Load Forecasting of Hybrid Electric Vehicles Under Real Time Pricing

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Abstract

This paper presents a generalized formulation to forecast the loads of Plug-in hybrid electric vehicles. With this method, utilities can implement customer-oriented pricing strategy to influence the load profiles and the amount of electricity demand. The pricing strategy increases customer satisfaction and produces desired changes in the utility's system load shape. The pricing strategy incorporates utilities and customer requirements into integrated planning procedures. A case study is conducted to illustrate the application of the load forecasting method.

Keywords

hybrid electric vehicle, pricing

1. INTRODUCTION

After electricity market deregulation, utilities have a greater degree of flexibility in marketing strategies to help their customers to control electricity costs and change electricity demand patterns in mutually beneficial ways. Customer characterization is used for an integrated planning system. Information on customer load patterns is available by means of daily load diagrams, which were extensively used for years. In the competitive market scenario, utilities have to integrate the characteristics of future customers into utility planning [Cellings et al., 1989], [Kirschen, 2003].

Plug-in hybrid electric vehicles (PIHEVs) are the potential customers of utilities in the near future. Most of current hybrid electric vehicles (HEVs) do not use electricity from the utilities and they use gasoline only. Current HEVs are not the customers of utilities. PIHEVs use electricity from utilities and use much less gasoline. PIHEVs achieve better fuel economy and they are environmental friendly.

This paper aims to present a generalized formulation to forecast the loads of PIHEVs. With this formulation, utilities can implement customer-oriented pricing strategy to influence the load profiles and the amount of electricity demand. The pricing strategy increases the customer satisfaction and produce desired changes in the utilities' system load shape. The pricing strategy incorporates utilities and customer requirements into integrated planning procedures [Ashok et al., 2003], [Arroyo et al., 2000].

2. REVIEW OF HYBRID ELECTRIC VEHICLES

HEVs incorporating the engine and the electric motor, have been introduced as an interim solution before the full implementation of battery electric vehicles (BEVs). In this paper, a HEV is simply a vehicle having both the engine and the electric motor. The definite advantages of HEVs are to greatly extend the original BEV driving range by two to four times, and to offer rapid refuelling of liquid gasoline or diesel. An important plus is that it requires only little change in the energy supply infrastructure. The key drawbacks of the HEV are the loss of zero-emission concept and the increased complexity. Nevertheless, the HEV may be purposely operated as a BEV in the zero-emission zone. It is becoming a consensus that the HEV is not only an interim solution for implementation of zero-emission vehicles, but also a practical solution for commercialization of super-ultra-low-emission vehicles.

Due to the variations in energy management strategies, HEVs are further classified into two groups with reference to the charging strategy of the batteries. If the batteries are charged from the grid, they are classified as PIHEVs. On the other hand, if the batteries are charged by the gasoline engine, they are classified as HEVs. Figure 1 shows the characteristics of the vehicles. As shown in Figure 1, BEVs and internal combustion engine vehicles (ICEVs) are also grouped by this method. PIHEVs and HEVs are classified by the purpose but not the configuration. The drivetrain of PIHEVs is in parallel con-

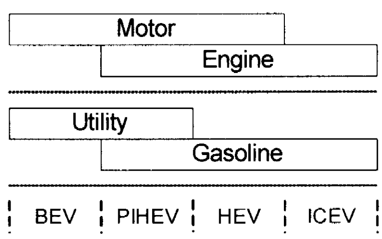

Fig. 1 Classification of vehicles

figuration. The gasoline engine and the electric motor are connected by a clutch [Wakefield, 1998].

3. LOAD FORCECAST OF PIHEVS

PIHEVs use electricity from the utilities and use much less gasoline. A PIHEV consists of both electrical and mechanical propulsion systems as shown in Figure 2. The gasoline engine is reduced to save space for the electrical propulsion system. PIHEVs use electricity first until the battery state-of-charge (SOC) depletes from 100% to 20%. Then they use both the gasoline engine and the electric motor to drive the vehicle and maintain the battery SOC at 20%. The fuel economy decreases when the battery SOC drops to 20%. Figure 3 shows the operations of a PIHEV.

