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STUDY OF ENVIRONMENTAL AND ECONOMICAL EFFECTS OF USING ELECTRIC VEHICLES

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Abstract: Carbon dioxide emissions from fossil fuels have a lasting detrimental effect on the environment, compounding the green house emissions. The transport industry is a major contributor to the problem; more specifically private transportation in the form of internal combustion engine (ICE) driven motor vehicles. Electric vehicles (EVs) are being considered as a promising alternative, but they will have an effect on the infrastructure they rely on, namely "the grid". This paper discusses and analyses this effect. The load forecast is based on the energy consumption of a concept car developed by the University of South Australia (UniSA), code-named TREV (Two-seater Renewable Energy Vehicle). The paper gives a brief overview of TREV and estimates the impact of adopting such an electric vehicle on the environment in terms of the reduction in carbon released due to the replacing ICE vehicles.

1. Introduction

The transport industry is a major contributor to greenhouse gas emissions which has a detrimental effect on the environment. This includes personal transportation by petrol fuelled cars.
The University of South Australia (UniSA) has developed an electric vehicle, code-named *TREV (**T**wo-seater **R**enewable **E**nergy **V**ehicle)* as a concept vehicle to inspire the future directions for commuter vehicle developments. This paper presents a brief overview of TREV and forecasts the consequences of implementing a fleet of cars based on the concept of TREV in terms of load on the power system in South Australia with the assumption that it can be projected onto regions with similar features globally. In addition, the paper estimates the impact of replacing combustion engine vehicles with electric vehicles on the environment in terms of the carbon dioxide released to the atmosphere [1].

2. The problem

The monumental issue of global warming is arguably the most dangerous environmental problem to be faced by the world in the 21st Century. It is observed that "The largest sources of greenhouse gas emissions are electricity generation from coal, followed by transport based on oil" [2].
ICE powered cars are one of the major contributors to the greenhouse effect. Their gradual replacement by EVs is one of the many proposed solutions to address the problem of global warming.

3. Electric vehicles

Electric vehicles are driven by an electric motor, powered by on-board batteries. The vehicles are recharged using mains power and when a renewable energy source selected, the transport becomes an excellent form of clean and sustainable zero emissions energy source.
Electric vehicles are being constantly developed all around the world. In Figure 1 below is the University of South Australia's Electric Vehicle TREV. It is the main object used in the paper for analysis and its test figures are used for all calculations.

Fig. 1. UniSA electric vehicle TREV

TREV has a range of 160km per charge and can travel up to speeds of 120km/h [3]. It can be easily driven by any licensed driver. The vehicle weighs a mere 350kg, and is designed for a daily commuting for one or two persons.

4. Assumptions

For the purpose of the calculations in this paper some assumptions have been made to improve the validity of the results:

- Type of the power supply for the fleet
- The number of cars adopted for the model
- An average travel distance per day per vehicle

4.1 Power supply

Electric vehicles can be charged using any power outlet including General Power Outlets (GPO), three phase outlets or higher powered configurations. For the purpose of this paper all power needed for charging, shall be assumed to be supplied through a standard 10A GPO.

4.2 TREV adoption

To obtain a realistic power demand estimate, it has been assumed that 10,000 electric vehicles with identical features to those of TREV will have entered the road traffic in Australia. This is considered to be a realistic scenario in view of the fact that it represents less than 1% of all registered passenger vehicles in Australia [4].

4.3 Daily commuting

To calculate the daily load on the grid an average daily commuting distance of 40.8km per vehicle has been adopted on the basis of figures provided by the Australian Bureau of Statistics [4].

5. Definitions

To calculate a concise demand on the grid due to the fleet of vehicles introduced, some definitions about TREV must be given. These include:

- The battery charging characteristic of TREV
- Daily load profile of the grid

5.1 Battery charge characteristic

The battery charge characteristic depends on the size of the battery and the size of the charging source. In simple terms, a battery charge characteristic is the profile of the battery while being charged, i.e. a plot of the input power in the form of current versus time. This characteristic can substantially change the instantaneous load on the grid.

