Charging optimization using service operational data

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Abstract

This thesis deals with the optimization of charging of electric buses in depot. The goal is to draw up an economic feasibility, optimize battery charging and discharging and create a priority index of bus placement in depot. With real data provided by Hitachi Rail, a MATLAB code for optimization has been implemented. The results obtained have economically validated the transition from diesel to electric bus use.

1. Introduction

Nowadays, the transportation paradigm shift is determining the transition from diesel (DB) and/or hybrid to electric buses (EB). In this outlook, Hitachi Rail seeks to achieve this goal in the field of city buses. To carry out this electrification it is necessary to estimate all the costs that derive from it. In order to optimize costs, in my thesis I worked on the optimal charging strategy with the possibility of a V2G. The optimization tries to minimize cost when the battery of the buses is in charge and, at the same time, maximize profit in case the residual charge is sold to the grid. In order to reduce the number of charging stations (CS) it is possible to define a priority index (PI) of bus positioning with the result of a lower energy demand from the grid in depot.

2. Input Data

The development of the thesis is based on real data provided by the transport company AMT of Genoa. The data refers to electric buses operating in line 44, whose data is shown in Tab.1.

Table 1: Real Bus Operational Data.

Variables	Value	
Kilometers per year	30000	km/year
Avg. Operating Day per year	250	
Nominal Capacity of Battery	350	kWh
Power - Charging Station	50	kW
Nominal Power of Depot	2	MW

3. System Model

In order to simulate the equivalent circuit of the battery it is first necessary to evaluate the elements that are part of it. The HPPC test (a methodology used to determine the dynamic performance characteristics of a battery) defines the parameters of the equivalent circuit as a function of the battery SoC. Each variable of the equivalent circuit (implemented on Simulink Fig.1), has two Look Up Tables (LUTs) that define their charging and discharging behavior. The simulation output shows the voltage trend during charging and discharging mode.

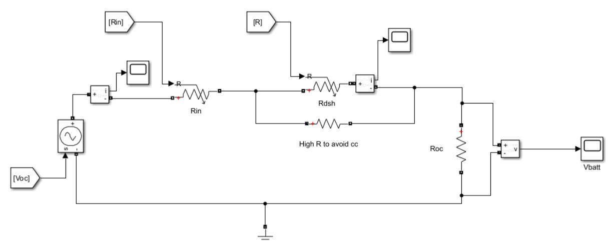

Figure 1: Equivalent Circuit of Battery Model in Simulink.

In the thesis, I developed a Genetic Algorithm (GA) summarized in Fig.2, which minimizes charge cost or maximize energy sales profit. To perform this, in the algorithm an Objective Function is built with the following inputs:

- The voltage (600V) and capacity of the battery;
- The maximum current of the CS (125A);
- The time interval in which the algorithm operates;
- Loss of SoC equal to 5% for each route of the bus;
- The number of the buses (5) and their SoC_{in}.

The algorithm operates under the following constraints:

- Current of a CS $0 \leq I_{cs} \leq 125A$;
- Sum of all currents of each CS $0 \leq I_{cs,all} \leq 625A$;
- Equality between final and required battery energy $E_{fin} = E_{req}$.

The objective function depends on the cost that is from the Day-ahead market cost of energy. If the equality between the required and final energy of the battery is respected, then the algorithm proceeds to the calculation of the SoC and SoH. An evaluation of SoH is necessary considering the use of V2G technology, as it might affect the battery lifetime.

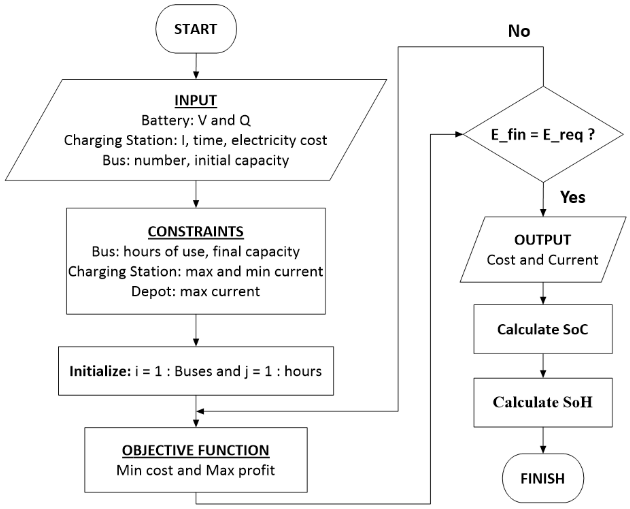

Figure 2: Flow Diagram of the Genetic Algorithm.

