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Smart Community Based Solution for Energy Management

An Experimental Setup for Encouraging Residential and Commercial Consumers Participation in Demand Response Program

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Abstract

Smart grid technology development progression has created a possibility for the end users' participation in the electricity market possible. Recently, the Singapore government has changed the rule for participation in the wholesale market. The Smart Community project, developed by NTU, DNV GL and Green Koncepts, will look into critical factors that will help retail consumers to participate in the demand responses (DR) program and time of use (TOU) pricing. This study reviews benefits for current retail consumer, the impact of DR and TOU on real-time energy consumption of the users, the impact of user experience-focus application toward smart grid participation program on participation reliability and contribution in power reduction during curtailment period. The DR program allows the users to become an active participant in the energy market. It also allows the government to plan better on the limited and costly energy resources, improve system reliability, and reduce transmission and distribution congestion, check and balance on the market power generation. A mobile-based user-experience focus on convenience application is to be developed for consumers to actively participate in the demand-side management programme, which make Singapore Wholesale Energy Market more resilient and reducing market power by introducing competition.

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1. Introduction

Singapore has launched a Smart Nation initiative in 2014, coordinated by the Smart Nation Program Office under the Prime Minister Office of Singapore. The program aims to improve the people of Singapore as a society and factor of livability, using technology to solve its problem and address existential challenge, assist the citizen to leverage on the technology in the daily routine, and allowing the citizen to lead a more meaningful and fulfilling live.

The existential challenge of energy field in Singapore is identified as a high dependence on imported energy, the sharply rising oil prices of recent times are posing a serious challenge to Singapore's economic competitiveness and growth. The recent rapid development in the digital information technologies has made it possible to develop a data layer in the existing infrastructure to have better information on energy demand and supply requirement in real-time. The addition of data layer in the infrastructure layer is the definition of smart grid [1].

The Smart Grid system with the digital communication capability has the capability to solve the Singapore energy challenges. The consumer will be able to participate as an energy producer, reducing Singapore, as a nation, dependence on fossil fuels. Subsequently, the traditional single directional energy distribution system will evolve into a bi-directional energy distribution system. Energy productions are no longer located only in the high voltage system. The previously traditional consumer, connected to the low voltage distribution system, will be able to become an energy producer. The development of renewable energy technology and storage system has reached a critical economic scale to allow deployment in mass retail consumers. The digital communication in the energy distribution system will provide the necessary information to ensure availability of the required energy in the grid to ensure energy grid reliability.

The EcoCampus initiative, a flagship project of Energy Research Institute @ NTU (ERI@N), under the umbrella of Sustainable Earth Office (SEO), for the Nanyang Technological University (NTU), aims to reduce energy intensity in the NTU Yunnan Garden campus. The campus energy intensity ratio per square meter of Gross Floor Area (GFA) has actually decreased by 7% since the Financial Year 2011. The commitment for continued development in NTU has increased the GFA by 58,000m^2 in the year 2014 in comparison to 2011. As of December 2015, 20 building projects in NTU have been Green Mark-certified. Out of which, 18 buildings achieved Green Mark Platinum [2]. The Eco Campus initiative identified Smart Grid and Renewable Energy Integration as an area of Research, Development and Deployment in the Campus [3].

The Smart Community Solution for Energy Management aim to develop a model to engage retail consumers, increase participation in the energy market, and increase resilience in the Singapore energy model. A known popular tools will be develop to address the challenges in user engagement. Various packages will be offered to identify the responsiveness of the consumers to the program.

2. Demand Response – Identification of Critical Changes and Benefits

Demand Response in the Singapore

The Energy Market Authority (EMA), a statutory board under the Ministry of Trade and Industry in Singapore, aims to ensure reliability and secure energy supply, promote effective competition in the energy market and develop a dynamic energy sector in Singapore. Since the year 2001, new rules have been continuously implemented to liberalize energy market in Singapore. Consumers have more options to choose the source and types of energy available for them. However, the participation rates from residential and commercial consumers are not significant.

There are three critical factors that made electricity market liberalization possible. First, establishment of National Energy Market of Singapore (NEMS) which eventually leads to establishment of wholesale market, which allow participation of smaller, non-baseload generator. Second, the threshold for contestable consumer category has been progressively reduced. In 1 July 2015, the minimum limit for participation is consumer with energy bill 2000 kWh per month. Under this new threshold, multi-tenanted building and commercial will be able to participate in the new liberalize market. Lastly, the contestable consumer are able to buy energy from more than one retailer, which was not

the case before 2001. The retailers are able to buy energy from energy generators through vesting contract or spot price market [4].

The two types of market in wholesale markets, "real-time market" and "procurement market", provide possibility for retailers to provide more variety of services, and consumer to reduced financial spending for electricity. This could be achieved by leveraging on the low rates during surplus, and reduced usage during high rates. In the past, consumer received a constant energy price throughout the day, and the price peg against estimated oil price for the next three months. The commercial and residential consumers in Singapore makes up about 36.6% and 16.1% of the total electricity consumers in Singapore.

