Multi-objective optimization and life-cycle-cost analysis of a smart home

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1. Introduction

In order to improve the power system performance and protect the environment, new technology advances in the power generation, transmission and distribution, and energy storage. A smart home is a miniature power system. It has an automatic control through a home energy management system (HEMS) on household appliances. With its own generators or home backup batteries, the home can be operated in two modes: standalone or grid connected. For a grid-connected home, there are two-way flows of power and information. This information includes the electricity tariff on the grid and it enables the HEMS to schedule the running of the household appliances. Thus, the load profile can be shaped to improve the reliability of the power grid, reduce the utility cost, and maintain the comfort of the residents

2. Model

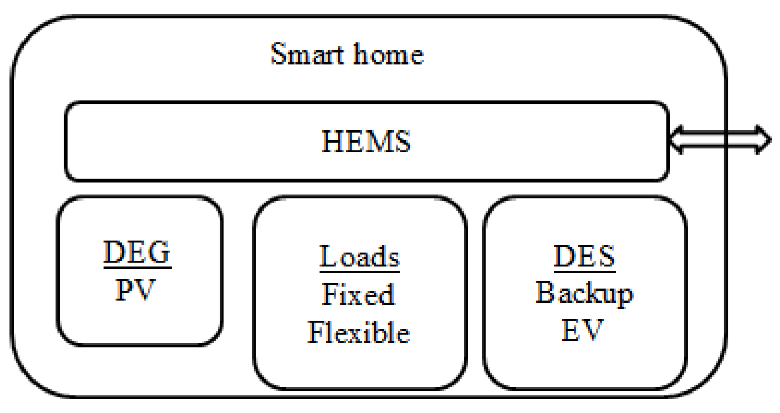

Figure 1 The structure of a smart home

Fig.1 shows the model of a smart home, which includes a rooftop PV system, fixed and flexible loads, a backup battery, and an EV. This home is connected to the grid with a predictable day-ahead dynamic price.

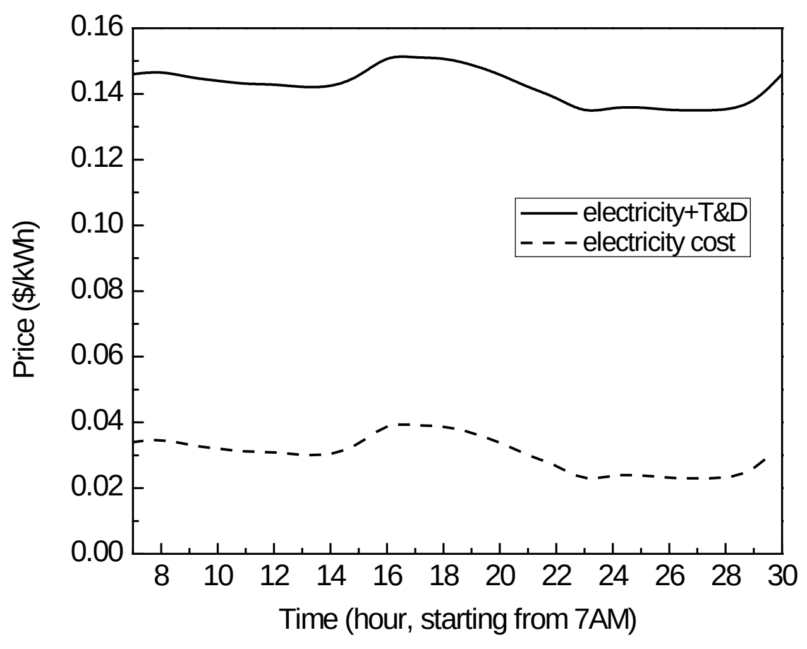

Figure 2 Electricity tariff

Since the home is connected to the grid, there is a two-way information and power transmission between the home and the grid. The day-ahead prices of electricity are shown in Fig. 2: one price is paid by the residents to the utility company and it includes the cost of the electricity generation, transmission and distribution. The other one is the credit to the residents who sell their spare electricity to the grid

3. Control of the power flow

Performance evaluation

Performance of the home power system is defined and evaluated with the consideration of utility cost and resident comfort, the comfort is converted to uncomfortableness and an overall performance index Q is the weighted total of cost, C, and uncomfortableness, U:

$$Q = w_1 C + w_2 U \qquad (1)$$

Particle swarm optimization

It is an evolutionary computation technique developed in 1995. The particle swarm concept originated as a simulation of a simplified social system and the original intent was to graphically simulate the graceful but unpredictable choreography of a bird flock. PSO is initialized with a population of random solutions called as particles and these particles are kept updating to get a final best solution.

