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A Simple Electric Bus Schedule using Energy Demand

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***Abstract*:** *This paper presents a method for scheduling electric bus for a day. A simple method to schedule the electric is developed using energy demand of electric bus related to total driving distance and energy consumption rate. The proposed method can be used as a tool for scheduling or travel planning for electric buses for multiple stops.*

Keywords: Electric vehicle, electric bus, energy management, tour schedule, transportation

1. Introduction

Electric vehicles (EVs) have been extensively studied by researchers worldwide due to its effective, efficient, and low emissions under operation compared to conventional internal combustion engine (ICE) vehicles. EVs emit near zero greenhouse gas (GHG) emissions while driving on electricity but electricity from fossil fuel extraction can have high GHG emissions. Electrical grid, the main power source nowadays, combines power from various types of power plants; coal-fired, gas turbine-fired, hydroelectric, solar and wind power plants. The electricity generation and upstream emissions are controlled by policies of that state or country. Coal, nuclear, hydroelectric and renewable energy source can supply base load power continuously 24 hours and electricity cost is low during base load. On the other hand, expensive power plants were operated during high power demand or peak load and electricity cost is high during this period of time. Oil, natural gas power plants with expensive fuel price are used for peak load power generation [1, 2].

Electric grid with addition new load such EV may face operation difficulty during peak load. Marginal grid mix GHG emissions of an electrical grid also increase because high operating cost and high GHG emissions power plant are operated by high GHG emissions power plants. To reduce the GHG emissions, coal and natural gas plants must be replaced with lower GHG emission plants.

At present state of development, electric vehicle has some draw backs in range and battery limitation and has high cost so an effective approach for utilizing and managing EV is needed. EV penetration is rising in many countries [3, 4]. There are several types of EVs includes passenger vehicle, truck, van, and bus. For public transportation electric bus has lower cost per person than private vehicle. Electric bus has been implemented and tested and shows good performance and energy saving. Electric bus can be used as fixed or flexible routes as school bus, metropolitan transportation bus, airport bus, tour bus, and share taxi. The electric bus is expected to be widely used more than private vehicles due to lower investment cost per person and less cost on maintenance.

Electric bus such as transit bus, airport bus, and school bus travels on specified destinations and stops. Passengers are drop off and pick up at each stop. The electric bus with travel schedule can be managed for better utilization energy storage of the electric bus. In this paper, an electric bus schedule is proposed using several parameters. The simple method based on energy demand of the vehicle relates to total driving distance and energy consumption rate. For night charging, electric bus battery can be fully charged at the beginning of the first trip and sufficient to run several trips per day. For day and night charging, total driving distance is greater

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than maximum distance but electric bus energy is not well utilized. Hence the proposed approach can be used to improve the electric bus in planning and scheduling.

2. Electric Bus Schedule Description

2.1. Electric Bus

Electric bus can carry several people in one trip. Electric bus has battery as the main energy storage system located on the vehicles. The mechanical and electrical subsystems are controlled depending on performance design. Electric bus manufacturers include BYD motors, Protera, and the Smith Newton eTrans electric bus [5-6]. Each electric bus has different electric power and energy requirement, battery capacity, battery peak charge and discharge power and driving distance.

Energy consumption of an electric bus for a driving distance (d) for k trips can be written as (1) [7].

$$E_{bus}(k) = R \cdot d(k) \tag{1}$$

Where

R is electricity consumption rate of electric bus in kWh/km.

2.2. Driving Distance

Driving distance of an electric bus depends on the onboard battery capacity that use for electric motor to propel the vehicle. In this study electric bus for distance less than 250 km per charge with multiple stops is studied. Several trips per day can be assigned based on traveling time and charging time per trip. For each stop, the electric bus stops for a few minutes to drop-off and pick up passengers. The bus travels in specified chronological order as shown in Fig.1 from the starting point (point-1) to next destination (point-2, point-3,..) until ending point (point-n) is reached. The longer the total trip distance the higher the electric bus's battery energy demand. The energy demand of electric bus must not greater than usable energy available of battery otherwise electric bus may run out of energy before reaching final destination or a charging station. Electric bus can carry several people in one trip. Electric bus has battery as the main energy storage system located on the vehicles. The mechanical and electrical subsystems are controlled depending on performance design.

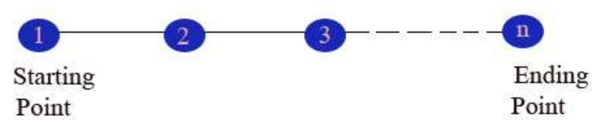

Fig. 1: Vehicle travelling trip.

Total distance for a trip can be written as (2).

$$d(k) = \sum_{i=1}^{n-1} d_i(k) \tag{2}$$

Where

d_i is distance from the previous point- i to the next point- (i+1) in km.

