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A privacy protection scheme of smart home electricity information based on plug-in electric vehicle

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Abstract: The smart meter collects the user's fine-grained real-time power information and uploads it to the control center. The control center feeds back the control commands to the smart meter. The bi-directional interaction may lead to user's privacy leakage. Aiming at the problem above, a privacy protection scheme of smart home electricity information based on plug-in electric vehicle is proposed in this paper. The electric vehicle energy storage is used to blur the user's electricity consumption data to ensure user privacy, and at the same time, the user's electricity cost can be reduced.

1. Introduction

In the smart home environment, Smart Home Energy Management System (SHEMS) collects smart home real-time fine-grained electricity information through smart meters (SM), and smart meters [1] upload electricity information to Control Center (CC). Since real-time fine-grained data contains detailed user's information, this process may lead to user's privacy leakage [2]. In order to solve the problem of privacy leakage, the researchers conducted a variety of research projects. Some studies have proposed data injection technology [3], which is to inject new data into the smart meter data to cover the user's electricity consumption data. The data injection technology mainly includes data aggregation technology and rechargeable battery technology. The data aggregation technology [4] cannot provide value-added services to a single user, and the calculation cost of the solution is large, and it is not suitable for intelligent terminal devices with limited storage capacity and computing power. The low-cost installation of rechargeable batteries and good privacy protection have been favored. The literature [5] proposes a smart meter privacy protection scheme that includes solar power and rechargeable batteries, analyzing the impact of battery capacity and solar power generation for privacy protection. But the program uses solar power to generate electricity at a higher cost. In [6], load scheduling is used to protect user privacy, and the weighted sum of privacy leakage, electricity bill and sacrificing user experience is minimized, and the multi-objective optimization problem is solved by randomization method. This solution reduces the battery capacity requirements and reduces battery consumption while ensuring user privacy. In order to overcome the problem that the energy demand is too high or too low to guarantee privacy, the literature [7] proposes a heuristic method by considering the time-varying target output load. The program protects user privacy while reducing energy costs. In order to reduce the dependence on rechargeable batteries, the literature [8] combines electric vehicles with air conditioning systems to replace rechargeable batteries to ensure user privacy, and proposes a Markov decision process that considers the randomness of user needs and evaluates the performance of the program. This solution can reduce the dependence on the battery and reduce the user cost. Literature [9] proposes a privacy-based home energy management scheduling strategy that uses rechargeable batteries to protect user privacy and introduces a preference factor that allows users to trade off operating costs and privacy. Since the installation and maintenance of the rechargeable battery also requires a certain cost, this article replaces the rechargeable battery with a Plug-in Electric Vehicle (PEV), which saves costs and guarantees user privacy. The electric vehicle access to the home distribution network (Vehicle to Home, V2H) provides technical support for the bi-directional interaction between PEV and smart home. PEV can guarantee user’s privacy and hide the actual power, so that the actual smart home consumes less than the power detected by the smart meter.

In summary, the contribution of this paper is as follows: a privacy protection scheme of smart home electricity information based on plug-in electric vehicle is proposed in this paper, and gives a smart home electricity load model with electric vehicle energy storage. The multi-objective function of electricity cost and privacy protection reduces the user's electricity cost while ensuring user privacy.

The rest of the paper is as follows. The second part introduces the structure of smart home. The third part establishes the electric load model with electric vehicle energy storage. The fourth part gives the scheduling target of the program. The fifth part is the summary of this paper.

2. Related technology

2.1. V2G technology

The large-scale popularization of electric vehicles will inevitably bring great challenges to the power system, affecting the safe and stable operation of the power system. The disordered charging line of electric vehicles may cause voltage limit violations, power line overload, and load fluctuations in the power system. However, electric vehicles, as a controllable flexible load, have a storage function and can also transmit power to the power system. Professor Kempton first proposed the Vehicle to Grid (V2G) technology. The idea is using the power battery as a distributed energy storage device when a large number of electric vehicles are idle, so as to realize the bi-directional interaction between the power grid and the electric vehicle to solve the problem of low grid efficiency and distributed renewable energy fluctuations; in addition, V2G technology can also improve the load curve of the grid, that is, PEV users use low electricity prices to charge through charging piles when the load is low. When the electricity price is high, the smart home load is supplied with power to achieve the purpose of cutting the peaks and filling the valley.

2.2. V2H technology

V2H means vehicle to home, which can be regarded as the family version of V2G, but the object of two-way interaction with EV is replaced by the household residential distribution network. The power of V2H is relatively small and its regional distribution is more dispersed. By rationalizing the charging and discharging process of EV, V2H can improve the regulation capacity, average load rate, operation economy and other indicators of power system. Therefore, the promotion and application of V2H means the significant reduction of vehicle exhaust emissions, the enhancement of power system regulation capacity and the improvement of renewable energy generation penetration, which have a profound impact on energy conservation and emission reduction and the development of smart grid. But at the same time, the direct access of electric vehicles to the home distribution network in the V2H system may bring serious power quality problems to users, and put forward higher requirements for the safety protection and operation control of the distribution network.

