption, the grid voltage is decreasing because the demand is higher than supply, this case affects to low voltage, for maintaining the grid voltage, load aggregator sends the signal to the customers who used aBEMS-Iot integrated in the building for stabilizing the grid voltage by load clipping, decreasing the load demand. After the power quality of the grid is maintained by the DR program, the simulation result can be explained as shown below.

3. The Results and Discussion

Here are the results for the simulations that were simulated, the first simulating a typical 22 kV test distribution system and the second simulating smart building integrated with aBEMS-IoT, also connected to a 22 kV distribution test system.

3.1 The result of the typical 22 kV test distribution system

Generally, the grid voltage in the profile of the 22 kV test distribution system in each study busbars was fluctuated by unbalance of supply and demand. basically, the overvoltage because voltage source is from the location of the load and it injected the electrical power to the grid. The voltage drop occurred in the distribution system because the electric current travels through passive elements (such as wires, conductors, the load itself, etc.) that create resistance dragging on the voltage and decreasing. Figure(8) shows voltage profiles for ten busbars of the typical 22 kV distribution test system.

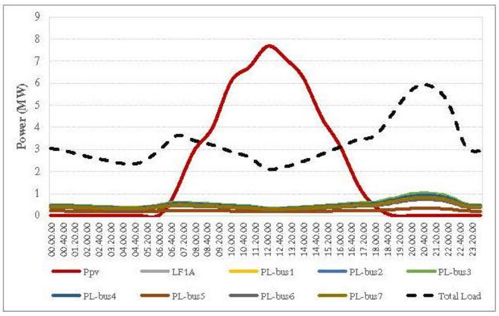

Fig.8. The typical 22 kV distribution system

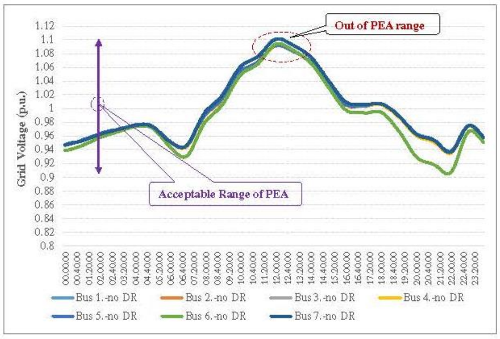

Fig.9. The voltage profile of the 22 kV typical 22 kV distribution system

The voltage profile in the typical 22 kV distribution system without the demand response program was fluctuation which depends on the demand power and supply power from the PV system. during the day time grid voltage was increasing because the active power is injected to the grid, considering the grid voltage value at the study busbar 5 (05) was 1.01 which is higher than the limitation of Thailand requirement. This case may affect the power outage because of the control switch is disconnected. On the other hand, during evening time when high load demand, the grid voltage was decreased, considering at bus 7 grid voltage was 0.89 p.u. which was lower than the requirement of Thailand. The grid voltage fluctuation problem as mention above will be solved by load management as described below.

3.2 The result of the typical 22 kV test distribution system integrated with aBEMS-IoT

According to the power quality problems of grid voltage fluctuation, this research found the solution to solve this problem by balancing supply and demand. The assumption of this research is in the 22 kV distribution test system connected to the groups of the smart building which were integrated with aBEMS-IoTs. Here has the Load Agregrator for controlling the load when grid operator needs. The concept is that when the power quality has been changed to the point that needs to maintain then the grid operator sends the command to the load aggregator for controlling the controllable load which is managed by aBEMS-IoT. The algorithm is that when the grid voltage has been changed to point of control, under and over voltage, the load aggregator sends the signal control to the customer in this distribution system for load building or load clipping to balance the supply and demand. As mentioned above then the aBEMS-IoT operates for stabilizing the grid voltage which is controlled by the grid operator or load aggregator following the algorithm as shown in figure 7.

The dynamic load flow simulation was done following the topology described above. The result of the simulation by Digsilent power factory software of the 22 kV distribution system with aBEMS-IoT can be shown in Figure (10).

