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RESIDENTIAL CUSTOMER DEMAND RESPONSE PROGRAM IN MICROGRID SYSTEM: A SURVEY LITERATURE

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ABSTRACT: Electricity supply in microgrid power systems often faces limited power supply constraints. Besides adding more power generation and organizing power plants scheduling, efforts to balance supply and power requirements in the power system can be made by regulating the amount of electrical load. Demand-side management (DSM) program can be done to control energy consumption and limit peak loads. The demand response (DR), as one of the DSM program, can be implemented to regulate the electric load to balance supply and demand. Residential customers demand response is a program that aims to reduce peak load by shifting or shedding residential electricity loads. This load reduction method has been used to control the peak load to be able to adjust to power supply conditions. This paper presents a literature survey of articles that address the application of DR for residential customers. The study uses the assumption that majority of electrical loads in microgrid systems are residential customers. It is expected that a balance between supply and demand for electricity in the power system can be achieved through demand response activities for residential customers. Here, a review of effective demand response methods is performed to precisely and accurately regulate the use of electricity by residential customers to limit peak load and control electrical energy consumption. In the end, this paper also discusses the possible implementation of demand response method for residential customers on a microgrid system.

Keywords: Residential customers demand response, Load and power supply balancing, Electricity price, Incentives, Efficiency, Home energy management system

1. INTRODUCTION

Indonesia is an archipelagic country, consisting of over 16,000 islands. In the effort to provide the electrical power supply for small, leading and outermost islands, Indonesia is developing microgrid technology. In day-to-day operation of microgrid power system to provide electricity supply for customers, often encountered constraints of a limited power supply of electricity. In general, this problem is solved by adding power generation capacity and scheduling the operation of each generating unit, including renewable energy (RE) plants, which is integrated into the existing power system to increase power capacity. Besides adding power plants, efforts to create a balance between supply and demand in the power system are carried out by controlling the electrical load. Here, the balance between the supply of electric power and variable load must be regulated and maintained [1].

On the demand side of a power system, controlling electrical loads and load scheduling can be done by using demand-side management (DSM) method, with the aim to balance the load and electricity power supply. DSM is a method to regulate customer's demand load intelligently by reforming the load profile through efforts to change energy consumption patterns of electricity customers [2], [3]. With the arrangement of power usage on the customer side, it can create a condition of power reserves that are still available, so the need for additional new generators can be postponed. That fact is stated by Peter Palensky and D. Dietrich (2011) who delivered the results of their research, DSM could be used to intelligently influence the load, rather than building a new power plant [4]. The concept of DSM was first developed by a utility with an aim to influence the customer's use of electricity [2]. In the report of EPRI (1993), utility companies have load control programs that encourage the DSM programs.

Charles River Associates (2005) mentioned that the DSM has two main categories: energy efficiency and demand response (DR) [1]. The purpose of energy efficiency is a reduction of energy consumption, and the implementation of the DR refers to load profile adjustment, by implementing load shifting, shaving, and shedding, driven by market incentives.

DR scheme is an ability of an electric customer to reduce kWh usage or kW demand over a period or shift the usage to another period, in response to price or financial incentives [1]. Considering that the most significant part of electricity customers consist of residential customers, then DR program for residential customers may have enormous potential in electrical load controlling [5]. In electric power systems in remote areas or islands such as in Indonesia, where electricity supply is limited, DR schemes can be one of the appropriate ways to manage electricity loads, to be adapted to the electric power supply capability.

The proper design and scenario of DR implementation for residential customers will determine the successful implementation of intelligent electricity demand management to change the customer load profile. Therefore, some types of technology schemes, business models, and methods of application of the DR program for residential customers must be mastered and identified for the successful implementation of the program.

This paper presents a literature review of articles discussing the development and implementation of DR program for residential customers. In general, discussions address the objectives, general concepts, and technology schemes that are applied to residential customers. In particular, the review will focus on residential customer demand response optimization algorithms, control scheme mechanisms, program scheduling, and types of offers provided to motivate residential customers to participate in DR programs. Finally, it is discussed the implementation of DR schemes for residential customers on a microgrid power system to create a balance between demand and supply

2. HEADINGS DEMAND RESPONSE CONCEPT

The demand response (DR) for residential customers can be described as a program to reduce peak load of electricity usage of residential customers by shifting or shedding electricity consumption, in response to power supply conditions.