3. Scheme design

3.1. Design ideas

In order to alleviate the pressure on the power grid and realize the peak-shaving of the power load curve, PEV is widely used in the smart grid. A privacy protection scheme of smart home electricity information based on plug-in electric vehicle is designed in this paper, which considers electric vehicles replace rechargeable batteries, using PEV energy storage batteries to power smart homes can blur the smart home power mode, ensuring user privacy while reducing the cost of electricity for users.

3.2. Scheme model

According to the smart home architecture diagram of [10], a smart home structure diagram consisting of SHEMS, electric vehicle PEV, household load, smart meter SM and other entities is constructed, as shown in Figure 1. The functions of each entity are as follows:

SHEMS: The home energy management system is the control center for realizing smart home energy dispatching. On the one hand, SHEMS collects the power consumption information of smart home load through smart meter, and arranges the household load power plan through HAN, priority to eliminate the power of the PEV energy storage battery, in order to minimize the user's electricity consumption.

PEV: In addition to cutting the peaks and filling the valley to maintain the stability of the power grid, the electric vehicle can also store the power for the users during the peak period, and the user can obtain the difference profit. And PEV energy storage battery for smart home power supply can fuzzy smart home power consumption mode to ensure user privacy.

SM: The smart meter collects the electricity consumption information of all the power load of the smart home and sends it to the power supplier. In addition, smart meters are also responsible for receiving electricity price signals and bills sent by power suppliers.

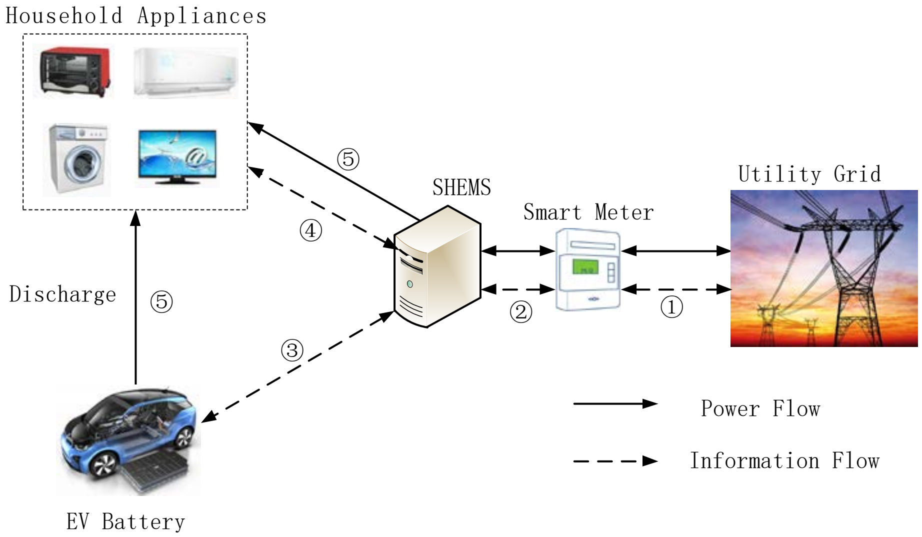

Figure 1: Smart home data transmission architecture diagram.

3.3. Scheme implementation process

①The power supplier adjusts the electricity price for a certain period of time, and transmits it to the smart meter.

②The smart meter transmits the received signal to the SHEMS.

③SHEMS arranges the optimal scheduling strategy, and preferentially dispatches the PEV energy storage battery to power the smart home load during peak usage.

④The energy of the PEV energy storage battery is exhausted, and the SHEMS arranges the power grid to supply power to the smart home.

⑤According to the optimal scheduling strategy, the PEV energy storage battery and the power grid supply power to the smart home at the same time or separately.

4. Scheme implementation

4.1. Electric vehicle model

The smart home power flow model with PEV energy storage is as follows:

$$P_{grid}^{t} = P_{DE}^{t} + P_{UN}^{t} - S_{pev}^{t} \cdot P_{pev}^{t}, t = 0,1,\cdots,T-1 \qquad (1)$$

Where P_{PEV}^{t} indicates the power of an electric vehicle, P_{DE}^{t} indicates the total power of interruptible load in the smart home except PEV. P_{grid}^{t} indicates the power that needs to be obtained from the grid. $P_{\min}$ with $P_{\max}$ represents the minimum power and maximum power of the electric vehicle, respectively. Binary variable $S_{pev}^{t} = 0$ indicates that the electric vehicle is in a discharged state. $S_{pev}^{t} = 1$ indicates that the electric vehicle is charging.

