Impacts Assessment of Fuel Change into Plug-in Battery Electric Vehicle on Base-load Power Plants

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Ⅰ. Introduction

Many eco-friendly vehicles, especially plug-in battery electric vehicles (PBEV), are in the spotlight because they have great economy and less Greenhouse gases (GHGs) emission compared to internal combustion vehicles (ICV). PBEV is an electric vehicle that can be driven by electric motor generator and battery, instead of engine and fuel tank. Since PBEV can be driven only by stored electricity in the battery, it needs to be charged after consuming charged electricity. Electric vehicle drivers can use either a low-speed battery charger, which takes about 7 hours, or a high-speed battery charger which takes about 30 minutes. If a driver is not on emergency, it is better to use a low-speed battery charger, since a high-speed battery charger can reduce battery life. In this article, diffusion pattern is evaluated and the impacts which electric vehicle can bring about are investigated.

Other studies on PBEV conduct the information from studies done in United States, whereas this study conducts the information from studies done in Korea. In this paper, it is analyzed how PBEV diffuse and penetration impacts base-load, and what the necessary conditions are for power plants. For this, state-of-the-art PBEV penetration and real time pricing have been surveyed to study how these factors affect a load curve.

Ⅱ. Predicting penetration of PBEV and increment of electricity due to PBEV

1. Feature of PBEV

PBEV uses a rechargeable battery pack and electric motor instead of a fuel tank and internal combustion engine. The electricity stored in the secondary battery packs drives or contributes to driving the wheels. Since a plug is built on a PBEV, it can be recharged from any external source of electricity. PBEV should be recharged after driver uses certain amount of electricity. Charging time is dependent on several factors, such as power supply, charger system, and battery capacity. In case of Korea, which uses 220V power supply, the average charging time of a compact PBEV is 7 hours by low-speed battery charger, and 30 minutes by high-speed battery charger [1]. There are several PBEV that have already come out, such as Nissan Leaf and Mitsubishi I-MiEV [2].

2. Comparison of PBEV and ICV

Table 1 shows a specification of PBEV compares with ICV. In this comparison, vehicle type is a

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compact sedan. These are average values that are referred in several previous papers [3-9]. As a result, ICV drivers emit twice amount of CO_2 and spend more than ten times in operation cost than PBEV drivers.

<표 1> Main parameters

	PBEV	ICV
Driving Efficiency	7.9 km/kwh	15 km/liter
Energy Price	90 ₩/kwh	2000 ₩/liter
CO_2 Emission	71.6 g/km	145.3 g/km
User expense	11.4 ₩/km	133.3 ₩/km

Remarks) ₩ represents Korean currency unit Won.

3. Penetration of PBEV and increment of electric power consumption

To predict number of PBEVs that will be diffused in the future, Bass diffusion model is applied. The original Bass model was published by Management Science [10] in 1969, and it has been featured as one of the best diffusion models to predict market penetration of new products. Even Bass model was ranked number five in the ten most frequently cited papers in the 50-year history of Management Science. Also, it was reprinted in the December 2004 issue of Management Science [11]. Bass model is represented as follows;