2.1. Main Objectives of the DR Scheme

Residential DR program refers directly to demand-side management (DSM) which has main purposes as follows:

The first objective is the reduction of peak electricity usage on residential customers. Rajasekhar B. and Naran M. P. (2015) stated that the purpose of residential DR program is the reduction of electricity consumption by shifting, shaving, and shaping electricity usage for residential customers [6].

The next purpose is to change the behavior of residential customers, so the load profile of residential customers may be modified into more adaptable load profile to electrical power system condition. Robin Roche (2012), mentioned that changes in residential customer load profiles could be done using new technologies and function of DR aggregator [5]. As the load profile changes, the DR can also reduce the possibility of overload conditions, which will also lead to a reduction in the need for large-capacity power plants [3].

2.2. Work Mechanism of Demand Response

In implementing the DR scheme, one of the important things is how to make customers interested in participating in the program. This review of some of the DR implementation mechanisms will be a good reference for implementation of DR on microgrid power systems. Here, DR schemes can be classified according to the mechanism offered.

- DR Scheme based on the electricity price

This DR scheme is highly dependent on electricity tariff. The different electricity tariffs, presented in real time pricing (RTP), critical peak pricing (CTP) and time of use (TOU) that provides the option for customers to participate in the DR program. In their research, Peter Palensky (2011) explains that residential customers may join on DR activities by looking at real-time pricing and price signals [4]. In another study, P.T. Baboli et al. (2012) find that if the price difference is quite significant, customers may adjust the time of electricity usage to take advantage of the lower tariff period. Here, customer reaction to the application of price-based DR scheme becomes an important phenomenon [7].

- DR schemes based on incentives

This programme is provided by the utility or network operator. Here, customers will receive incentives for reducing electricity consumption, which associated with DR programs. In their study, James C Holyhead (2015) suggest that in DR implementation, especially on incentive-based schemes, it must be preceded by the selection of customers whose behavior leads to cost reduction to suppliers [8].

- DR programs imposed by state or utility

The implementation of DR is done by requiring a particular group of residential customers to participate. In this way, the percentage of participation will be high, and the effect on the electrical system will be very influential.

Based on the above discussion, it is understood that the success of DR implementation for residential customers depends on its strategy. Particularly how to explain to residential customers the importance of following the DR program with a choice of competitive electric prices or incentives offered. Here, the mindset change is required, where knowledge and awareness about energy management and efficiency also depend on customer engagement.

In the implementation of DR for residential customers, Rajasekhar B. and Naran M. P. (2015), states that residential customers tend to follow DR schemes based on the price offered. Depending on pricing scheme used, DR programs may operate in real-time, while others may work on a daily/hourly scheduling basis. For individual residential customers coordination of day-ahead scheduling and real-time DR need to be focused on optimization strategy of usage time. In the residential group, cooperative methods will result in greater efficiency impacts [6].

Meanwhile, P.T. Baboli et al. (2012), state that the successful implementation of DR schemes depends on customer behavior. The implementation of DR on a single customer and multi-customer give results that incentive-based DR schemes can be successful with a formation of customers habits. This plan depends on the proper education and socialization program [7].

Amir and Alberto (2010) presented on their study that although the price-based DR scheme has several advantages, it's limited due to the lack of automation systems (HEMS) and real-time pricing scheme cannot be executed manually. Therefore, scheduling the consumption of electrical energy for residential customers is proposed to be done automatically to provide more optimal results [8].

In coordination between systems and equipment in the DR scheme, Bingnan Jiang and Yunsi Fei (2011) disclose the concept of dynamic demand response and distributed generation (DG) management for DR implementation in a group of residential customers [9]. With dynamic updating mechanism, DR will operate automatically to adjust the current condition. The results show the system's effectiveness in reducing the cost of energy consumption.

2.3. Architecture and Components Framework DR Scheme

Architecture and components of DR scheme described by Barbato and Capone (2014). Specifically, individual user methods are designed to manage users' electrical resources individually, while for cooperative consumers, users collaborate in determining their operating plans [10]. The frameworks for DSM are designed to be able to adjust its user's power source optimally, as shown in Fig. 1.

Fig. 1 shows the necessary components of DSM. It consists of power generation, power monitoring system, sensors, energy storage, and energy management unit (EMU). The EMU works as an exchange information tool to other devices and manages resources electricity of the user based on DR mechanism [12].

