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Method for evaluating user-side flexible device access to power grid

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Abstract: In this paper, the benefit model of energy saving and emission reduction for electric vehicles and fuel vehicles are established, the situation of energy consumption and carbon emission between the two sides were comprehensively analyzed. Then, the reliability model of distribution network was established. Based on the theory of peak-valley time-of-use electricity price and V2G market regulation agreement, the reliability of connecting electric vehicles to distribution network is evaluated accordingly. The results show that the energy consumption of electric vehicles is much lower than fuel vehicles and the economy is better. For example, according to 2017 data, more than 130,000 electric vehicles in Beijing can save up 70,000 RMB per kilometer during peak hours. Reasonable connection of electric vehicles to power distribution network can effectively reduce carbon emissions and has remarkable environmental protection effect. Compared with disorderly charging of electric vehicles, V2G market with peak-valley time-of-use electricity price can obviously improve the stability of the system.

1. Introduction

Automobiles are an indispensable means of transportation for the progress and development of today's society, but traditional automobiles are driven by internal combustion engines and rely on fuel to provide power [1]. While forming a high dependence on oil, it also releases a large amount of tail gas, causing air pollution. Compared with traditional fuel vehicles, electric vehicles can directly solve the problems of energy dependence, exhaust emission, environmental pollution, etc. As a new type of transportation, it has attracted worldwide attention for its clean and environmentally friendly advantages [2].

Reference [3] carried out the reliability evaluation of electric vehicles connected to distribution network, it is concluded that increasing the proportion of wireless chargeable electric vehicles can effectively improve the power supply reliability of the power distribution system. Reference [4] analyzed the reliability indexes of different numbers of electric vehicles connected to the distribution network. They have not considered the evaluation of peak-valley time-of-use electricity price and the benefits of energy conservation and emission reduction. This paper will comprehensively evaluate the efficiency of electric vehicles in energy conservation and emission reduction and the reliability of power distribution network.



2. Impact analysis of electric vehicles connecting to distribution network

At present, the two main technologies in the research field of electric vehicles are plug-in hybrid electric vehicles and pure electric vehicles. These two types of electric vehicles in energy supplement are by connecting to the power grid. Therefore, they are suitable for current people to use. With the popularization of electric vehicles in the future, large-scale charging of electric vehicles connecting to power grids will have a noticeable impact on the operation and planning of power systems. These impacts mainly include: (1) Power grid load growth, a large number of electric vehicles connected to the power grid for charging will greatly increase the operating load of the power grid. If charging is concentrated in the peak load period, it will further lead to an increase in grid load, it will improve the possibility of power grid interruption accidents, affecting the normal life of the people. (2) The difficulty of optimal control of power grid operation increases. The behavior of electric vehicle users, charging time and spatial distribution are uncertain. These are all decided by users, thus making the charging load of electric vehicles more random, which will increase the difficulty of grid control. (3) It is difficult to plan the power grid. Large-scale use of electric vehicles requires adding charging facilities in cities to facilitate charging of electric vehicles. Adding many charging facilities and a large number of electric vehicles to the distribution network will change the load structure and characteristics of the distribution network. This has a certain impact on the distribution network planning. (4) It has a certain impact on the power quality. The load generated by electric vehicles during charging is a nonlinear load. This type of load will produce harmonic waves in power equipments and will have a certain impact on the power quality.

3. Comprehensive evaluation model

3.1 Energy consumption evaluation model for electric vehicle

We use N to represent the power set. $\eta_{p,i}$ represents the energy efficiency in the process of mining the i -th fuel. $\eta_{t,i}$ represents the energy efficiency during transportation of the i -th fuel. For the power generation efficiency of fossil energy, we define the following expression:

$$\eta_i = \frac{E_{out}}{E_{in,i}} \quad (1)$$

Where, E_{out} is the unit electric energy, $E_{in,i}$ is the calorific value of the i -th average fuel consumed to produce unit electric energy.

The comprehensive power generation efficiency in the region is shown in formula (2):

$$\eta = E_{out} \left/ \sum_{i \in N} \frac{I_i \cdot E_{out}}{\eta_i \cdot \eta_{p,i} \cdot \eta_{t,i}} \right. \quad (2)$$

Where, I_i represents the percentage of the annual power generation of i -th power source in the total annual power generation in the study area. We use $\beta_{km,EV}$ to express the energy consumption of electric vehicles for 100 kilometers, η_c represents the charging efficiency of electric vehicles, η_t represents the average transmission efficiency in the study area. The energy consumption of electric vehicles for 100 kilometers is shown in the following formula:

$$\alpha_{EV} = \beta_{km,EV} / (\eta_t \cdot \eta \cdot \eta_c) \quad (3)$$

The energy consumption of traditional fuel vehicles for 100 kilometers is:

$$\alpha_T = \beta_{km,T} \cdot Q_{oil} / (\eta_{t,petrol} \cdot \eta_{pro} \cdot \eta_{p,oil} \cdot \eta_{t,oil}) \quad (4)$$

Where, $\eta_{p,oil}$ is crude oil extraction efficiency, $\eta_{t,oil}$ is the transportation efficiency, η_{pro} is the efficiency of crude oil processing into petrol. $\eta_{t,petrol}$ is the transportation efficiency of petrol, Q_{oil} is the unit calorific value of petrol. $\beta_{km,T}$ is the oil consumption of traditional fuel vehicles for 100 kilometers.

