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User Behavior Assessment of Household Electric Usage

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Abstract. *Energy resilience is one of the famous issues among researchers and practitioners in energy sector. With enabling new technologies in power engineering for smart grid such as distributed generation, distributed storage, and intelligent information and management, each household community can establish a resilience energy production, distribution, and consumption. A household in smart grid system behaves as a customer and producer at the same time. This condition enabled them to reduce the power shortage in the peak hours, reduce CO2 pollution using renewable electricity, and minimizing electricity usage by changing life style. In developing countries, the amount of electricity supply is less than its demand. Most of the demand comes from the household that has peak load on nighttime. Understanding the user behavior toward electricity usage is important to minimize peak load and avoid power blackout. In this research, we propose a methodology - using game theory- to model a behavior of the household tenant in using electricity especially the use of cooling and heating appliances tenant. We found that the users behavior is greatly affected by the cost they are willing to pay for avoiding uncomfortable situation.*

Keywords: *User behavior, Game theory, Smart grid, Heating and cooling appliances, Energy resilient.*

1. Introduction

Recently, the demand of electricity increased significantly and fluctuated dynamically. This fluctuation decreases generation efficiency and the peak load drives minimum requirements of electricity to be generated and transmitted (Molderink et al, 2010). In most developing countries, where the major user of electricity is a household, the peak load occurs at 18 PM – 21 PM.

On the other hand, in developed countries, the peak load occurs at daytime due to high electricity consumption of the industrial sector. In addition, the urgent need of CO2 emission reduction issue have led to the development of new grid technologies. Originally, the grid terminology refers to an electricity system that involves activities like electricity generation, transmission, distribution, and control (Fang et al, 2013).

The grid carries electricity power from a large capacity central generator to the users. In the early of 21^{th} century, a smarter electricity grid (commonly called smart grid) had been established using two ways flows of electricity and integrated information management in a distribution network. Smart grid technologies have a capability to generate and distribute power in an efficient way, and respond effectively to a wide range conditions that may occur anywhere in the grid.

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The introduction of electric generation based on renewable resources like sun, water, and wind, is one of the major parts of smart grid. However, the amount of electricity generated from renewable sources (called micro grid) is fluctuating and uncontrollable (Molderink et al, 2010). In this situation, additional production of electricity power is necessary to reduce demand fluctuation, supply uncertainty, and avoid power shortage for some users.

Each of the users in smart grid can become a producer of electricity by installing renewable electricity source. We can call this user as the active user. They have an ability to manage their appliance load, generate a small amount of electricity from renewable sources, and keep their own energy in term of electricity and heat. Active users in decentralized power system have two obvious advantages over passive user in centralized ones, such as improve energy usage and contribute to emission reduction (Gu et al, 2014). Active users can both buy and sell electricity to the other active users or to the electric company.

Besides increasing the production capacity of the renewable energy in house, the household tenants have to be able to manage their electricity usage trough changing their behavior. Understanding the behavior of the user in using electricity is important in this situation. By adjusting their behavior, they can maximize utilization of renewable energy sources, minimize usage of electricity, and help the other user in needs. Similar with lateral transshipment of inventory system in disaster recovery (Mulyono and Ishida, 2014), each active user can mutually help the other active users having electric shortage.

We proposed a methodology to understand the behavior of the active users in using electricity. We utilize game theory to model the behavior and interaction between active users on their way to maximize their benefit over electricity consumption and production. The active users are players in a game that defined by a common goal with different constraints and conflicting objectives. We use game against nature to predict the behavior of electricity consumption of active users. We are focusing on the cooling and heating appliances since those appliances are major contributor of electricity consumption.

The remaining of this paper is structured as follows. The following section provides an overview of several related work on smart grid. Section three introduces a model of user interaction to minimize the electricity consumption and support the other active users. Section four describes an implementation of the model trough simulation process. We conclude this paper with a discussion of the result.

2. Related Work

Development of smart power grid, that augments traditional power grid system, is one of the greatest inventions in the last decade. In contrast with traditional power grid system, that carries electricity power from a few central generators to a large number of users, smart grid uses two-way flows of electricity and information to create and distribute electricity. Smart grid includes the entire spectrum of the energy system from the points of generation to the points of consumption. Smart grid is decentralized electricity power system that uses two ways information and computational intelligence in an integrated fashion toward electricity generation, transmission, substations, distribution, and consumption to achieve electricity system that is safe, clean, secure, reliable, efficient, resilient, and sustainable (Gharavi and Ghafurian, 2011).