$$\frac{f(t)}{1-F(t)} = p + qF(t)$$

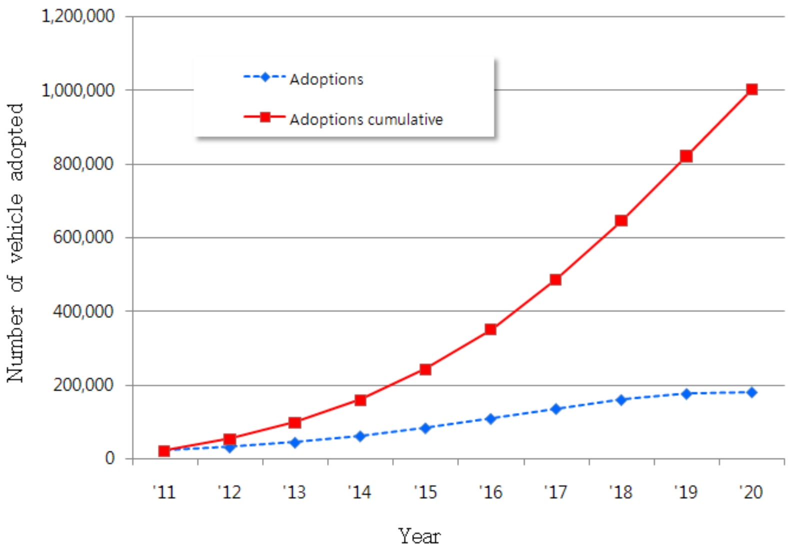
Where,
f(t) is the rate of change of the installed base fraction at time *t*
F(t) is the installed base fraction at time *t*
p is the coefficient of innovation
q is the coefficient of imitation

Sales S(t) is the rate of change of installed base (i.e. adoption) f(t) multiplied by the ultimate market potential m:

$$S(t) = mf(t)$$

$$S(t) = m\frac{(p+q)^2}{p} \cdot \frac{e^{-(p+q)t}}{(1+\frac{q}{p}e^{-(p+q)t})^2}$$

Three parameters are set based on the market share of PBEV in United States [10, 12]. The coefficient of innovation was 0.01, the coefficient of imitation was 0.38 and market potential was 1 million. According to the Bass model, there will be about 1 million PBEVs in 2020 (Figure 1).



(그림 1) Market penetration of PBEV

The current average driving distance of Korean compact sedan drivers is 40 km per day. Based on this information, each driver drives 14,600 km every year. Therefore, new electricity consumption will be about 2,086 GWh per year or 5,714 MWh per day as a whole.

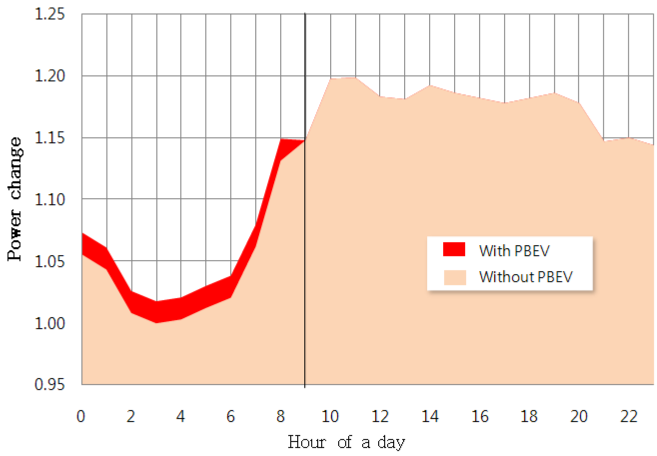
Ⅲ. Real time pricing affecting change of load curve

1. Real time pricing and Korean government plan

If power rates do not matter with time, PBEV cannot affect the base-load positively. Drivers do not have to recharge their electric vehicles at night if power rates are the same at all day. In this case, it can bring a higher power demand on its peak time. Then, PBEV causes the making of a bigger gap between peak and base-load. As a result load curve is going to be more unstable in this situation. This is why real time pricing is needed. As power consumption is high, electricity price goes up, so it induces customers to reduce the use of electricity. This can help electric enterprises to spend less on generating plants. Producers and customers can gain benefits at the same time if customers use electricity economically.

Recently, Korean government tested Real Time Pricing (RTP) in 2010. Korean government is going to apply RTP in near future. Thus, Korea Electric Power Corporation (KEPCO) is going to support to replace the coulometer to a smart one. As a result of RTP, Korean government is expecting about 330 billion won of social benefits [13, 14].

2. Change of daily load curve



(그림 2) Change of Daily Load Curve in 2020

Due to penetration of PBEV and launch of RTP, the result comes out as Figure 2. There are 3 assumption was made.