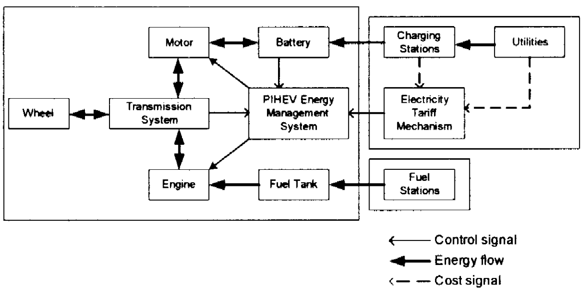

Fig. 2 Propulsion systems

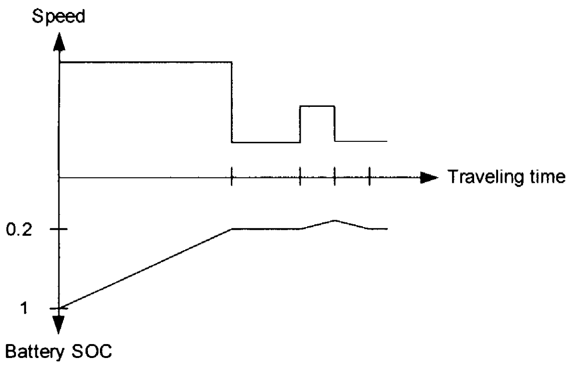

Fig. 3 Operations of a PIHEV

PIHEVs are the potential customers of utilities in the near future. PIHEVs use both electricity and gasoline. Utilities have to implement PIHEV-oriented pricing strategy to boost up the use of electricity from PIHEVs and to produce desired changes in the utilities' load shape. The load shape is the daily electricity demand. Loads of PIHEVs can be used for valley filling of the load shape. Valley filling is a classic form of load managements. The off-peak loads are increased by offering low electricity price to the PIHEV customers. The changes in load shapes enhance economic dispatch and reduce the average and marginal costs of utilities. Figure 4 shows the purpose of the PIHEV-oriented pricing strategy.

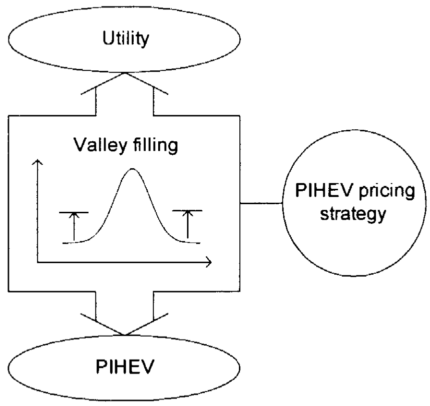

Fig. 4 Pricing strategy for PIHEVs

Utilities have to apply a variety of market research techniques to assess the behavior of PIHEVs. The primary behavior of the loads of PIHEVs is the daily energy demand profile. This daily energy demand profile is location dependent and vehicle dependent. It is derived from the driving cycles and the driving habits of the drivers. Figure 5 shows a typical daily energy demand profile, where μ_{Veh} is the mean energy demand of the vehicle.

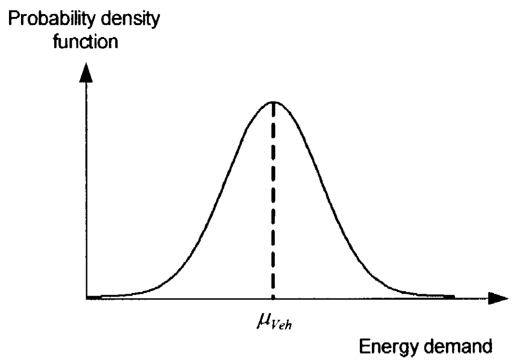

Fig. 5 Typical energy demand of a vehicle

The secondary behavior of the loads of PIHEVs is the price elasticity of PIHEVs. Drivers of PIHEVs may tend to use less electricity when the price of electricity is high. Figure 6 shows a typical price elasticity of a

