Modelling and Simulation of a Pure Electric Bus

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***Abstract*—This thesis is focused on the analysis of the behavior of a pure electric bus assigned to a certain route. The model is obtained by the interaction between SUMO -which is a microscopic traffic simulator- and Simulink, put together by using MATLAB. With SUMO, a route with high fidelity to the original linea 44 of Genoa has been made, respecting the positions of traffic lights, reserved ways and slope profile. Feasibility of the vehicle with respect of the specific situation can be quantified by an Idoneity index.**

I. Introduction

Electrification is rapidly taking more and more space inside the sectors which require a high quantity of energy, in particular, in the transport sector. Due to the low energy density of the batteries -which are the main power storage of the electric vehicles- and the high time that the recharge system needs, their usage must be optimized in the most precise form. Several variables can alter the consumption of the vehicle, both technological and operatives. In particular, operative variable such as drive style, traffic and passenger on board can be crucial in the calculations.

II. Simulink Model

Simulink model is a closed loop speed following model, and the powertrain components have been mainly implemented by using look-up tables. It is composed by different subsystems:

1) **Control subsystem**: is the main input of Simulink. The speed profile gathered by SUMO is followed by the longitudinal driver, a PID controller which acts on accelerator and brake pedals;
2) **Passenger subsystem**: number of passenger can be fixed or implemented by using a lookup table distance based. They change the equivalent mass of the vehicle;
3) **Auxiliary subsystem**: deeply linked to the passenger subsystem. Number of passenger and external temperature alter the auxiliary consumption, which data have been given by AMT of Genoa;
4) **Road subsystem**: based on the 1-D longitudinal model, it contains aerodynamic, tire rolling, gradient and inertial resistances;

$$F_{res}(v, \alpha, t) = F_A(v) + F_v(\alpha) + F_s(\alpha) + F_a(t) \quad (1)$$

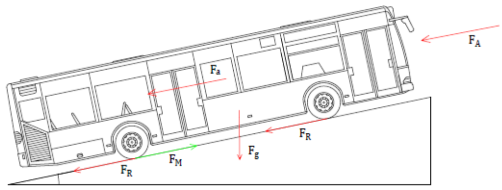

Figure 1: 1-D longitudinal model.

5) **Motor subsystem**: schematized as two lookup table, one for torque-speed characteristics, and one for the efficiency regions based on torque and speed. It is controlled by accelerator and brake pedals;
6) **Brake subsystem**: composed by both mechanical and electrical brake. Regeneration ratio is determined by the Fuzzy logic toolbox and is dependent from speed, brake pressure and SOC in the actual time.

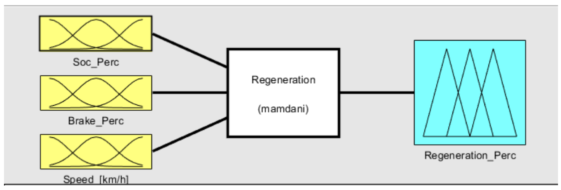

Figure 2: Fuzzy logic toolbox.

Electrical brake is saturated to the maximum torque that the motor can give.

7) **Transmission subsystem**: interface between motor, brake, road and control subsystems. Differential ratio and inertia are crucial data in this step.

$$T_M \cdot i_{diff} \cdot \eta_g - T_W = \alpha \cdot I \quad (2)$$

Its outputs are the actual speed, acceleration and distance made.

8) **Battery subsystem**: it can be charged or descharged and its outputs are the actual SOC and the kWh/km;
9) **Idoneity index**: based on the following formula:

$$I_{dx} = (1 - \frac{SOC_{initial} - SOC_{ending}}{SOC_{initial}}) \cdot \frac{\int 2 - \frac{T_{res}(t)}{T_{mot}(t)} dt}{t_{trip}} \quad (3)$$

It quantifies how much a bus is feasible for the specific route and situation.

III. SUMO model

SUMO is a traffic simulator where different scenarios can be tested. For the purpose of this thesis, the effect of traffic and drive style will be analyzed.

1) **Drive style**: by changing the maximum acceleration and deceleration, it is possible to pass from an aggressive drive style to a mild one;
2) **Traffic**: by changing the vehicle refresh rate and their probability that the routes will last longer, it is possible to create contingencies.

Emission comparisons can be calculated by using lookup tables inside SUMO, constantly updated.