The objective fitness function is based on equation (1) as

$$f = w_1 \sum_{j=1}^{n} price_j \bullet p_{Gj} + w_2 \sum_{j=1}^{n} (p_{fj} - l_{fj}) \qquad (2)$$

The objective in the optimization is to minimize equation (2) with the following constraints:

- The EV battery should be around fully charged at 7 AM in the next morning.
- The SOC of the home backup and the EV batteries should be between 20% and 100%.
- There is a power balance among loads, batteries, and grid.
- There is a current limit for the batteries as 20A.

4. Results and discussion

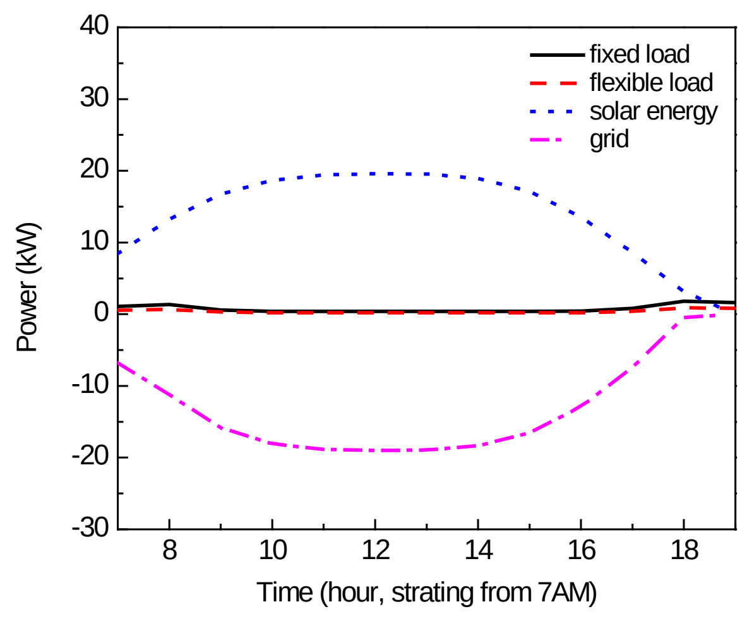

Figure 3 Day time power flow with the PV array size as 200m^2

Table 1 The total day-time electricity cost

PV size (m^2)	Cost ($)
200	-5.71
150	-4.62
100	-3.55
50	-2.46

Fig. 3 shows the maximum PV output power is 20kW and it is much higher than the loads. The spare electricity flows to the grid for the creditsshown in Table 1.

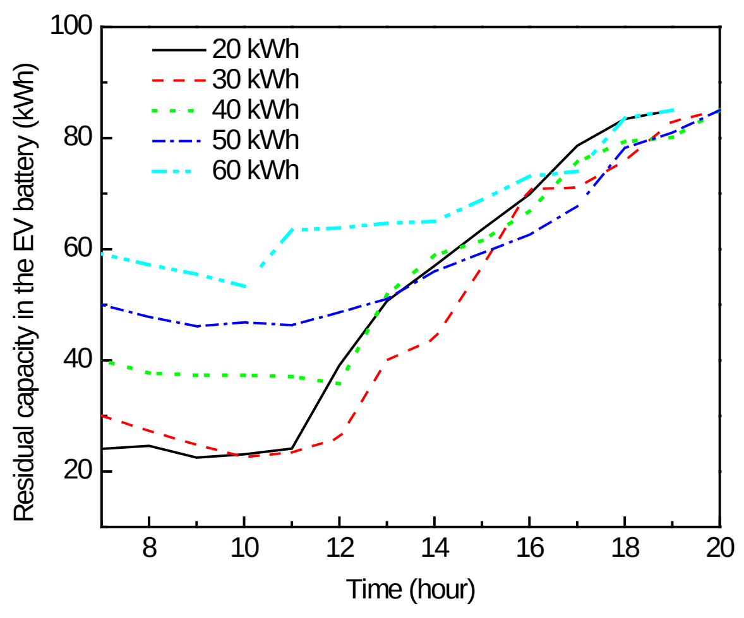

Figure 4 The profiles of EV battery residual capacity with different initial residual capacity

Fig. 4 shows the residual capacity change of an EV battery in the night from 7PM to 7AM. Although the initial residual capacities are different, all of them are eventually above 80kWh around 7AM in the next morning.