The thesis deals with the problem of scheduling the buses in depot, to avoid congestion of the charging stations. Fuzzy Logic allowed to use the combinatorial logic to derive the PI, which manages the charging order and power of the buses according to their SoC level and scheduled route times.

4. Results

A first result of this thesis is the cost comparison between a DB and EB, whose result is shown in Fig.3.

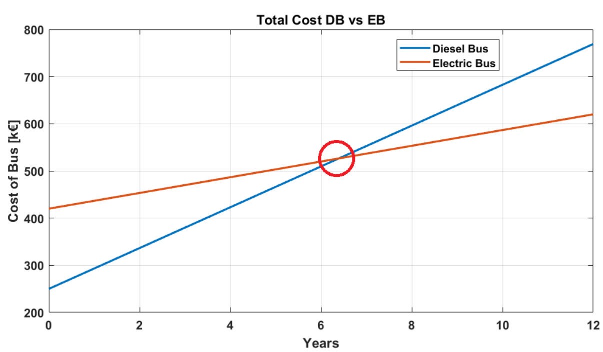

Figure 3: Total Cost of Electric and Diesel Bus.

With these specific data the use of the electric buses allows to obtain an economic saving of about 19.39% (149k€) after 12 years of use compared to diesel. The EB is already economically advantageous after 6.5 years of life (552 k€, Fig.3).

The rules I defined in the Fuzzy Logic generate the priority index (Fig.4) for bus charging that works as follows:

- Drops to about 0 when the bus leaves the depot;
- Increases when the bus is about to leave the depot;
- During the V2G period (between 600-700s and 1200-1300s) there is an increase because the SoC of the bus and the length of Exit Time in depot are reduced.

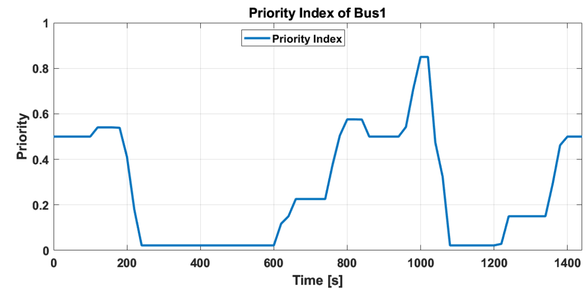

Figure 4: Priority trend of Bus1.

The use of this index and the optimization of the charging (GA) together with the V2G leads to further economic advantages: average daily savings of 4.2% is obtained considering a variable electricity price instead of average; moreover, V2G leads to an economic return of 24.28% on the total spent in the day.

Despite the use of the V2G which increases the number of charging and discharging cycles of the battery, as it can be seen in Fig.5, there is an increase of battery life with use as energy storage, meaning that the SoH decreases less during the EB life. The reason is that the value of the SoC in these conditions does not reach values above 90% or below 30% (where the capacity fade is greater).

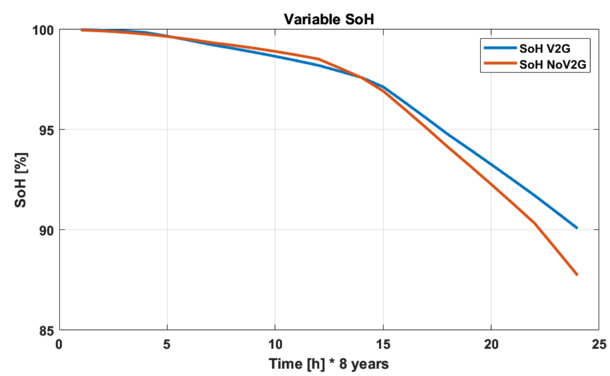

Figure 5: Trend of average SoH in 8 years.

5. Conclusions

The use of real data allowed to simulate a real use of a fleet of electric buses. The charging optimization and the use of the V2G technology have defined an increase in the useful life of the battery with annexed economic savings both for the maintenance costs and for the sale of energy.

Personal Contribution

- Assessment of all economic aspects for DB and EB;
- Build an GA using MATLAB that takes advantage of V2G technology and the cost of electricity defined by the day-ahead market to get the optimal;
- Determine the effect of V2G use on the battery by calculating SoH;
- Evaluation of the economic saving of using the V2G and a PI of the positioning of the buses in the depot.