3. Test-bed Design and Case Study

3.1. Methodology: Automating Consumer Participation for Demand Response Participation

Several stages of decision-making process are required for participation in the DR programme. The stages are simplified in the case of participation by residential or smaller commercial consumer. Fig. 1 indicates the decision making process of participating in Demand-Side Management.

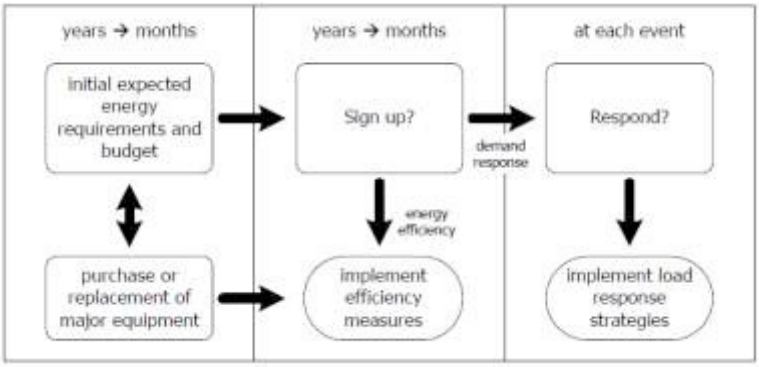

Fig. 1. Consumer decision for Demand-Side Management [1]

In our study, we have to consider both process. NTU, as an entity, is a contestable consumer with it's own peak load profile. However, the residences and commercial buildings in NTU, is the smaller consumer contributing to the overall NTU load profile.

3.2. Objective of the Test-bed

The Smart Community project includes program which is applicable for residential and commercial users.

The two main experiments for users are: 1) Provide residential users with smart meters for a real-time electricity monitoring and auto-electricity billing mobile application. 2) Encourage residential users with Internet of Things devices to create smart devices (e.g. Air-Conditioner controller, Washing machine controller and so on.) to participate in the Demand Response Programme of Singapore.

Additional potential capability of the proposed Test-bed is its adaptability to demonstrate--model residential-commercial users' response to the DR program and build a hierarchical level model. The proposed model can include Machine Learning prediction algorithms and techniques [5] and leverage hierarchical game theoretic models like reverse Stackelberg game for adaptive incentive design [6]. Machine learning gives real-time - forecasting capabilities to the Test-bed. Moreover, game theoretic models ensure a well-defined predictive model that captures the uncertainty of costumers decision-making process, while provides a useful feedback about an optimal incentive design [7], [8].

Demand Response (DR) program aimed to enhance competition in the wholesale electricity market. DR enables contestable consumers to reduce their electricity demand voluntarily, in exchange for a share in the system-wide benefits, in terms of reduction in wholesale energy prices as a result of their actions. Such reductions in electricity consumption typically take place when wholesale electricity prices are high or when generation supply is tight, as shown in Figure 2.

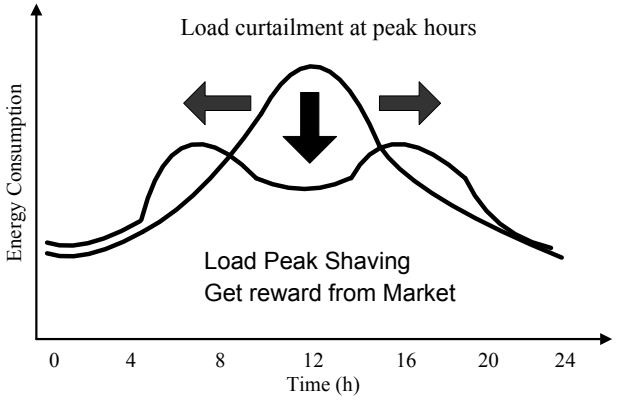

Fig. 2. Objective of Demand Response Programme

In the experiment an application will be developed for users to review their monthly bill and daily electricity usage. Engaging users' participation in the DR can be done via appropriate incentive designs driven by accurately estimated game theoretic models leveraging Machine Learning and inverse optimization methodologies [7], [8]. The overall experiment is aimed to proof that a) consumer is able and responsible to participate in the demand response programme. b) The contribution of the residential and commercial users should not be neglected for the wholesale market and electricity grid system of Singapore. c) The consumer financial benefit would be identified through this experiment. d) Consumers will get frequent feedback about their contribution to CO_2 emissions and greenhouse effect.

3.3. Test-bed Tools and Platform

The core idea of the Smart Community Programme is to encourage retail consumers with smart grid technology to participate in electricity market of Singapore, and increase the resilience of Singapore Energy Market.

As such, the aggregator would be involved to integrate the information and technology to provide users—both residential and commercial users—better energy solutions. An example of the proposed service and software for residential users is shown in Figure 3. The aggregator would collect data from electricity market, renewable generation and consumers. According to the current market information and consumers' historical energy data, an optimization algorithm would be applied to provide consumers an energy solution for decreasing greenhouse emissions and making economic benefits. Optimization algorithm should potentially involve the following requirements:

1. By adaptive to real time data from the market and costumers
2. Run in a feasible time and has low complexity requirements
3. Can leverage incentive design mechanism and uncertainty in the decision making process of the costumers

Under the Smart Community Solution for Energy Management, two applications would be offered to the consumers: 1) Application for the current retail consumers, mainly for Residential and Commercial Building; 2) Application for Demand Response (DR) aggregator: Smart Community Aggregator (SCA).

