ECONOMIC ANALYSIS OF HOME-BASED MICRO-GRID UNDER NON-REAL-TIME PRICING MECHANISM

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ABSTRACT

The subject addressed is to discuss economic efficiency of home-based micro-grids under non-real-time pricing mechanism. Firstly, configurations of investment and return are decomposed in terms of home-based micro-grid under the background of China's current renewable generation policies and residential non-real-time electricity pricing mechanism. Secondly, a mathematic model of cost/benefit is developed to analyse the economic efficiency during its whole life cycle. One practical case from a demonstration project in Guangzhou is provided to illustrate the analysis in this paper. Furthermore, sensitivity analysis is applied to main factors which potentially impact on economic efficiency of home-based micro-grid system. Results show that price and quality of main equipment are the most potential keys to enhance economic incentives of home-based micro-grid power system in China.

INTRODUCTION

In Chinese urban areas, the construction of new urbanization and market-oriented reform has greatly increased the external environment for the implementation of large-amount distributed energy access. Particularly, success in manufacture of small-capacity compact control equipment led to the reality of home-based micro-grid. The home-based micro-grid discussed in this paper is a photovoltaic(PV) micro-grid that is built based on the outdoor resources within one family, and that contains electrical load of the family, a certain capacity of energy storage, and its voltage level is 400V or below. Such micro-grid is able to operate independently under certain conditions.

Home-based micro-grid technology and its application have made significant progress among Europe, the United States, Japan and other regions. These regions have commonly established the mature electricity market trading mechanism. Generation strategy can be made for optimal economic benefits, according to the generation profile of micro-grid power system and changes in the real-time price in the electricity market. Since that China's electricity market has not yet been established, poor economic incentives gradually become an important reason hindering the development of home-based micro-grid. For home-based micro-grid, high initial investment, complicated control equipment and long payback period reduce the acceptability of residents. Many researches in China are focused on stability and controllability of micro-grids, mainly in optimization of micro-grid capacity, operation control and environmental protection[1-3]. However, few researches focus on this problem and find out what are the key factors and how sensitive they are to residential acceptance[4-5].

Given the above, this paper aims to develop an evaluation model to analyze economy of home-based micro-grids under non-real-time pricing mechanism. At first, the typical structure of home-based micro-grid is fully introduced. Secondly, life-cycle costs/benefits model is developed on the base of fully decomposition of investments as long as earnings. Then a practical case, which is constructed in China Southern Power Grid, second large power company in China, is provided to illustrate the analysis of this paper. Last by not the least, sensitivity analysis based on this practical case is applied to factors such as equipment prices, subsidy policies, etc. Bottleneck of economic insensitive is aimed to be found in the development of home-based micro-gird under China's background.

THE TYPICAL STRUCTURE OF HOME-BASED MICRO-GRID

Similar to the structure of large-capacity micro-grids, typical structure of one home-based micro-grid is shown as in Figure 1.

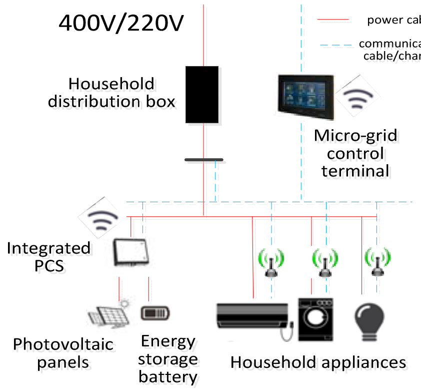

Figure 1 Typical structure of home-based micro-grid

The primary electrical system of this micro-grid includes household distribution equipment, photovoltaic components, energy storage devices, integrated power conversion system (PCS) and household appliances, which together manage the electrical power generation-power flow-consumption within the home-based micro-grid system. Electrical secondary system contains comprehensive micro-grid control terminals, smart meters, integrated PCS, smart appliances and the like. These devices have functions of multiple communication and data interaction with each other, to realize home energy management and ultimately to obtain higher energy utilization efficiency. With the constantly elevating of intelligent manufacturing technology, more highly integrated smart devices become available, and then hardware integration of electrical primary and secondary system will be probably realized in home-based micro-grids.

MATHEMATICAL MODEL FOR ECONOMIC ANALYSIS OF HOME-BASED MICRO-GRID

Investment configuration

The investment of home-based micro-grid mainly consists of two parts: construction cost and maintenance cost after construction.