The International Energy Agency concludes that, although decentralized electricity system has a higher cost than centralized ones, it has potential to supply all demand with the same reliability but with lower capacity margin (International Energy Agency, 2002). We can simply define smart grid as a decentralized power grid that involves four operations like power generation, transmission, distribution, and control. Table 1 shows the difference between conventional power grid and smart grid (Farhangi, 2010). From the technical perspective, smart grid consists of three major systems such as smart infrastructure system, smart management system, and smart protection system (Fang et al, 2013).

Smart infrastructure system is the energy, information, and communication infrastructure underlying the smart grid. This infrastructure supports two-way flow of electricity and information. Smart management system provides advanced management and control services and functionalities. Smart protection system provides advanced grid reliability analysis, failure protection, security, and privacy system.

Table 1. Comparison between conventional grid and smart grid (Farhangi, 2010)

Conventional Power Grid	**Smart Grid**
Electromechanical	Digital
One-way communication	Two-way communication
Centralized generation	Distributed generation
Few sensors	Sensors throughout
Manual monitoring	Self-monitoring
Manual restoration	Self-healing
Failures and blackouts	Adaptive and islanding
Limited control	Pervasive control
Few customer choices	Many customer choices

In the beginning of smart grid development, many research focused on distributed generation management, energy storage and demand side management. Stability of the grid is studied intensively by (Azmy and Erlich, 2005) having a conclusion that electric generators are key to grid stability. In energy storage field, one of the hot topics is level out the electricity demand fluctuation by combining electricity storage with renewable resource such as windmill (Costa et al, 2008). Most literature in demand side load management used the agent-based solution having a hierarchical structure ensures the scalability of the solution (Molderink et al, 2010). Interaction of the electricity user also modeled using agent-based solution. Each of the smart grid users is an active user having the ability to consume, produce, and share electricity between them.

Game theory is the best tool to model the interaction of a user to maximize their payoff. Game theory related to the actions of decision makers who are conscious about their actions and its effect. A game consists of a principal and a finite set of players, each of which selects a strategy with the objective of maximizing his utility (Charilas and Panagopoulos, 2010). The utility function represents each player’s sensitivity to others actions.

3. Behavior of Electricity Consumption

In every household, there are many electric appliances commonly used such as refrigerator, heater, air conditioner, microwave oven, television, water pump, and dehumidifier. Each of them consumes different range of electricity like refrigerator (725 watt), heater (750-1500 watt), air conditioner (900-1500 watt). Among all of them, the appliances for cooling and heating take the highest electric consumption level. It takes about 8-34% of the overall energy consumption and about 12-38% of the overall energy consumption in summer and winter, respectively (Takuma et al, 2006).

Furthermore, the consumption level of those appliances is sensitive to the environmental temperature and lifestyle of the users. For that reason, we propose a game theory model against nature to understand the behavior of the users in using the cooling and heating appliances. Thermal comfort of the human depends on air temperature, radiant temperature, air velocity, and humidity (Health and Safety Executive, 2013). Comfortable air temperature is from 21^{o}C to $23\,^{o}$C during winter, and from 23.5 ^{o}C to 25.5 ^{o}C during summer. In this research, we focus on one adjustable variable, which is air temperature.

The user of the household has three strategies such as not use the cooling/heating appliances, use the cooling/heating appliances economically and use the cooling/heating comfortably. If the user uses the cooling/heating comfortably, amount of electricity will increase at the maximum level. On the other hand, if the user uses the cooling/heating economically, he can reduce the cost while maintaining thermal comfort at a minimum level. Figure 1 illustrates tradeoff between comfort level and expenses. The more expenses spend to turn on the cooling or heating appliances, the user feels more comfortable; nevertheless, at some point the comfort level is decreasing as the expense increases. Based on Figure 1, there are there important points such as economic point, comfort point, and waste point.