The functional specification of the application are described below:

Consumers Applications

This consumer application is designed to provide higher granularity information to the user. It will provide the following information:

- Detailed summary about the energy historical consumption and peer to peer comparison in this community
- A control panel to read the real-time data of each device and control these devices.
- Data about emissions and impact to climate change
- Inform the user the current package they are using, including the tariff information and demand response information.
- Make changes to different package (electricity price/curtailment reward).
- The curtailment event notification, incentive/penalties settlement and energy curtailment event history review.
- Statistical data comparing their actions – participation to other consumers (anonymous). This will potential lead to some Socio-behavioral impact to their decision-making process.
- Detailed report of the bill (month/year), including the energy consumption bill and the summary of curtailment event.

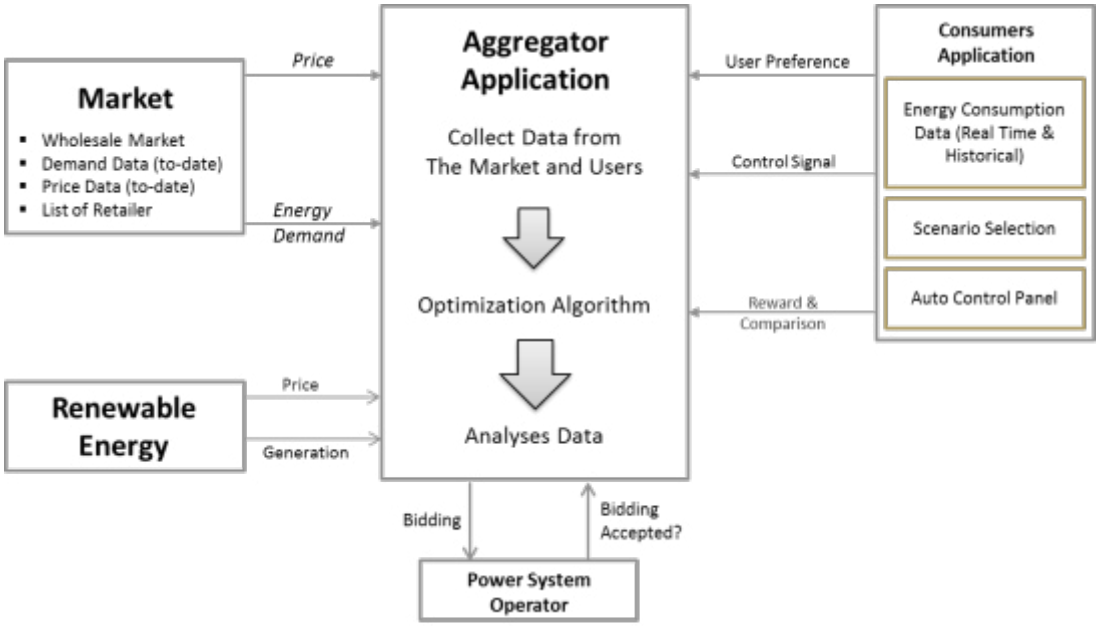

Fig. 3. Applications Structure

Aggregator Application

The SCA aims is to provide ease for the aggregator to manage participants, understands the results and benefits. The functions are described below:

- Energy Dashboard. Provide summary of energy consumption.
- Consumer Participation in the Curtailment event.
- Curtailment planning and predictive results.
- Call for curtailment event and the results

Table 1. Experiment plan.

	Price Sensitivity			Flexibility Sensitivity			Benefit Sensitivity	
Scenario	**SP Rates**	**"Green" Sources**	**Time-of-Use**	**Device Control**	**Comfort Level**	**Curtailment Event**	**Incentive**	**Penalties**

Stage 1	Y	N	N	Y	Y	Y	Y	N
Stage 2	Y	Y	N	Y	Y	N	Y	Y
Stage 3	Y	N	Y	N	N	N	Y	Y

3.4. Test-bed Plan

The test-bed experiment of Smart Community would be carried out using the tools and platform mentioned above. The experiment would last for one year in several stages. The participants would be provided with variety of electricity price package and curtailment options package.

The experiment plan is designed with increasing restriction and penalties to identify the consumer reaction to the process. Table 1 describe the experiment plan in more details.

The rewards and penalties is based on a randomized historical price, which will be available in the application half an hour before curtailment time.

4. Conclusions and Future Work

This paper proposes a model to increases the participation rates in the wholesale electricity market of Singapore and improve its resilience. It proposes and constructs an experimental plan and platform based on the current EcoCampus project in NTU. It is going to carry out an experiment based on the platform with residential and commercial building in Nanyang Technology University, Singapore. The experiment aims to develop a model to engage more users to participate in the Singapore wholesale electricity market, in this case, we an application, a popular platform, will be used for user engagement. The future work will focus on how to build a suitable business and management processes, to increase competition and resilience of the Singapore electricity market, which will bring benefits to the operator, the aggregator and the end-users.

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