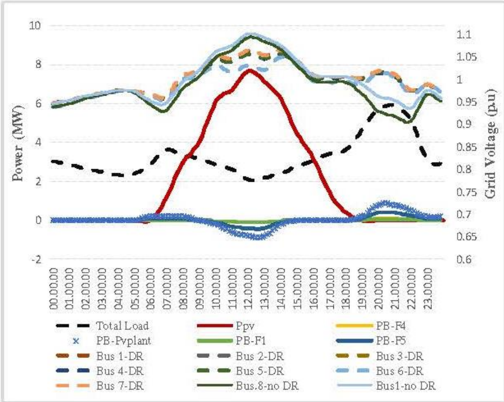

Fig.10. The grid voltage of the 22 kV test system which operated with the DR program for load management by aBEMS-IoT

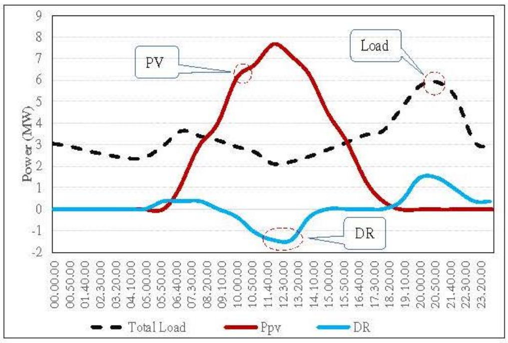

Fig.10. The total DR power in the 22 kV test system

Figure 10. and Figure 11. indicated that the power quality of every busbar in the test distribution system integrated with aBEMS-IoT was getting better when compared to the typical system. Considering, during the daytime (11.00 p.u. -13.00 p.u.) the grid voltage was decreased from 1.01 p.u. to 1.08 p.u because the aBEMS-IoT turned on the controllable load to increase the power demand. When the load increased, the power production from the PV system was supplied to load, then the supply and demand were more balanced. On the other hand, when the peak load occurred during the peak demand at 6.00 p.m. – 10.00 p.m, the grid voltage dropped in case of high load consumption. To stabilize the grid voltage, aBEMS-IoT decreased the controllable load by the switch of the not critical load then the grid voltage was increased because of load decreased. To stabilize the power quality by demand-side management with aBEMS-IoT, it directly affects the load profiles in the distribution system, when the load power ramps up or ramps down, the ramp rate is not steep so, can be concluded that the demand-side management by DR program with aBEMS-IoT can be flattened the duck curve as shown in Figure (12).

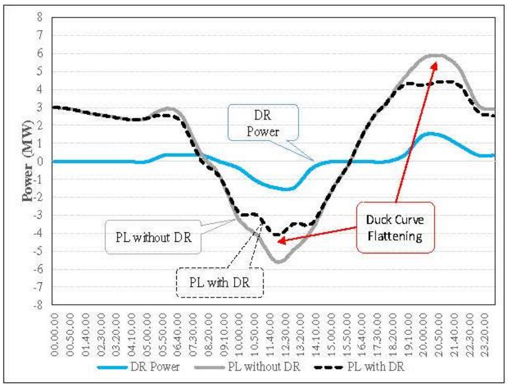

Fig. 12. Flattening the duck curve by aBEMS-IoT

3.3 The comparison between the two simulation cases

The comparison of dynamic load flow simulation of two cases, the typical 22 kV distribution system and the 22 kV distribution integrated with aBEMS-IoT can be shown in Figure (13).

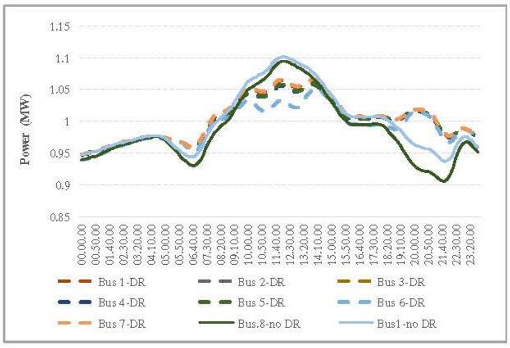

Fig.11. The grid voltage comparison

The grid voltage profile with the demand side management can stabilize the power quality of the 22 kV test system. Then load aggregator or the organization that collecting the customer with the controllable load is necessary for the near future. Because the power demand has been increased every year, but the power plant is limited. To build the fossil power plant is very difficult not only the limitation of fossil but also environmental problems. Therefore, demand response is one of the essential topics for the coming Smart Grid.

4. Conclusion

This paper discussed a concept of demand-side management by automated building energy management system using IoT (aBEMS-IoT) under the Demand Response program for maintaining the power quality in the distribution system. The simulated and analyzed results indicated that the aBEMS-IoT can be managed the controllable load following any situations such as to stabilize the grid voltage as commanded by load aggregator or grid operator. The load flow dynamic simulations were done with two cases, It can be concluded that in the case of the typical 22 kV distribution system some time the grid voltage may fluctuate out of the acceptable range of the PEA requirement, this may affect the power outage. On the other hand, the typical 22 kV distribution system with demand-side management by aBEMS-IoT operated under the Demand response program could maintain the grid voltage into the acceptable range of the Thailand equipment. Finally, the demand-side technology such as aBEMS-IoT is important for the coming the SmarGrid because building fossil fuel power plants is difficult due to the limitation of fossil fuel and environment problems.

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