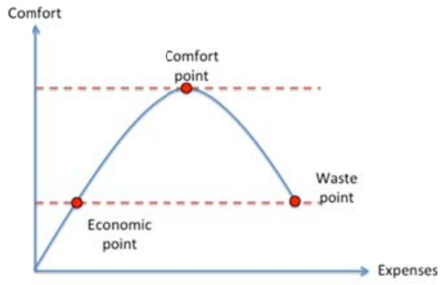

Figure 1. Expenses vs. comfort

Table 2. User strategy vs. temperature condition

Strategy		Temperature		
		Low	Medium	High
User	Not use cooling/heating	P_1	P_2	P_3
	Use cooling/heating economically	P_4	P_5	P_6
	Use cooling/heating comfortably	P_7	P_8	P_9

Based on the temperature level where the user lived, we made three conditions such as low, medium, and high temperature. In game theory, nature represents those three situations. Each temperature condition has a certain probability of occurrence. The users have three strategies such as not using cooling/heating, using cooling/heating economically, and using cooling/heating comfortably. Table 2 shows a matrix between user strategy and temperature condition.

Variable P (P_1 to P_9) represents a payoff for each strategy. We consider several variables as follow:

AT = maximum or minimum temperature possible to achieve by cooling or heating appliance
ST = the temperature set by the user
ET = the economic temperature
CT = the comfort temperature
NT = the current temperature
EC = electricity cost
PC = suffer cost

Suffer cost is the expenses to get the pleasure that varied according to the current temperature level. This cost varies according to the user. Basic payoff formula derives from the amount of saving electricity and amount of comfort sacrificed. The formula 1 shows basic payoff calculation.

$$PayOff = \left|\frac{AT-ST}{AT-NT}\right| xEC - \left|\frac{CT-ST}{CT-NT}\right| xPC \quad (1)$$

If the user chooses not using cooling/heating device, the set temperature is equal with the current temperature. Furthermore, if the user chooses to use cooling/heating device economically, the set temperature is equal with the economic temperature. Finally, if the user chooses to use cooling/heating device comfortably, the set temperature is equal with the comfortable temperature. The payoff formulas (P_1- P_9) are shown at Appendix A.

We can calculate the expected payoff for all possible temperature by multiplying the payoff formula with occurrence probability of low, medium, and high temperature. The formula 2 show expected payoff for all temperature condition.

$$ExpPayOff = \sum probability\ x\ Payoff \quad (2)$$

4. Numerical Analysis and Discussion

In this section, the proposed model is applied to the household community having dual bus system. First of all, we analyze the user behavior toward electricity consumption. We pick up tentative data of heating and cooling appliance of one household as given at Table 3. These data show temperature situation during the winter season. If the suffer cost for low, medium, and high temperature is 10, 5, and 3, respectively, the expected payoff is given at Table 4. Furthermore, if the suffer cost for low, medium, and high temperature is 20, 15, and 10, respectively, the expected payoff is given at Table 5. Lastly, If the suffer cost for low, medium, and high temperature is 25, 20, and 15, respectively, the expected payoff is given at Table 6.

Those three tables imply that expected payoff is sensitive toward suffer cost. If average suffer cost is above the electricity cost, the user prefers to use cooling and heating appliances in a comfortable setting. On the other hand, the user does not prefer to use cooling and heating appliances if the average suffer cost is below the electricity cost. Figure 2 and 3 illustrate the trend of the suffer cost to the payoff and trend of the suffer cost to selected strategy, respectively. This figure clearly show that there is a trade off between suffer cost and payoff and the active user tend to use cooling/heating appliance comfortably as the suffer cost increases.

Table 3. Heating and cooling appliance data for one household

No	Description	Value
1	AT (maximum or minimum temperature possible to achieve by cooling or heating appliance)	Max: 30°C, Min: 18°C
2	ST (the temperature set by the tenant)	23°C
3	ET (the economic temperature)	20°C
4	CT (the comfort temperature)	25 °C
5	EC (electricity cost)	JPY20/Kwh
6	PC (suffer cost)	JPY10/Kwh
7	Temperature probability	Low: 0.3, Medium: 0.4, High: 0.3
8	Temperature range	Low: <5 °C, Medium: 5 °C - 10 °C, High: 10 °C-15 °C