Construction cost usually refers to initial investment. It includes equipment cost, labor cost, material cost, and auxiliary fees, as shown in Equation (1).

$$C_o = I_E + I_L + I_M + I_A, \tag{1}$$

where C_o indicates the total costs of initial construction; I_E, I_L, I_M, I_A refer to equipment cost, labor cost, material cost, and auxiliary fees respectively. According to engineering experience in China, equipment cost takes most percentage of initial investment, about 70%±5%; labor cost takes approximately 15%~18% of C_o; material cost and auxiliary fees take 5% and 2%~10%.

Maintenance cost is the follow-up investment to ensure the micro-gird system functioning as expected. It is generally due to old equipment replacement or the daily maintenance. To simplify the calculation, a certain period of maintenance cost could be estimated in accordance with a certain percentage of the construction cost. Therefore, calculation of average annual maintenance cost can be written as shown in Equation (2).

$$C_m = \varphi \times C_o, \tag{2}$$

where, C_m represents average annual maintenance cost of the micro-grid; φ is the corresponding coefficient, usually taken as 1% to 2%.

Return configuration

China has been committed to develop renewable generation projects since 2009. To solve the problem of expensive investment but lack of incentives in return among the projects, the central and local governments developed subsidy policies to different extent [6], to foster the development of renewable generation industry. Distributed PV generation projects mainly apply to the subsidy policy for actual electricity output.

However, due to disadvantages of small capacity, long payback period, decentralized operation, etc., home-based micro-grid projects are difficult to attract a third party to invest under energy management contracts, which are widely used in projects of large-scale industrial-zone or commercial-building micro-grid. Common mode for investment and management of home-based micro-grids is self-investing, self-managing, self-consuming first or selling surplus electricity to the local power company.

Discussion is performed under the above mode in this paper. Consequently, return of home-based micro-gird should include government subsidies of PV generation, savings of household consumptive electricity and earnings of surplus electricity for sale. Annual return can be calculated as Equation (3).

$$A = A_1 + A_2 + A_3, \tag{3}$$

where, A represents total annual return; A_1~A_3 refer to subsidy incomes, savings of household consumptive electricity and earnings of surplus electricity for sale respectively in one year.

Firstly, according to subsidy policy, A_1 is product of annual PV generation P_1 of the home-based micro-grid system and subsidized rate δ. That is

$$A_1 = \delta \times P_1. \tag{4}$$

Secondly, savings of household consumptive electricity depend on residential electricity prices and settlement pattern. In China, there are two alternative electricity billing ways: one is based on ladder price mechanism and another based on time-of-use price mechanism. Most of the residents choose the first one in reality however. In this paper, only cases under ladder price mechanism are involved. A real example of ladder price mechanism from somewhere is shown as Table 1.

Table **1 A real example of Ladder price mechanism**

Period	Division		Price (¥/kWh)
May to Oct.	First level	0~260 kWh /month/family	0.61
	Second level	261~600 kWh /month/family	0.66
	Third level	⩾601 kWh /month/family	0.91
Nov. to Apr.	First level	0~200 kWh /month/family	0.61
	Second level	200~400 kWh /month/family	0.66
	Third level	⩾401 kWh /month/family	0.91

Under the ladder price mechanism, residential consumption is divided into 3 levels. Each level is corresponding to one set electricity price. Consumption in the same level has the same price. This mechanism is applied to encourage residents to reduce electricity consumption and thus save energy. In this mode, savings of household consumptive electricity A_2 can be expressed as

$$A_2 = \mu_1 \times P_2^1 + \mu_2 \times P_2^2 + \mu_3 \times P_2^3, \tag{5}$$

where, μ_1~μ_3 and $P_2^1 \sim P_2^3$ represent the electricity price and consumption savings from first level to third level.

Thirdly, for most families, its load profile is negatively correlated to PV generation profile. Residential activity pattern of being out in the day and being in at night results in load profile characteristics of daytime low and nighttime high. PV generation profile is just the opposite. But PV modules can only absorb solar energy and generate electricity during the day. Thus, home-based micro-grid could make earnings from selling surplus electricity to power company, such as Equation (6).

$$A_3 = \gamma \times P_3, \tag{6}$$

where, γ and P_3 represent the benchmark price of distributed PV generation and total amount of electricity for sale respectively.