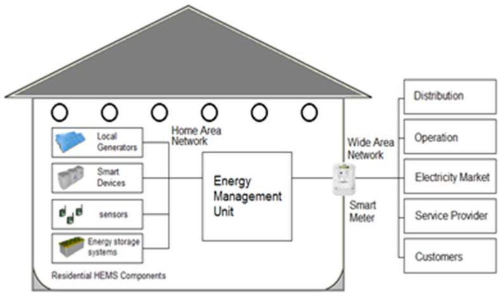

Fig. 1 Frameworks architecture of DR

In another paper, M. Pipattanasomporn et al. [11] stated that the HEM system could control and manage the operation of household appliances to maintain the consumption of electrical energy in DR programs. Here, HEMS can be operated on a priority scale to optimize customer electricity savings and comfort levels.

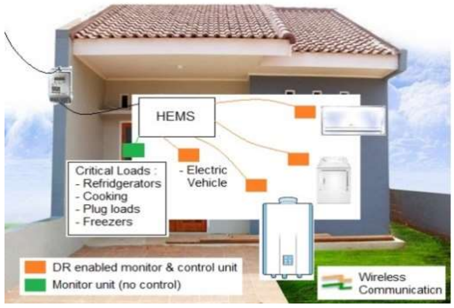

Fig. 2 Architecture of HEM system

Both of the above concepts discussed the DR architectural scheme for individual residential customers. The management of individual customer's electricity resources is managed separately, comprising operational plans of household appliances, energy storage systems, and renewable energy sources, as well as handling energy transactions with a network of electrical systems.

2.4. DR Method Based on the Decision Variable

Decision variables can also group DR methods: the first group refers to the DR program that decides when to activate the requested electrical load, while the second group of DR method determines the amount of energy that can be allocated to each consumer, as stated by Vardakas et al. (2015). In the DR scheme with load scheduling, the most important thing is to control the activation time of the requested load [14].

In here, the load is divided into two types:

1. The type of load that must be operated (such as lights and refrigerators).
2. Type of load that can be scheduled and may be discontinued, or can be shifted.

In the implementation of DR with decision variable, James C. Holyhead et al. (2015) stated that the success of DR program could be improved by targeting a certain group of customers. Evaluation of the algorithm to all customers within the targeted group will be able to reduce demand for a given period and show that a higher peak load reduction solution and increased cost savings [9].

M. Rastegar et al. (2012), suggested an optimal framework for the implementation of commitments and an automatic load of residential customers [14]. The issue of load commitment (LC) is formulated with a purpose for determining the status on/off for responsive equipment. This formulation expanded to combine the capabilities of direct load control.

The importance of decision-making in equipment scheduling is also discussed by Alessandro et al. (2011). In residential, the problem occurs at the time of scheduling the operation of equipment, to be able to adjust with goals of cost savings and convenience related to the weather, and timeliness [15].

The second DR method is based on energy management by limiting power consumption of the load, so total power consumption in peak period will decrease. This is implemented by controlling operation of electrical appliances that will consume less power when there are capacity limitations in power system.

3. RESIDENTIAL DR AND HOME ENERGY MANAGEMENT SYSTEM

In performing the DR scheme for residential customers, the key to successful implementation of the program may depend on the willingness of customers to participate in the program. For residential customers who are willing to follow the program this DR scheme, customers should also be able to implement energy management in each residential home (home energy management) [7].

Implementation of HEM can be done manually and automatically using auxiliary equipment for energy management. For manual implementation, HEM can be conducted by informing customers not to operate household electrical appliances at peak periods. The implementation of HEMS can be done automatically by the algorithmic programming operation. Fig. 3 shows the DR algorithm for residential smart home [7].

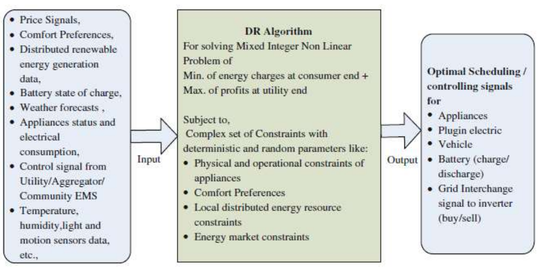

Fig. 3 DR Algorithm for Smart Home Residential

Formulation of algorithms DR and load control strategies depending on the characteristics of the load consisting of types of loads, usage patterns, the duty cycle, consideration of the uncertainty, modeling behavior, technical obstacles and renewable energy generation and energy storage facilities. Therefore, the potential of DR scheme for various home appliances needs to be assessed as a consideration in designing DR algorithms.