Table 4. Payoff for each user strategy with suffer cost 10, 5, 3

		Temperature			Expected
		Low	Medium	High	
User	Not use cooling/ heating	10.0	15.0	17.0	14.1
	Use cooling/ heating economically	5.1	7.3	11.1	7.8
	Use cooling/ heating comfortably	3.7	4.3	6.3	4.7

Table 5. Payoff for each user strategy with suffer cost 20, 15, 10

		Temperature			Expected
		Low	Medium	High	
User	Not use cooling/ heating	0.0	5.0	10.0	5.0
	Use cooling/ heating economically	2.9	4.5	8.0	5.1
	Use cooling/ heating comfortably	3.7	4.3	6.3	4.7

5. Conclusion

This paper successfully built deterministic model in power engineering based on game theory. The result shows unique behavior of the active users toward electricity usage especially in using heating and cooling appliances. The user strategy is highly affected by the suffer cost. This suffer cost is related with the physical condition of the user, their financial condition, and their life style.

Table 6. Payoff for each user strategy with suffer cost 25, 20, 15

		Temperature			Expected
		Low	Medium	High	
User	Not use cooling/ heating	-5.0	0.0	5.0	0.0
	Use cooling/ heating economically	1.7	3.1	5.7	3.5
	Use cooling/ heating comfortably	3.7	4.3	6.3	4.7

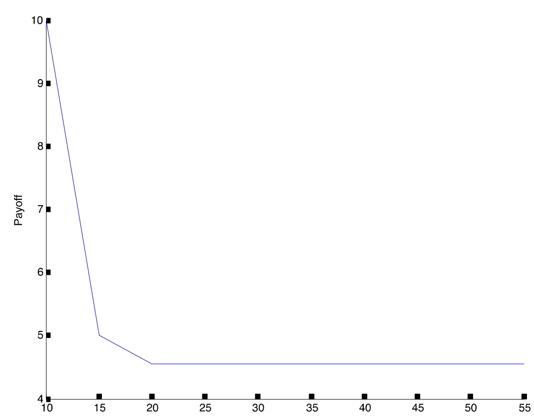

Figure 2. Suffer cost vs. payoff

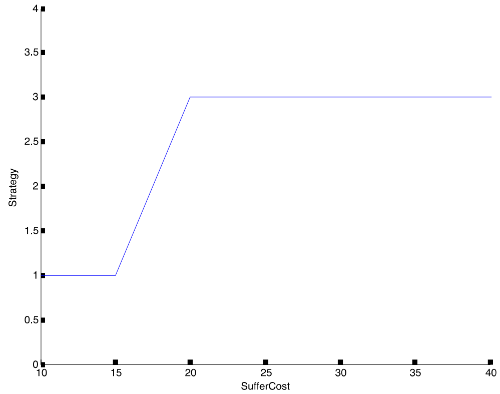

Figure 3. Suffer cost vs. strategy selection (1=not use cooling/heating appliances, 2 use cooling/heating appliances economically, 3 use cooling/heating appliances comfortably)

This model is practically applicable to be used in smart grid with dual bus system. Future development of this research can be directed to the development of probabilistic model of mutual support system in electricity generation and distribution.

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APPENDIX A

$$P_1 = EC - PC_{low} \tag{1}$$

$$P_2 = EC - PC_{medium} \tag{2}$$

$$P_3 = EC - PC_{high} \tag{3}$$

$$P_4 = \left|\frac{AT - ET}{AT - NT}\right| xEC - \left|\frac{CT - ET}{CT - NT}\right| xPC_{low} \tag{4}$$

$$P_5 = \left|\frac{AT - ET}{AT - NT}\right| xEC - \left|\frac{CT - ET}{CT - NT}\right| xPC_{medium} \tag{5}$$

$$P_6 = \left|\frac{AT - ET}{AT - NT}\right| xEC - \left|\frac{CT - ET}{CT - NT}\right| xPC_{high} \tag{6}$$

$$P_7 = \left|\frac{AT - CT}{AT - NT}\right| xEC \tag{7}$$

$$P_8 = \left|\frac{AT - CT}{AT - NT}\right| xEC \tag{8}$$

$$P_9 = \left|\frac{AT - CT}{AT - NT}\right| xEC \tag{9}$$