When internal line loss within the family is ignored, P_1, P_2, and P_3 are subject to Equation (7).

$$P_1 = \sum_{i=1}^{3} P_2^i + P_3. \tag{7}$$

Mathem atical model for economic analysis

Generally, life cycle of micro-grid system is expected to be 20~25 years. Suppose operation life of home-based micro-grid is T years, and the discount rate is η. The life cycle cost (specified as C) of home-based micro-grid system consists of construction cost and annual average maintenance cost and their time value, as shown in Equation (8).

$$C = \sum_{t=1}^{T} C_o \times \eta^{t-1} + \sum_{t=1}^{T} C_m \times (1+\eta)^{T-t}, \tag{8}$$

Life cycle return (specified as R) of home-base micro-grid system is expressed as

$$R = \sum_{t=1}^{T} A \times (1+\eta)^{T-t}. \tag{9}$$

Cost-benefit analysis is applied to assess economic efficiency of home-based micro-grid, as shown in Equation (10).

$$\varepsilon = C/R, \tag{10}$$

where, ε represents life cycle economic efficiency and the larger it is, the higher economic efficiency the system achieves.

CASE ANALYSIS

A practical case constructed in China Southern Power Grid is provided to further illustrate the analysis of this paper. This case locates in Guangzhou city, where daily illumination time is about 7:00~18:00 and average annual time of photovoltaic power generation is around 1095 hours.

In this case, the building has maximum load about 16kW, 40% of which is important and needs uninterruptible power supply. Based on the result of site investigation, this house has maximum installation capacity of 6kWp for PV panels. Therefore, a home-based micro-grid system is configured with 5.4kWp PV generation system and 5.4kWh lithium battery storage in case of unexpected power outages of the public distribution system. Its structure is in accordance with that as shown in Figure 1.

Configuration of construction costs is listed in table 2. The initial investment is ¥346,200 Yuan. Given that φ equals to 1.5%, average annual maintenance cost is ¥5,190 Yuan.

Table 2 Configuration of construction costs

Configuration	Cost (¥)	Percentage
C_o	346,200	100%
I_E	234,100	67.62%
I_L	64,400	18.60%
I_M	18,100	5.23%
I_A	29,600	8.55%

The load profile and PV generation on typical day of this family is shown as Figure 2. This family pays electricity tariff based on ladder price mechanism, as shown in Table 1.

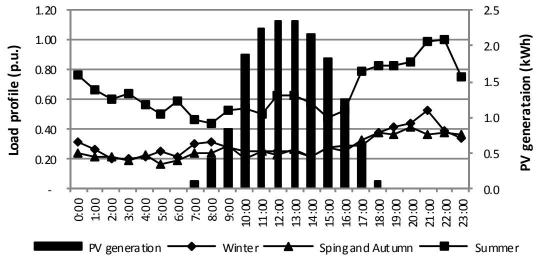

Figure 2 load profile and PV generation on typical day

Assumption is made that the electricity consumption patterns of the family remain the same after micro-grid commissioning. Since the daily electricity consumption is higher than generation from the micro-grid system, all of PV generation is completely self- consumptive and there is no left for sale. In addition, the family consumes electricity monthly far exceeding the third level of ladder price mechanism. Consequently, the PV generation serves as an offset against highest priced electricity consumed in the third level. Statistics of P_1, P_2, and P_3 in one year are shown in Table 3.

Table 3 Statistics of P_1, P_2, and P_3 in one year (kWh)

	Winter	Spring and Autumn	Summer	Total
P_1	1478	1479	2956	5913
P_2^1	0	0	0	0
P_2^2	0	0	0	0
P_2^3	1478	1479	2956	5913
P_3	0	0	0	0

In Guangzhou, subsidized rate δ is ¥ 0.52/kWh, of which ¥0.42 /kWh from central government and ¥0.1/kWh from local government. The local benchmark electricity price is set at ¥0.514 /kWh. The annual return is shown as Table 4.

Table 4 Annual return of the home-based micro-grid

Return	Earnings (¥)
A	8,456
A_1	3,075
A_2	5,381
A_3	0

Suppose that the life cycle is supposed to be 25 year, and the discount rate η is assumed to be 10%, life cycle cost C, life cycle return R and life cycle economic efficiency ε can be obtained as shown in Table 5.