3.2 Evaluation model for emission reduction of electric vehicle

The CO₂ emission of 100 kilometers for electric vehicles can be calculated by the following formula:

$$e_{EV} = \beta_{km,EV} \cdot \sum_{i \in N} I_i \cdot (e_{p,j} + e_{b,j}) / (\eta_t \cdot \eta_i) \quad (5)$$

In the formula, $e_{b,j}$ represents CO₂ emission of per unit calorific value generated by corresponding materials, is CO₂ emission factor, $e_{p,j}$ is the CO₂ emission factor of i -th fuel during mining and transportation.

The CO₂ emission of 100 kilometers for fuel vehicles can be calculated by the following formula:

$$e_T = \beta_{km,T} \cdot Q_{oil} \cdot (e_{p,T} + e_{b,T}) \quad (6)$$

In the formula, $e_{p,T}$ is the CO₂ emission factor in the process of petrol production, transportation and conversion. $e_{b,T}$ is the CO₂ emission factor during petrol combustion.

3.3 Reliability evaluation model of electric vehicles connected to distribution network

Reliability indexes of power distribution system include SAIFI, SAIDI, CAIDI and ASAI, etc. Their respective meanings and calculation methods are as follows (Set the average failure rate, average outage time and average outage time of each load point as λ_i , U_i and r_i respectively).

SAIFI is the average system outage frequency, it means the average number of power outages per unit time for each user powered by the system. The expression is as follows:

$$SAIFI = \frac{\sum \lambda_i N}{N} \quad (7)$$

Where N is the total number of users and $\sum \lambda_i N$ is the total number of power outages for users.

SAIDI is the average power failure duration time of the system, it means the average power failure duration time experienced by each user powered by the system in one year. The expression is as follows:

$$SAIDI = \frac{\sum U_i N}{N} \quad (8)$$

In the formula, $\sum U_i N$ is the total power failure duration time for users.

CAIDI is average power failure duration time for users. It means the average power failure duration time experienced by the power outage users in one year. The expression is as follows:

$$CAIDI = \frac{\sum U_i N}{\sum \lambda_i N} \quad (9)$$

ASAI is the average power availability rate, it means the ratio of the total number of no power outages hours experienced by users to the total number of power supply hours required by users in a year. The expression is as follows:

$$ASAI = \frac{\sum 8760N - \sum U_i N}{\sum 8760N} \quad (10)$$

4. Case study

The electricity price parameters in this paper refer to the data of a power company in Beijing, peak hour (1.0044 RMB/kWh), smooth time (0.6950 RMB/kWh), valley time (0.3946 RMB/kWh). Peak price execution periods are 10: 00 to 15: 00 and 18: 00 to 21: 00 daily. The execution period of valley time price is from 23 o'clock on the same day to 7 o'clock on the next day.

4.1 Energy consumption comparison of different vehicle

The following data were obtained from some references, the crude oil mining rate is 98%, the crude oil transportation efficiency is 99%, the petrol transportation and filling efficiency is 83%, the processing efficiency is 85%, the unit calorific value is 43 kJ/g, fuel consumption per kilometer for fuel vehicle is 65ml. From formula (4) we know $\alpha_T=0.830$ kWh/km. From relevant data, the comprehensive power generation efficiency $\eta=45\%$ is obtained from formula (2). Electricity consumption per kilometer for electric vehicle is 0.121 kWh/km, the average transmission efficiency of the power grid is 92%, the charging efficiency is 92%, the energy consumption per kilometer of the electric vehicle obtained from formula (3) is $\alpha_{EV}=0.315$ kWh/km. The comparison chart of energy consumption between fuel vehicle and electric vehicle is shown in figure 1.