Plug-in electric vehicles not only serve as a daily transportation vehicle, but also serve as a carrier for storing energy in smart home. Therefore, PEV can alleviate household voltage power during peak hours. The grid needs to be constrained as follows: the distance that PEV can travel, the charge and discharge power of PEV, and the available capacity of the PEV energy storage battery. The constraint model is as follows:

PEV can travel distance

$$M_{max}=\begin{cases}(E_{out}-E_{in})\cdot M_{avg}, E_{in}>E_{\min}\\(E_{out}-E_{\min})\cdot M_{avg}, E_{in}<E_{\min}\end{cases} \quad (2)$$

Where E_{in} and E_{out} indicate the amount of electricity used by the electric vehicle during power-on and power-off respectively. $E_{\min}$ as a critical value of electric vehicle power, it plays a role in protecting electric vehicles. M_{avg} refers to the distance that a unit of electric vehicle can travel.

PEV charging and discharging power

$$0 \le P_{ch}^{t} \le S_{pev}^{t} \cdot P_{ch}^{\max} \quad (3)$$

$$0 \le P_{dish}^{t} \le (1-S_{pev}^{t}) \cdot P_{dish}^{\max} \quad (4)$$

Where P_{ch}^{t} and P_{dish}^{t} refer to the charge and discharge power of PEV, $P_{ch}^{\max}$ and $P_{dish}^{\max}$ refer to the maximum value of PEV charge and discharge power. To protect the PEV energy storage battery, the specified charge and discharge can not be carried out at the same time, then:

$$P_{ch}^{t_1} \cdot P_{dish}^{t_1} = 0 \quad (5)$$

PEV energy storage battery available capacity

$$SOC(t+1) = SOC(t)\cdot(1-\delta) + \frac{\left[\left(P_{ch}^{t} - \eta_1\left|P_{ch}^{t}\right|\right) - \left(P_{dich}^{t} + \eta_2\left|P_{dish}^{t}\right|\right)\right]\cdot\Delta t}{E_{bat}} \quad (6)$$

$$SOC_{\min} \le SOC(t) \le SOC_{\max} \quad (7)$$

Where $SOC(t)$ express t the initial state of charge (SOC) of the energy storage battery, the SOC is used to indicate the remaining power of the battery, and the SOC can be obtained by the ratio of the remaining capacity of the battery to the rated capacity of the battery. δ indicates the self-loss rate of the energy storage battery, η_1 and η_2 refer to the rate of power loss in the state of charge and discharge, E_{bat} refers to the rated capacity of the energy storage battery.

4.2. Electric vehicle protect smart home electricity privacy

In order to quantify the effect of privacy protection, the literature [9] introduced the decision coefficient R^2, $R^2=1$ indicates that the power value recorded by the smart meter is exactly the same as the actual household load. $R^2=0$ represents the load data measured by smart meter does not reflect the actual total power consumption. That is to say, the more R^2 tends to zero, the better the effect of privacy protection.

$$R^2 = 1 - \frac{\sum_{t=1}^{T}\left(P_{meter}^{t} - P_{load}^{t}\right)^2}{\sum_{t=1}^{T}\left(P_{meter}^{t} - \overline{P_{meter}}\right)^2 + \sum_{t=1}^{T}\left(P_{meter}^{t} - P_{load}^{t}\right)^2} \quad (8)$$

Where P_{load}^{t} indicates the total power consumption of all loads in the smart home. $\overline{P_{meter}}$ represents the average of smart meter.

5. Scheme objective function

The household energy management system's scheduling goal is to save the user's electricity cost while satisfying the user's needs as much as possible. That is to say, the SHEMS should arrange the household load work reasonably, and at the same time, the energy of PEV should be reasonably distributed in the peak period of power consumption and minimize the amount of electricity purchased by household load from the large grid, thus ensuring the minimum cost for the user. In addition, when considering privacy protection, the above-mentioned single-objective optimization problem is transformed into a multi-objective optimization problem. By introducing a preference factor α, transform it into a single-objective optimization model [9], as shown in Eq.9:

$$\min F = \alpha\left(\rho\sum_{t=1}^{T}P_{grid}\right)+(1-\alpha)\beta\sum_{t=1}^{T-1}\left(P_{meter}^{t+1}-P_{meter}^{t}\right)^2 \qquad (9)$$

Where P_{meter}^{t} indicates the total power consumption of the smart meter detection. $\alpha\in(0,1)$ set by the user to measure between electricity bills and privacy, β is a constant used to calculate the privacy leak of a currency unit.

6. Conclusion

In order to ensure the privacy and security of smart home electricity, a privacy protection scheme of smart home electricity information based on plug-in electric vehicle is proposed in this paper. The PEV energy storage battery is introduced in this scheme, which reduces the user's electricity cost while ensuring the user's privacy.

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