Adam Taylor et al. (2014) delivered on the evaluation of several algorithms have been designed to include a variety of conditions on the application of DR [16]. It was concluded that the algorithm residential DR should be following the structure of the electricity network so that the compliance between the data acquisition and dissemination of control commands can be synchronized without any significant delay time.

In specific about the load profile, Sara Ghaemi and Gunther Brauner (2010) presented the results of an analysis of the stochastic model for generating customer load profile [17]. This model can allow for the assessment of potential energy savings through the replacement of energy-saving devices and changing the customer's behavior.

4. OPTIMIZATION MODEL FOR RESIDENTIAL CUSTOMER DEMAND RESPONSE

In this section, a review of the optimization of several DR schemes: for single houses, and for a group of houses or communities. The optimization process is defined as a process of discovering the conditions that provide a maximum benefit or minimal cost of a process [9]. The research which is conducted on optimizing the DR program aimed at minimizing power consumption while maintaining a level of customer comfort.

4.1. Optimization of DR Model for Single home

The problem of optimization of a DR model is to manage electricity consumption, generation, and customer's energy storage over a period, which is divided into some time slots from a few minutes to hour periods. The purposes of DR model optimization are as follows:

1) Minimizing the total cost of electricity
2) Minimize the discomfort experienced by customer of delay operation time
3) Maximizing network's power resources with electricity transactions from/to the network
4) Peak load reduction and ratio of PAR

An optimization model for the above purpose can be provided by the following formula:

1) To minimize the cost of electrical power
Focus on reducing the cost of electricity

$$\mathbf{min}\sum_{\mathbf{t\in N}}(\mathbf{c_t}.\,\mathbf{y_t}-\mathbf{d_t}.\,\mathbf{z_t}) \qquad (1)$$

When the reward parameter included in the calculation, then the formula becomes:

$$\boldsymbol{min}\sum_{t\in N}(\boldsymbol{c_t}.\,\boldsymbol{y_t}-\boldsymbol{d_t}.\,\boldsymbol{z_t}-(\boldsymbol{R_t^U}.\,\boldsymbol{a_t^U}+\boldsymbol{R_t^L}.\,\boldsymbol{a_t^L})) \qquad (2)$$

Where c_t, d_t are buying, selling cost of energy and y_t, z_t are energy brought and injected into the grid at time t. $\boldsymbol{R_t^U}$ can be reward paid/penalty collected depending on demand request satisfaction.

2) To minimize the inconvenience that perceived by the customer. Here, the focus is on minimizing the inconvenience experience

$$\mathbf{min}\sum_{\mathbf{t\in N}}(\boldsymbol{\alpha}\sum_{\mathbf{s\in S}}\mathbf{f_{st}^S}.\,\mathbf{x_{st}}+\boldsymbol{\beta}\sum_{\mathbf{e\in\varepsilon^{CB}}}\mathbf{f_{et}^{\varepsilon CB}}) \qquad (3)$$

3) To maximize the energy from local generation

$$\mathbf{max}\frac{\sum_{\mathbf{n\in N}}(\boldsymbol{\pi}_\mathbf{t}^{\mathbf{R,PV}}-\boldsymbol{\pi}_\mathbf{t}^{\mathbf{net}})}{\boldsymbol{\mu}.\,\mathbf{p_t^{TOT}}} \qquad (4)$$

Where $\boldsymbol{\pi}_\mathbf{t}^{\mathbf{R,PV}}$ is energy that generated by the PV panel at time t and $\boldsymbol{p_t^{TOT}}$ is total power, and $\boldsymbol{\pi_t^{net}}$ is the net generation.

In the single home model, customers have four types of equipment that are distinguished by their control functions: fixed/critical, time and power shiftable, comfort base and local renewable energy generation and energy storage.