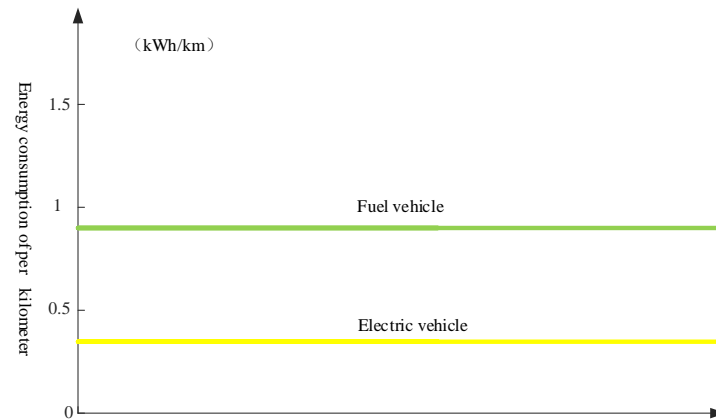


Figure 1. The comparison of energy consumption of per kilometer in fuel vehicle and EV

From figure 1, it can be clearly seen that the energy consumption of fuel vehicle is much higher than the electric vehicle. There is a difference of 0.515 kWh/km between α_T and α_{EV} . That is, 0.515 kWh per kilometer of energy is saved. According to the pricing of a power company in Beijing at peak and valley hours. It can save 0.517 RMB during peak hours, save 0.358 RMB during smooth hours, save 0.203 RMB during valley hours. For example, according to 2017 data, more than 130,000 electric vehicles in Beijing can save up 70,000 RMB per kilometer during peak hours. It can be seen that the energy consumption of electric vehicles is much lower than the fuel vehicles and the economy is good.

4.2 CO₂ emissions comparison

Assume the emission factor of CO₂ of petrol and CO₂ of natural gas during the mining process is 20g/kWh, 7 g/kWh, the CO₂ emission factor of coal is 6. The emission factors of CO₂ during combustion are 260 g/kWh, 330 g/kWh and 200 g/kWh respectively. According to formula (5) and (6), the CO₂ emission per kilometer of fuel and electric vehicle are calculated as shown in figure 2.

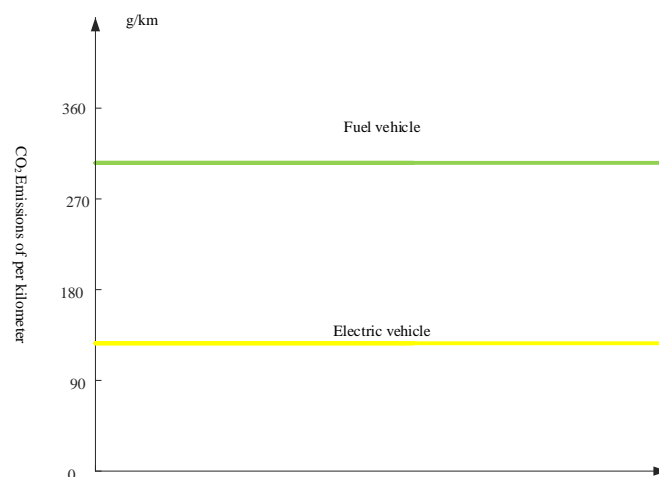


Figure 2. The comparison of CO₂ emissions of per kilometer in fuel vehicle and EV

Electric vehicles can reduce 180.07g of emissions compared with fuel vehicles. According to the calculation that each car travels 20,000 kilometers per year, the average car reduces carbon emissions by 3601.4 kg CO₂ per year. Therefore, the reasonable connection of electric vehicle to the distribution network can effectively reduce carbon emissions and achieve good environmental protection effect.

4.3 Reliability evaluation index

In order to evaluate the reliability of electric vehicle connected to the distribution network, this paper analyzes the reliability of F4 main feeder of RBTS Bus6 test system. Reliability parameters and load parameters of components in examples reference to [5]. The stability of distribution network under the following three conditions is compared and analyzed: No EV, EV under disorderly charging and EV under V2G market with peak-valley time-of-use electricity price. The reliability indexes are shown in table 1.

Table 1. System reliability comparison

Cases	SAIFI	SAIDI	CAIDI	ASAI
No EV	1.0433	4.2351	3.2546	98.98
EV under disorderly charging	1.2781	4.3245	3.3521	98.97
EV under V2G market with peak-valley TOU price	1.0123	4.1203	3.1054	98.99

When the system is connected to a disorderly charging electric vehicle, the SAIFI, SAIDI and CAIDI indexes of the power distribution system will increase. ASAI decreased from 98.98% to 98.97%, the distribution network increases the system load value, which increases the peak-valley difference of system load. The stability of the system is reduced. EV under V2G market with peak-valley time-of-use electricity price, SAIFI, SAIDI and CAIDI indexes of the system decreased and ASAI value increased by 98.99%. The stability of the system is increased. This shows that V2G market under peak-valley TOU price has a good prospect.

5. Conclusions

In this paper, the energy consumption model and CO₂ emission model of electric vehicle and fuel vehicle are established respectively. The energy consumption and carbon emission problems of electric vehicle and fuel vehicle are compared and analyzed. The stability of distribution network is also considered. The stability evaluation model is established and the conclusion is as follows: Electric vehicle have much lower energy consumption and better economy than fuel vehicle. Reasonable connection of electric vehicles to power distribution network can effectively reduce carbon emissions and achieve good environmental protection effect. EV under V2G market with peak-valley time-of-use electricity price can increase the stability of the system.

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