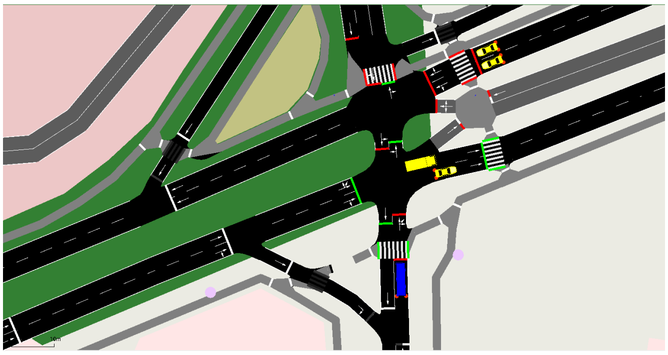

Figure 3: Example of SUMO simulation.

SUMO act as server and MATLAB as client by using the add-on Traci4Matlab. Each step of simulation has been memorized in MATLAB until the end. After that, data gathered are transferred inside Simulink and the energetic evaluation starts.

IV. Numerical evaluation

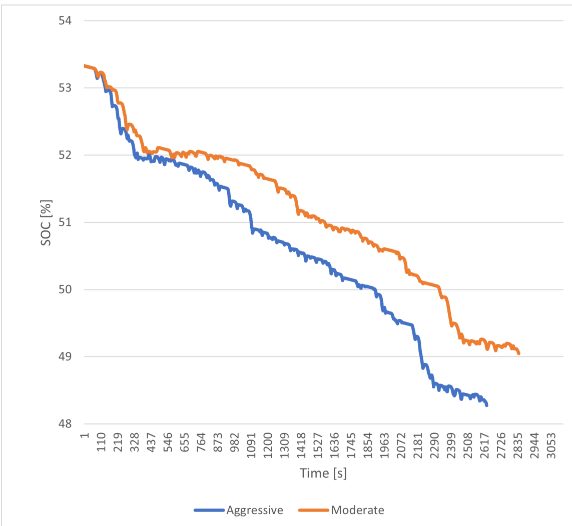

Figure 4: Linea 44 consumption with different drive style.

Drive style act on the brake and acceleration pedal's pressure. With smoother braking episodes, the regeneration ratio is higher. With smoother acceleration episodes, the electric motor working points are shifted inside areas with higher efficiency.

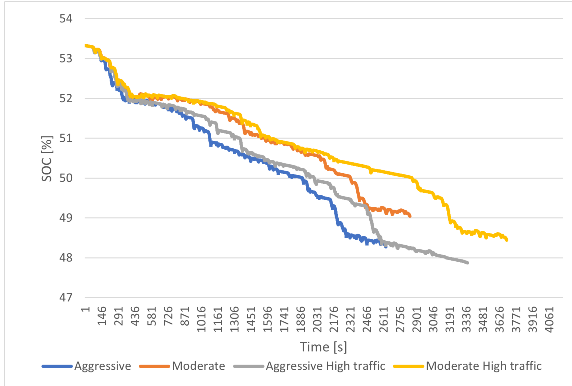

Figure 5: Linea 44 consumption with different drive style and traffic.

Traffic increases the number of braking and acceleration episodes, leading to a major energy waste. It also increases the time required for completing the route, and so the auxiliaries become more present. Even in this scenario, mild drive is advantageous with respect of the aggressive one.

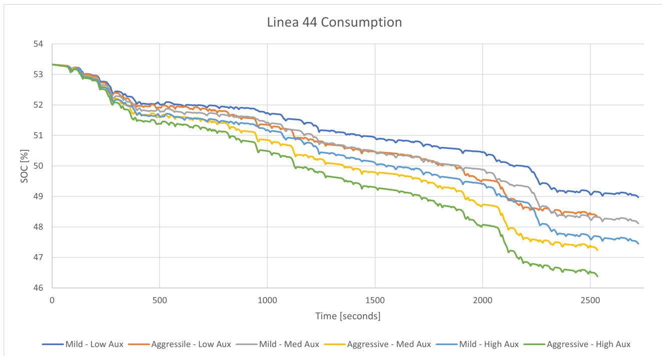

Figure 6: Linea 44 consumption with different auxiliaries and drive style.

Auxiliaries can significantly change the bus consumption even in case of low traffic. Drive style can alter this consumption, because auxiliaries are also associated to a different occupation rate, and so different mass of the vehicle and braking/acceleration force.

Idoneity index and consumptions:

- Aggressive/low traffic/low aux: 1.614 - kWh/km: 1.592
- Mild/low traffic/low aux: 1.686 - kWh/km: 1.537
- Aggressive/high traffic/low aux: 1.62 - kWh/km: 1.717
- Mild/high traffic/low aux: 1.677 - kWh/km: 1.369

V. Conclusions

A method which can estimate the consumption of an electric bus with different operative conditions has been tested. Despite not being validated due to the lack of experimental tests, the absorption in the different scenarios are coherent with the statistical mean consumption of electric buses.