- 1 million PBEVs are penetrated in 2020
- 5,714 MWh per day is increased in power demand
- Every PBEV drivers recharge their car at lower price band, which is between 12 am to 9 am.

The red colored area represents the new load curve when 1 million PBEVs are penetrated in 2020. It includes new power demand.

Ⅳ. Considerations in generation fuel mix

1. Increased role of base-load power plant

PBEV diffusion will bring new power consumption. At the time when 1 million PBEVs are diffused in 2020, the change of power consumption at the base-load is considered. Sometimes it is emphasized that PBEV is not a green car because there is much GHGs emitted when electricity is generated from thermal power generation.

However, if PBEV is charged with power generation from inferior energy sources in terms of environmental aspect, the PBEV would be treated as not sustainable in the future. Then fossil fuel thermal power generation does not prefer. There are several other energies that do not emit much GHGs while producing electricity.

If the PBEV is resolved by the technology, it would lessen the GHGs, and also would increase the diffuse of economic side of customers. The increase of the diffuse of PBEVs would lead additional demand of the electricity. A possible conclusion is that because it is not a substitution of demand, it requires the increased role of base-loaded power plants. Figure 2 shows that base-load demand’s net increase is about 1.6%-1.7%.

2. Different types of energy that can supply electricity.

PBEV would not be a good solution for clean resources to reduce the GHGs, for the image of thermal power generator is the main reason for GHGs. And if the power loss of energy is stayed at

60-70% at current technology, it means energy conversion rate is 30-40%. The adoption of PBEV should be studied with available energy sources to provide the net rise of the electricity demand. There are several other fuels that do not emit much GHGs while producing electricity.

<표 2> CO_2 emissionandenergypriceinpowergeneration

	Coal	Oil	LNG	Solar	Hydro	Wind	Nuclear
CO_2 emission(g/kWh)	953.1	776.8	525.2	81.1	64.6	64.8	28.2
Generation cost (₩/kWh)	100.4	216.1	138.3	128.4	133.5	138.5	39.6

Remarks) CO_2 emissionandgenerationcostrefer[15]and[16],respectively

One of the concepts of the electric vehicle is that fuel is much cheaper than ICV. PBEVs will not diffuse well if electricity price is high. The other concept is that PBEVs are eco-friendly. The PBEVs produce less GHGs than ICVs, because they do not burn fuels to drive the vehicle.

Also, the new generation plants deal with several conditions that should be considered before their first appearance to people. First, the new power generation plants should provide cheaper prices for people to use. Secondly, new power generation plants should not emit.

Since power consumption will increase because of PBEVs, people have to build more power generation plants. Table 2 shows the CO_2 emissions through power plant's life cycle assessment (LCA) and clearing costs of different types of energy that can produce electricity. CO_2 emission and energy prices are the most important factors to be considered [15,16].

V. Result and Policy Recommendation

Diffusion of PBEVs means the replacement from fossil fuels to electric power in transportation industry. As the number of PBEVs increase, it creates a new electric power demand. At the same time, RTP is going to be enforced. Therefore, these factors will affect the load duration positively, especially base-load. Until now Coal and nuclear have dominated, the economic feasibility and availability of mass generation of energy in base-load. The external cost of base-load power generation technologies should be also considered to respond effectively to the increment of base-load. External costs should include biz, social, health, safety and environmental aspects.

The diffusion of new technologies, such as PBEVs should have sustainability of property. Furthermore, the sustainable technologies should be maintained throughout the whole life cycle. It would be meaningless if the process maintains PBEVs. For example, PBEVs can both qualify the economic and environmental feasibility, if used in car industries. But it would not be the best technology if PBEVs leave more environmental effect than ICVs in the process of generating electricity in upstream stage.

The future societies would also boost the electrification with new technologies such as PBEV. The pattern of electricity usage would stand out in the increase of base-load electricity usage because of development of electricity saving technologies.

The supply of the new demands of electricity should be observed from many aspects and wider concepts. And most importantly, social costs for conservative measuring should be also considered.

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