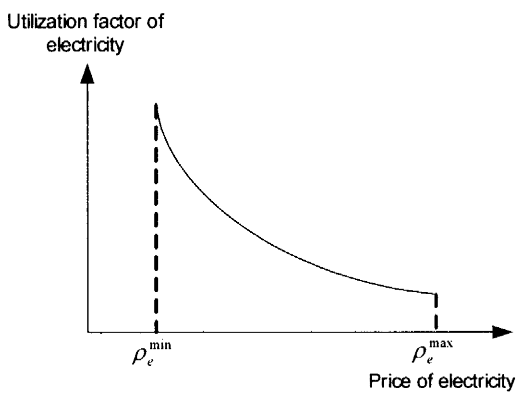

Fig. 6 Utilization factor of electricity

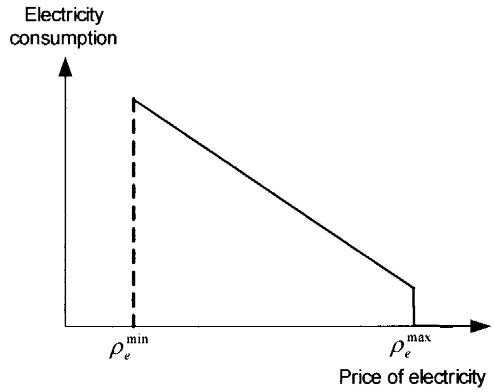

Fig. 7 Electricity consumption

PIHEV driver, where ρ_e^{min} and ρ_e^{max} are the minimum and maximum prices of electricity. The system efficiency of PIHEVs and price of electricity are the core parameters in calculating the loads of PIHEVs. Figure 7 shows the electricity consumption of a PIHEV at different prices of electricity. Because of the existence of gasoline engines and electric motors, the loads of PIHEVs can be effectively controlled by real-time pricing.

4. CASE STUDY

The proposed load forecasting scheme is illustrated with the scenario in Hong Kong, China. The vehicular performances of PIHEVs are assumed to be comparable to the ICEVs. The coordination of electric motor and gasoline engine is controlled by a controller which is governed by the battery SOC. Cost inputs for simulation are summarized in Table 1. Figure 8 shows the utilization factor of electricity in Hong Kong.

Table 1 Parameters of Hong Kong

Specific energy of gasoline	9.72 kWh/L
Gasoline cost	0.157 US$/kWh
Daily mileage	50 km
Cost of batteries	0.18 US$/kWh
Efficiency of engine	30%
Efficiency of motor	80%
Efficiency of battery	80%
Number of PIHEVs	7200
Grid capacity	600 MW

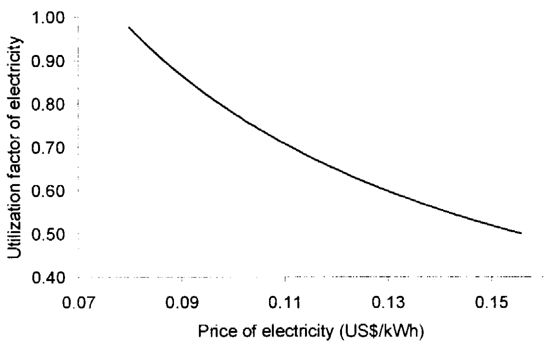

Fig. 8 Utilization factor of electricity in Hong Kong

The cost of the batteries in a PIHEV increases the selling price of the PIHEV. However, the fuel cost of PIHEVs is lower than that of ICEVs. The batteries of the PIHEVs should be properly sized to minimize the running cost of the PIHEVs. Figure 9 shows the impact of battery capacity to the cost of battery, the gain of fuel cost and the gain of a PIHEV when the price of electricity is 0.1US$/kWh. Cost of battery is the cost of the battery in the PIHEV. Gain of fuel cost is the save of the fuel cost achieved by a PIHEV when compares with an ICEV. Gain of PIHEV is the difference between the gain of fuel cost and the cost of batteries. With reference to Figure 9, if batteries of the PIHEV is sized at 19.2 kWh, the driver can save 1.94 US$ a day from driving a PIHEV instead of an ICEV.