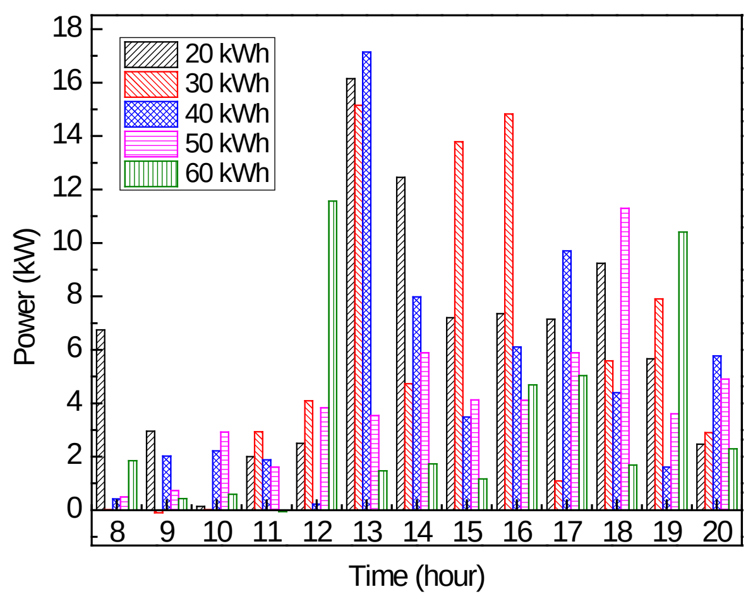

Figure 5 The power from the grid to the house in the night, starting from 7PM, with different initial EV battery residual capacities

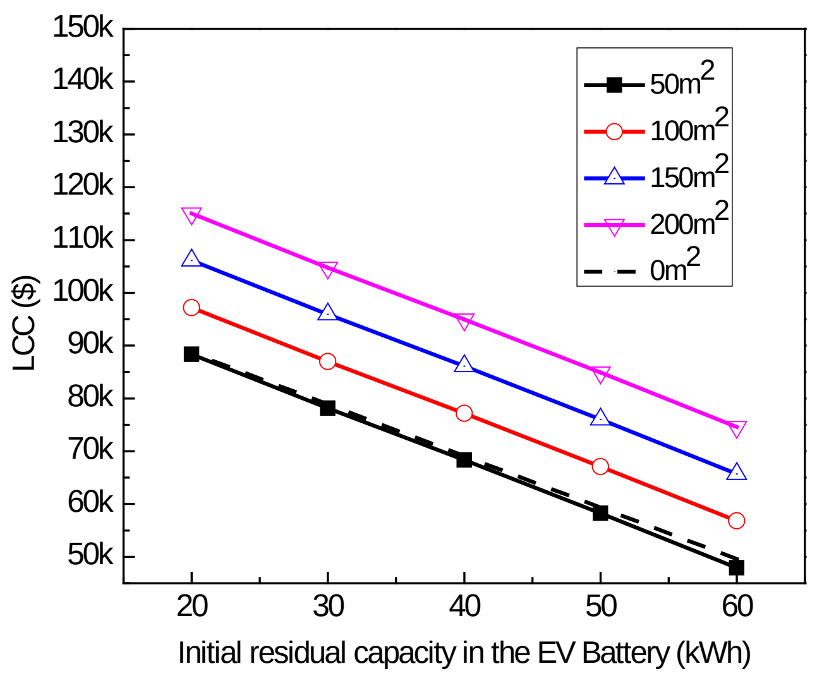

Figure 6 The life cycle cost of the power system at home

With the increasing of the PV size, the LCC increases at a rate of $200/m^2.

5. Conclusions

The PV size doesn't affect the comfort but the LCC. The power from the PV system flows to the loads and the spare goes to the grid for electricity credits in the day time.

References

1. Alsayegh, O., S., *Grid-connected renewable energy source systems: Challenges and proposed management schemes.* Energy Conversion and Management, 2010. **51**: p. 1690-1693.