5. OPTIMIZATION OF DR MODEL FOR GROUPS OF HOMES OR COMMUNITY TABLES

In this condition, a group of individual residential customers will cooperate with an aggregator or Community Energy Management System (CEMS) to conduct electricity transaction management with electricity company or power system grid [6], [10]. The main purpose is to reduce total cost of electricity from a group of homes or communities by setting the schedule for the time allowed. The formula for calculating cost minimization is:

$$min\sum_{u\in U}\sum_{t\in T}(c_t.\,y_t^u-d_t.\,z_t^u) \qquad (5)$$

Where $c_t y_t^u$ is energy received from system grid, and $d_t.\,z_t^u$ is selling cost of energy. The challenge remains the total peak load of users cannot exceed a total aggregate peak load customers. Cooperative methods of multiple residential homes have the potential to provide a more significant influence on the efficiency of the system when the settings are done with system-wide perspective.

Some papers also discuss DR scheme relationship with the electricity market. The influence of DR scheme can result from electricity price, and incentive offered so that customers are interested in participating in the program. Several types of the tariff are available for determining the price of electricity: time of use (TOU), critical peak pricing (CPP) and real-time pricing (RTP) [6], [10].

6. LOAD CHARACTERISTICS IN INDONESIAN ISLAND MICROGRID SYSTEM

In this chapter, it is discussed load characteristics of microgrid systems in the island where the DR scheme will be developed. The system has limited power supply, high electrical load during peak loads and loads, are dominated by residential customers.

Referring to an article from Tongam (2008), numbers of factors that may influence the demand for electrical energy in the residential sector are household income, prices or tariffs of electricity, electrical appliances, load characteristics, and other relevant variables [18]. These factors will affect load characteristics of the microgrid system, which is dominated by residential customers.

Characteristics of the electrical load in a microgrid system will greatly determine the strategies used to balance between the load profile and generation capacity.

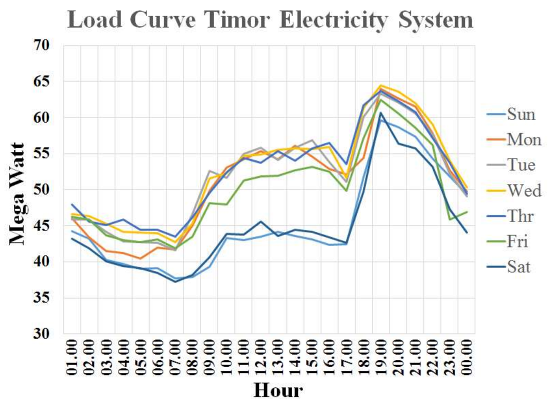

Fig. 4 Load Curve of Timor Power System

Fig. 4 shows the daily load curve of the Timor power system, in the period of 4 - 10 April 2016 (Monday-Sunday). It is shown a gap between peak load and off-peak load, about 23% of total power capacity in Timor electric power system.

At single residential homes in Timor electricity system, loading curve with details of energy consumption per equipment can be seen in Fig. 5. It has a similar pattern to a study on residential demand response scheduling [18].

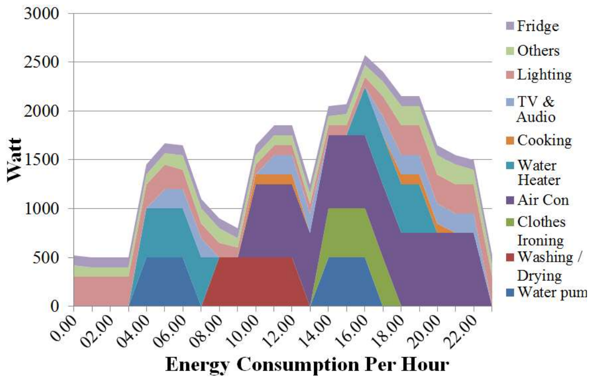

Fig. 5 Energy consumption per hour for every household electrical appliances

The demand for electricity with characteristics, as shown in Fig. 5 above, supplied by existing power plants, including renewable energy power plants that have intermittent characteristics. To maintain a balance between the power supply and the load, the implementation of demand response for residential customers need to be performed on the microgrid system such as in Timor power system.

7. CONCLUSION

From discussions in the preceding paragraph, several conclusions can be drawn as a reference and valuable lesson that can be used to conduct further research in the future:

1) In general, the purpose of applying the demand response is to reduce the peak load, and it directly impacts the reduction of generating the capacity to be operated and changes the customer behavior so that the load profile can be improved.
2) Optimization of DR scheme implementation are classified into individual customers and groups of customers that will define the architecture of the program and the success rate of implementation
3) Residential demand response has great potential to be used as a method of load balancing and power supply in microgrid systems in Indonesia.

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