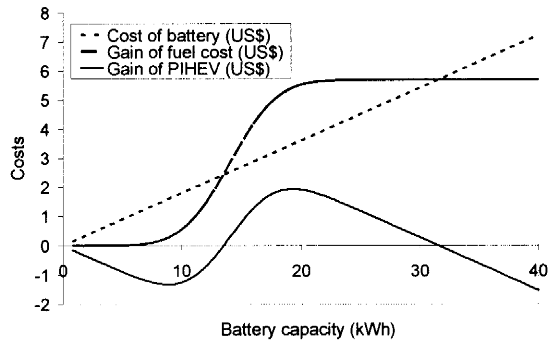

Fig. 9 Costs of a PIHEV

Utilities implement PIHEV-oriented pricing strategies to shift the loads of PIHEVs to the off-peak regions by decreasing the price of electricity at the off-peak regions. The fuel cost of PIHEVs is decreased while the off-peak loads of the utility are increased. This pricing strategy achieves mutual benefits. Figure 10 shows the electricity consumption of a PIHEV at different prices of electricity. Figure 11 shows the corresponding revenue from the PIHEV. The revenue is maximum when the price of electricity is 0.11 US$/kWh. In this scenario, there are 600 blocks of residential high-rise buildings and 7,200 PIHEVs in this district. The residential loads are low from 12:00am to 5:00am. The utility can set the price of electricity at 0.11 US$/kWh from 12:00am to 5:00am

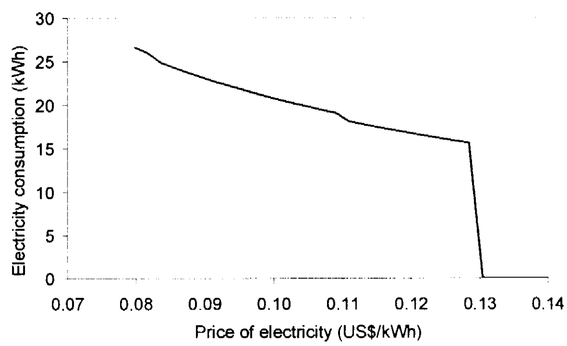

Fig. 10 Electricity consumption

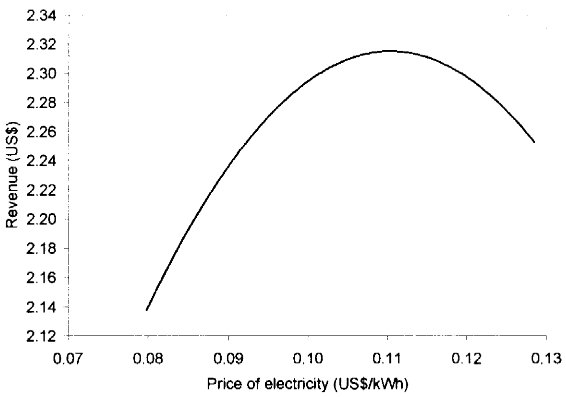

Fig. 11 Revenue from a PIHEV

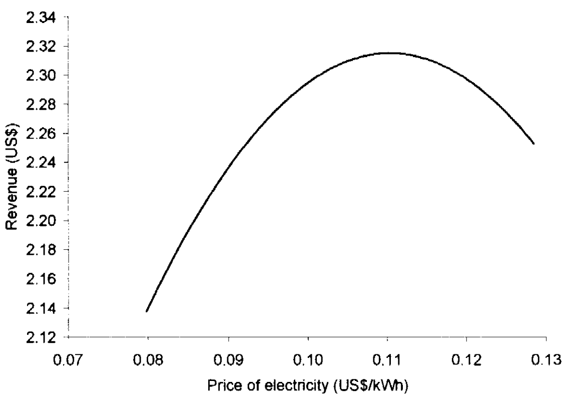

Fig. 12 System load shape

and set the price at 0.13 US$/kWh from 5:00am to 12:00am. All the loads of PIHEVs are shifted to the valley of the load shape. Figure 12 shows the corresponding shapes of the loads of PIHEVs, residential loads and the lumped loads.

5. CONCLUSION

Characteristics of PIHEVs are discussed. PIHEVs have the potential to replace the current ICEVs. PIHEVs are identified as the future customers of utilities. A generalized formulation is discussed to forecast the loads of PIHEVs.

A case study of a typical scenario in Hong Kong shows the application of the proposed load forecasting method. A PIHEV-oriented pricing strategy is proposed to increase the off-peak loads of the utility. The load shape of the utility is improved by the loads of PIHEVs.

Acknowledgments

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