Table 5 Economic analysis of this home-based micro-grid

Parameter	Value	Parameter	Value
T	25 years	C	¥ 895.35 million
η	10%	R	¥831.623 million
ε	0.93		

Obviously, ε<1 indicates that life cycle economic efficiency of this home-based micro-grid is far from satisfactory. Furthermore, it also can explain why home-based micro-grids are unattractive under current circumstances in China. To find out the factors which limit the economic efficiency, a few discussions is as follows of factors of life cycle , discount rate, electricity price mechanism, equipment cost, subsidy rate. Suppose that single one of the above factors varies as others remain the same, ε varies as shown in Table 6-10.

Table 6 variation of ε with T varies

Value of T	Value of ε
15 years	0.49
20 years	0.71
25 years (now)	0.93
30 years	1.12

Table 7 variation of ε with η varies

Value of η	Value of ε
6%	0.71
8%	0.82
10% (now)	0.93
12%	1.04

Table 8 variation of ε with equipment costs vary

Equipment cost	Value of ε
Drop 20%	1.07
Drop 15%	1.03
Drop 10%	1
Drop 5%	0.96
now	0.93

Table 9 variation of ε with subsidy rate varies

Subsidy rate	Value of ε
Drop 20%	0.86
Drop 10%	0.9
now	0.93
Up 10%	0.96
Up 20%	0.996

Table 10 variation of ε with PV power generation hours vary

PV power generation hours	Value of ε
Drop 20%	0.743
Drop 10%	0.836
now	0.93
Up 10%	1.02
Up 20%	1.115

Table 11 variation of ε with φ varies

Value of φ	Value of ε
1.00%	1.15
1.20%	1.05
1.50% (now)	0.93
1.80%	0.83
2.00%	0.78

From data in Table 6~11, interesting conclusions can be drawn:

(i) Each factor of life cycle, discount rate, subsidy rate, PV power generation hours, has positive correlation with economic efficiency ε of home-based micro-grid; however equipment cost and maintenance cost have negative correlations with it.

(ii)Equipment costs, maintenance cost, and PV power generation hours, life cycle significant impact ε. Among them, factors of equipment costs and maintenance cost have the most influence among them.

(iii) Discount rate and subsidy rate show slightly influent to the economic efficiency. Take variation of subsidy rate for example, even if it is increased at 120%, value of ε is still less than 1. It seems that increasing subsidy rate does little help for popularizing home-based micro-grid under current circumstances.

CONCLUSION

Up to now, under the circumstances of no reforms in electricity pricing mechanism, promotion of home-based micro-grid do not heavily dependent on increasing of discount rate or subsidy rate. According to analysis in this paper, prices of the control equipment, cost of maintenance, life cycle of the system functionally operating, and number of PV power generation hours are the keys factors. Those former three have inseparable relation to quality of equipment, and the last one has positive correlation to atmospheric environment. Data in this paper shows equipment costs seriously restrict the economic enhance of micro-grid power system. In order to make home-based micro-grid system be recognized and widely accepted in the residential side, it is intelligent, good-quality, highly integrated and miniaturized, but lower priced and maintenance-free that equipment of home-based micro-grid system need to be developed.

REFERENCES

[1] Chen J., Zhao B., Wang C., etc., 2014, Optimal Sizing Analysis on Grid-connected Microgrid with Different Self-balancing Capabilities, *AEPS* vol. 38(22), 1-5.

[2] Chen J., Wang C., Zhao B., etc., 2013, Optimal Sizing for Stand-Alone Microgrid Considering Different Control Strategies. *AEPS* vol. 37(11), 1-6.

[3] Xiao Jun, Zhang. Z., Zhang P., etc. 2014, A Capacity Optimization Method of Hybrid Energy Storage System for Optimizing Tie-line Power in Microgrids, *AEPS* vol.38(12), 19-26.

[4] Yan D., Wei G., Hu Y., etc., 2012, Microgrid Energy Optimization with Coordination of Reliability and Economy. *AEPS*, vol.8, 006.

[5] Zhang D., Shah N., Papageorgiou L.G., 2013, Efficient energy consumption and operation management in a smart building with microgrid. *Energy Conversion and Management*, vol.74, 209-222.

[6] Li C., Wang J., Ye X., etc., 2012, Development and Prospects of New Energy in China, *Electric Power Science and Engineering*, vol. 28(4), 1-8.