Ideally this characteristic is designed to provide the best possible scenario for the battery charging in following aspects:

- Speed of charge
- Energy efficiency
- Battery life
- Charger cost

A typical battery charge characteristic will initially exhibit the highest power possible from the source ensuring a quick charge. As the battery approaches full charge the charger will reduce the output to ensure the battery is not overcharged [5]. A good example of this can be seen in Figure 2.

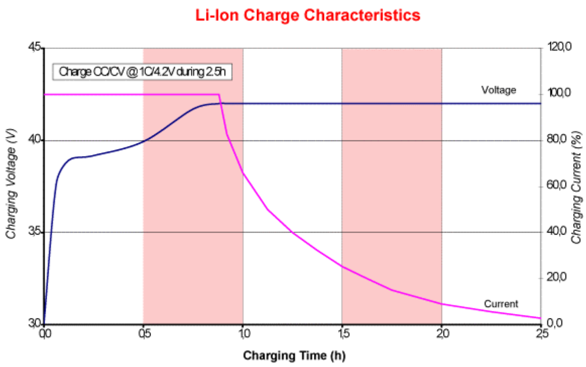

Fig. 2. A typical charging curve for a battery [5]

In the case of TREV, a Lithium Ion Polymer battery pack is used, made up of 36 cells connected in series each with a capacity of 40Ah at a nominal voltage of 3.7V. This results in an overall nominal battery voltage of 133V leading to a capacity of 5.3kWh [3].

In Figure 3 the above charge characteristic can be seen for one cell within the battery. This characteristic is for three levels of current 80A, 40A and 20A. For the purpose of this paper all charging is assumed to be completed via GPO of which the maximum current is only 10A. Therefore the charge profile is a longer three hour curve, where the battery is charged at 2.3kW for two hours and then at 0.7kW for an additional hour.

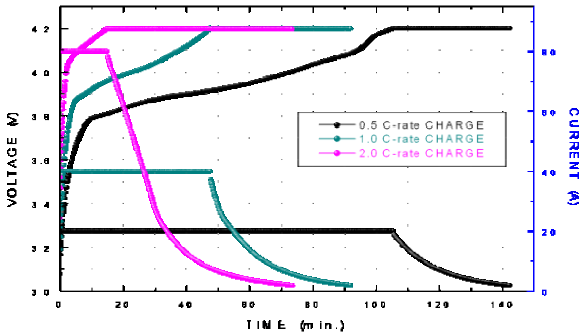

Fig. 3. TREV battery cell characteristics [3]

5.2 Daily load profile

The daily load profile is a curve showing the demand on the grid every hour for a whole day due to a fleet of 10,000 EVs. For simplification, this curve is assumed to be the same everyday of the year as the instantaneous demand is difficult to estimate.

The model [6] adopted in the paper assumes that the bulk of battery charging will occur during the time between 8pm and 1am. Residual charging will occur throughout the day randomly. An assumed charge pattern is illustrated in Figure 4. The random variation between 1am and 8pm reflects the modelling uncertainty in this conceptual model where no actual power levels are assigned to the variation of the charging power load [7], [8].

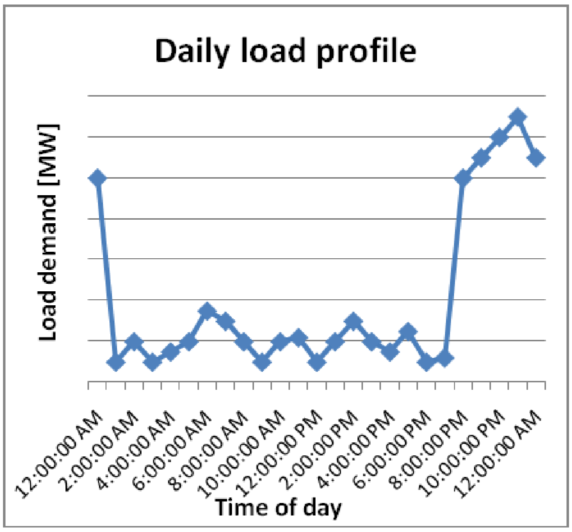

Fig. 4. Daily load profile curve

6. Load calculations

With the above assumptions, an overall load estimate can be attempted for a fleet of 10,000 electric vehicles. The first estimate is related to the number of charges needed per week for an average driver using TREV as their daily commuter vehicle. The average commuting distance and the range of TREV stated previously are to be used. The weekly charge requirement for the vehicle can be calculated through a simple ratio of the weekly travel distance and the charge distance (range) of the vehicle.