Capacity factor of battery energy is the ratio of the electric bus driving distance for m trips to the maximum driving distance before charging battery (d_{max}). This factor shows the suitable utilization of electric bus on travel and it can be written as,

$$C.F. = \frac{m \cdot d(k)}{d_{\max}} \tag{3}$$

Assume electric bus have constant waiting time at each stop at the same driving distance in each trip. Total travel time of k trips (tp(k)) per day can be written as (4).

$$t_p(k) = k \cdot \left[\sum_{i=1}^{n-1} t_{w,i} + \sum_{i=1}^{n-1} t_{d,i} \right] \tag{4}$$

Where

$t_{w.i}$ is waiting time at each stop

$t_{d.i}$ is travel time between the previous point- i and the next point- (i+1) in minutes.

Point- n is the point that electric bus is charged by charger connected to electrical grid. When an electric bus is parked at point- n it is charged to full state of charge (SOC). Note that point- n in previous trip becomes point- 1 for next trip.

2.3. Electric Bus Charging Scheme

There are two cases to charge the electric bus to operate for one day.

(1) Charging at night:

In this case, electric bus is driven to several stops and takes a few minutes of waiting times between stops during one trip. After completed all k trips, electric bus is recharged at night to fully charged battery.

(2) Charging during the day and at night:

In this case, electric bus is driven and takes a few minutes of waiting times between stops. After a number of trips m, the electric bus then is recharged during the day then it is operated several trips again (k-m). After completed all trips electric bus is charged at night.

The charging time can be written as (5).

$$t_{ch}(m) = \frac{m \cdot E_{bus}}{P_{ch}} \quad (5)$$

Electric bus battery in case (1) must larger than that in case (2) to hold the sufficient energy to operate for longer driving distance.

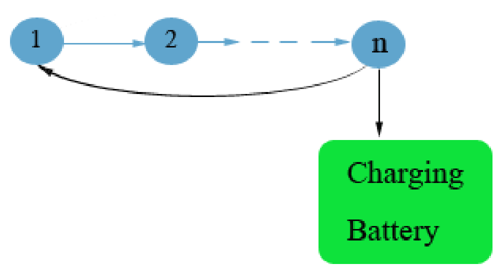

Fig. 2: Electric bus charging scheme

2.4. Electric Bus Travelling Schedule

Total travel time that electric bus delivery passengers between destinations depend on speed of the vehicle and traffic condition of the road. Assume electric bus consumes no electricity from battery when it is waited at each stop. Number of trips per day can be scheduled per one day depends on operating time of the electric bus and trip time and charging time if electic bus is charging during the day. Number of trips per day can be calculated by (6).

$$m = \frac{60 \cdot (T_e - T_b) - t_{ch}}{T_p(k)} \quad (6)$$

Where

T_b is the beginning operation time in hour

T_e is the ending operation time in hour

m is number of trips before charging battery and it is the nearest round down positive integer.

2.5. Electrical Grid Supplied Electric Bus

Electrical grid is responsible for GHG emissions of electricity charging to electric bus. The existing and readily available electric power source is normally supplied by diversity of power sources such as coal, natural gas, nuclear energy and renewable energy (solar, wind, and hydroelectric). Power plants used in electricity production are operated according to economic framework conditions resulting in different power generation mix, GHG emissions, and electricity cost. Fossil fuels power plant yield higher GHG emissions than wind and solar power plants. However renewable energy sources have small shares that have no impact on GHG emissions reduction especially on peak demand. For existing electrical grid, electricity production during the day are produced with marginal power plants that have high fuel cost. Charging electricity at night with lower fuel cost yields lower electricity cost for customer and day peak load reduction and load shifting for electrical grid [2, 7, 8]. Electricity generation cost in $/h depends on generation power.

3. Methodology

Electric bus can be scheduled by the developed mathematic equations as the following steps;

i) Parameter setting: parameter values are given as shown in Table I and Table 2: Energy consumption rate of electric bus, charging power, waiting time, operating hours, maximum distance , average speed and travel distance between destinations. Three scenarios are tested.

Scenario 1 (S1): Point 1-2-3-4-7

Scenario 2 (S2): Point 1-2-3-4-5-7

Scenario 3 (S3): Point 1-2-3-4-5-6-7

ii) Find solution: Determine number of trips per day.

iii) Calculate total travel distance and energy demand of electric bus per day.

Parameters was obtained based on available information of BYD Electric Bus.

TABLE I: Travel Distance between Destinations

To-From Destination	Distance (km)	To-From Destination	Distance (km)
1-2	1.9	4-7	3.1
2-3	3.9	5-6	61.3
3-4	4.1	5-7	28.7
4-5	31.7	6-7	52.8

TABLE II: Parameters

Parameters	Value
Energy consumption rate of electric bus(kWh/km)	1.193
Charging power(kW)	60
Waiting time (min.)	2
Operating hours	9.00-17.00
Maximum distance (km)	250
Average speed(km/h)	60

4. Results

The parameters are calculated using developed equations to schedule and find the energy demand of electric bus. Two charging cases are studied.