Weekly travel = 40.8km × 7 = 258.6km

Range = 160km

$$\frac{258}{160} = 2\ charges\ per\ week$$

Therefore, assuming the battery capacity of TREV, the weekly load per car would be:

$$2 \times 5.3kWh = 10.6kWh$$

And the daily load would be:

$$\frac{10.6kWh}{7} = 1.514kWh\ per\ day\ per\ car$$

Consequently, the annual demand would be:

$$1.514kWh \times 365 = 0.552MWh\ per\ car\ per\ annum$$

The load demand of all 10,000 electric vehicles per day would therefore be:

$$1.514kWh \times 10{,}000 = 15.140MWh\ per\ day$$

This constitutes an annual load of 55.2GWh for the whole fleet of 10,000 electric vehicles.
The above results can be put into perspective when compared with the yearly average power consumption of 11MWh per annum for an average household [9]. Therefore the yearly load of one TREV-like vehicle amounts to just about 5% of the total energy consumption of an average household.

7. Effects on the timing of fleet charging

The charging times of the fleet are critical in terms of the effect on the grid, as the price of electricity and the generating source will change in accordance with the time of day and the electricity market supplying the power [10]. Markets are numerous, but for the purpose of this paper two such markets are discussed providing the following:

- Baseload power
- Peak power/Load following power

It is the balance of these markets that is crucial for the introduction of the *electric vehicle* en masse as each has a different effect on both the consumer's pocket and the environment.

7.1 Baseload power

Baseload power is supplied at a constant rate round-the-clock and generally supplied by the cheaper forms of energy sources such as brown and black coal, considered to be dirtiest sources of energy. Consequently, there is a heavy toll on the environment.

Baseload power is maintained at a constant level around the clock and can not change its output power dynamically to suit changes in demand [10].

7.2 Peak power/Load following power

Peak power and load following power are called upon during times of high and extremely high loads where baseload can not supply the demand. To generate this power, plants that can be turned on almost instantly are used, deploying quick action prime movers such as gas turbines. These plants are only turned on for a short time. They are characterised by low efficiency and high operating costs, The price of electricity is highest when peak power demand occurs. Thus it stands to reason to avoid electric vehicle battery charging during peak demand periods and use basepower instead as stipulated above [10].

8. Carbon saving

Although the introduction of electric vehicles will cause an increase in demand on baseload power supply, it will indirectly reduce carbon emissions due to the replacement of internal combustion engine (ICE) powered passenger vehicles. It is this changeover that will cause benefits to be felt by the environment.

To illustrate, TREV will be compared with Holden Commodore, an average size family car manufactured in South Australia. According to the manufacturer, a Commodore generates 264 grams of CO_2 per kilometre [11]. By comparison, considering the worst case scenario for TREV, with all the energy to charge being drawn from baseload sources using black coal, the CO_2 output is 957 grams per kWh [12]. This constitutes 31 grams per kilometre travelled for TREV. Therefore for every ICE vehicle taken off the road, eight TREV vehicles may be put on the road for the same level of CO_2 emissions.

9. Conclusions

Electric vehicles constitute a plausible option for the future with a positive effect on the environment. However, if and when introduced, the effect they have on the electricity grid must be contemplated and controlled, ensuring an optimal daily load profile for the electricity supply grid. Among other methods, this could be achieved through the implementation of smart novel battery development and charge management processes.

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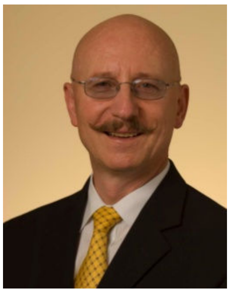

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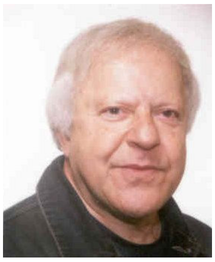

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