Case1: Charging at night (1 time)

Case2: Charging during the day (1 time) and at night (1 time)

The S1 and S3 scenarios have the shortest and longest distance and travel time per day, respectively, as shown in Fig.3.

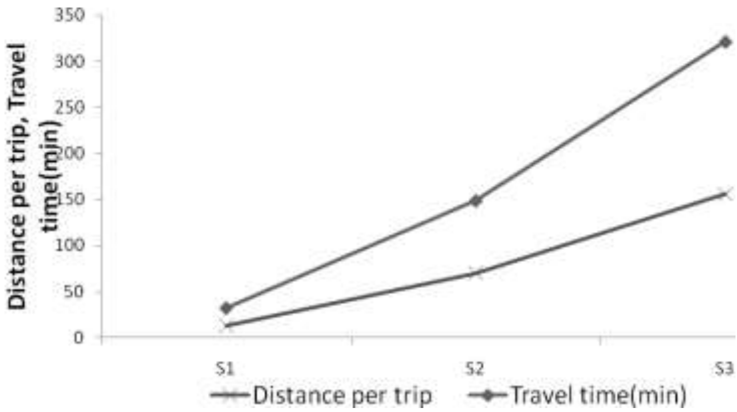

Fig. 3: Distance and travel time per trip

For electric bus schedule, number of trip that bus travels in specified chronological order is determined.

TABLE III: Results

Parameters	Case1			Case2		
Scenario	S1	S2	S3	S1	S2	S3
No. of trips per day	19	3	1	24	4	2
Energy demand (kWh)	294.7	251.6	185.8	372.2	335.5	371.5
Capacity Factor (%)	0.99	0.98	0.62	0.62	0.56	0.62
No. of trips per day	19	3	1	24	4	2
Total driving distance per day	247	210.9	155.7	312	281.26	155.7

Results from the calculation shows that the highest number of trips is 19 for case 1 and 24 for case 2. Capacity factor of S1 in case 1 is the highest value. Capacity ratio closed to 1 means that the travel distance is near maximum distance. Energy demand from electrical grid of S1 is 294.7 for case 1 and 372.2 for case 2.Charging during the day has lower maximum capacity factor compared between 2 cases. Electric bus should run closed to the maximum driving distance and charging at night based on capacity factor. On the other hand number of trips increases when number of charging increase (day and night charging).

5. Conclusion

A simple method to schedule the electric bus is presented. The schedule per day of an electric bus for two charging cases is determined. The proposed method can be applied for scheduling or travel planning for other electric buses. The number of trips can be improved if the electric bus battery was charged during the day or between trips. However the capacity factor is high when total driving distance is closed to maximum distance before charging the electric bus.

6. Acknowledgements

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7. References

[1] Martin Nicholson, Tom Biegler, Barry W. Brook, "How carbon pricing changes the relative competitiveness of low-carbon baseload generating technologies," *Energy*, vol. 36(1), pp. 305-313, Jan 2011 .

http://dx.doi.org/10.1016/j.energy.2010.10.039

[2] Kangkang Zhang, Liangfei Xu, Minggao Ouyang, Hewu Wang, Languang, Lu, Jianqiu Li, Zhe Li, "Optimal decentralized valley-filling charging strategy for electric vehicles," *Energy Conversion and Management*, vol.78, pp. 537-550, 2014.

http://dx.doi.org/10.1016/j.enconman.2013.11.011

[3] M. Kintner-Meyer, K. Schneider, R. Pratt, "Impacts Assessment of Plug-In Hybrid Vehicles on Electric Utilities and Regional U.S Power Grids Part 1: Technical Analysis," Pacific Northwest National Laboratory, 2007

[4] James Druitt, Wolf-Gerrit Fruh, "Simulation of demand management and grid balancing with electric vehicles," *J. Power Sources*, Vol. 216, pp.104-116, 2012.

http://dx.doi.org/10.1016/j.jpowsour.2012.05.033

[5] Greg Davis, BYD Electric bus, available at http://www.byd.com/na/auto/ElectricBus.html on 21 October 2014

[6] Tilde Herrera, Electric buses plug in to US Market with new models, more bucks, 25 October 2011 available at http://www.greenbiz.com/blog/2011/10/25/electric-buses-plug-into-us-markets-new-models-more-bucks on 21 October 2014

[7] Panhathai Buasri, Rathakarn Buasri, "AC charging PHEV by electrical grid," in *Proc. Power and Energy Systems and Applications Conf.*, 2010, pp. 1-4.

[8] H. Helm, M. Pehnt, U. Lambrecht, A. Liebich, "Electric vehicle and plug-in hybrid energy efficiency and life cycle emissions," in *Proc Int. Sym. Transport and Air Pollution conf.*, 2010, pp.113-274.