32nd Electric Vehicle Symposium (EVS32)
Lyon, France, May 19-22, 2019

Impact of Traffic Stops on Energy Consumption of Electric Vehicles

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Summary

The reduction of greenhouse gas emission and pollutants emission partly due to the transport sector is one important challenge for the 21st century. Universities can propose new mobility solutions to address this challenge. The University of Lille will propose free access charging stations to encourage users to change for EVs. The energy consumption of EVs will be evaluated to size the charging infrastructure. A simulation tool is developed to find the total energy consumption with the best accuracy in a minimum of time. Energy consumption of the EV can be calculated only if the driving cycle is known. A driving cycle generator has been developed to create any driving cycle based on routing data.
Furthermore, the energy consumption of a trip can fluctuate due to random conditions. One of these random conditions is traffic stops (including traffic lights). The developed driving cycle generator can generate these stops or not. Two scenarios are studied for the same trip: without any stop and with all possible stops. A comparison of the energy consumption of both scenarios lead to evaluate the difference between both cases. For the studied trips, a difference of 20% is obtained for the energy consumption.

Keywords: electric vehicle, energy consumption, simulation

1 Introduction

Transportation sector is one of the largest greenhouse gas producers. Electric Vehicles can be a good solution to reduce pollutant emissions [1].

At University of Lille, the CUMIN project (Campus of University with Mobility based on Innovation and carbon Neutral) aims to propose electro-mobility solutions as alternatives to conventional cars [2]. One of the solutions is to replace all thermal cars by Electric Vehicles (EVs). 5000 persons come every day to the Campus “Cité Scientifique”, one campus of University of Lille with a thermal car. The goal is to propose free charging stations for these drivers. To evaluate the amount of charging infrastructure needed, the energy consumption of the vehicles must be known.

A solution is to measure the energy consumption of each trip. But 5000 car trips demands important resources in time (to measure all the trips) and in materials (measurement tools, vehicles…). Also, to reduce the costs, digital tools are developed. One tool is an Electric Vehicle simulation tool to calculate energy consumption of different vehicles. A second tool is a driving cycle generator.

Driving cycles can be used to calculate the energy consumption achieved by a vehicle on a trip. Three methods exist to generate these cycles. Two methods are based on big data. An important amount of driving profiles are measured. Statistic is made to find the important characteristic of these profiles. Statistic is used to create the most representative driving cycle [3] [4]. The second method used these statistics to create probabilities. The stochastic method used these probabilities to create an infinite number of driving cycle [5]. Markov Chain is one possibility [6]. The third method is based on the limitation [7]-[10]. Velocities limitations on each segment of the road are applied. The accelerations can be limited by this type of generator. In comparison with other methods, the limitation method allows the set up of traffic stops with the respect of the same velocities for the two cycles. A driving cycle generator based on the limitation method is used in this article.

In a previous work [10], the generator is validated and used on a simple road without random conditions. In this article, a more complex urban trip with a lot of traffic stops (traffic lights, traffic stops, etc.) is considered to evaluate their influence on the energy consumption. Two scenarios are considered in this article. The same trip is considered with no stop and all stops. To have a fair comparison with the two trips, there are both simulated.

The vehicle model and the algorithm of the driving cycle generator are developed in Section 2. Section 3 concerns the urban trip without consideration if stops. In Section 4, the same urban are made with the consideration of the stops and compared with the result find in Section 3.

2 Vehicle modeling and driving cycle

2.1 Vehicle modeling for energy estimation

A simulation tool of an EV is developed. The model is based on a Renault Zoe (Fig. 1). The main parameters of the vehicle are presented in Table 1.

Figure 1: The Renault Zoe [11]

Table 1: Parameters of the Renault Zoe

Element	Parameters
Weight	1460 kg
Battery	Li–ion NMC–22 kWh
Electric Machine	Synchronous Machine – 65 kW

The vehicle model is composed of an electric machine coupled to the wheel throw the mechanical transmission. The chassis of the vehicle is connected to the wheel and the road. The complete model of the vehicle is developed below.

The electric machine and its inverter are modeled with a static equivalent model [12]. The efficiency of the electric drive is considered as a constant value of 92%.

$$\begin{cases} Ted = T_{ed\_ref} \\ i_{ed} = \frac{T_{ed}\,\Omega_{ed}\,\eta_{ed}^{k}}{u_{bat}} \end{cases} with\ k = \begin{cases} 1\ if\ P_{ed} > 0 \\ -1\ if\ P_{ed} \le 0 \end{cases} \quad (1)$$

The electric drive is connected to the gearbox that represents the mechanical transmission of the car.

$$\begin{cases} T_{gb} = k_{gb} T_{ed}\,\eta_{gb}^{k_{gb}} \\ \Omega_{ed} = k_{gb}\Omega_{gb} \end{cases} with\ k_{gb} = \begin{cases} 1\ if\ P_{gb} > 0 \\ -1\ if\ P_{gb} \le 0 \end{cases} \quad (2)$$

An equivalent wheel transforms the torque into force.

$$\begin{cases} F_{wh} = R_{wh} T_{gb} \\ \Omega_{gb} = R_{wh} v_{veh} \end{cases} \quad (3)$$

The force applied by the brakes are added to the propulsion force made by the wheel

$$F_{tot} = F_{wh} + F_{br} \quad (4)$$

The Newton law gives the velocity of the vehicle. This force is applied to the chassis of the vehicle.

$$M_{veh}\,\gamma_{veh} = M_{veh}\frac{d\,v_{veh}}{dt} = F_{tot} - F_{res} \quad (5)$$

The resistance force is composed of the aerodynamic force, the road force and the slope force applied by the environment to the vehicle.

$$F_{res} = F_{aero} + F_{road} + F_{slope} \quad (6)$$

The Energetic Macroscopic Representation (EMR) formalism is used to organize this model (Fig. 2) [13] [14]. The control path is deduced systematically from the EMR. The total force of the vehicle is distributed in wheel force and braking force by the braking strategy. When the vehicle brakes, the total force applied to the vehicle is negative, half energy goes to the front wheel and this energy is used to regenerate the battery. The other is burned on the rear brakes. The model of the EV has been already validated in [15].

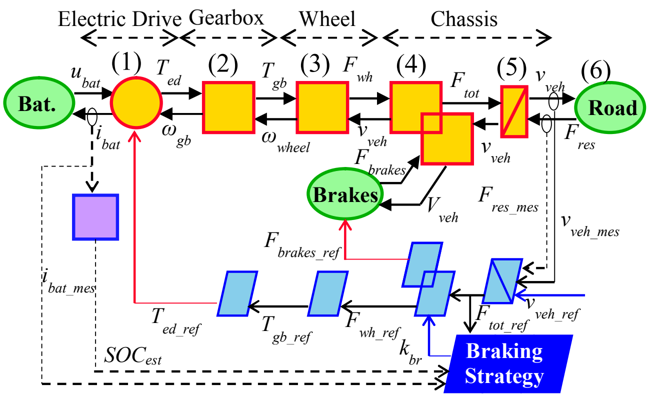

Figure 2: EMR of the studied vehicle

2.2 Automatic generation of real driving cycles

The automatic driving cycle generator provides the velocity reference applied to the vehicle [10]. This block will provide the vehicle reference V_{veh_ref} to the vehicle simulation. The generator requests segment distances and maximal velocities. The generator applies different limitations due to the road limitations, the vehicle limitations and the driver limitations (Fig. 3). In this article, the driver effect is neglected.

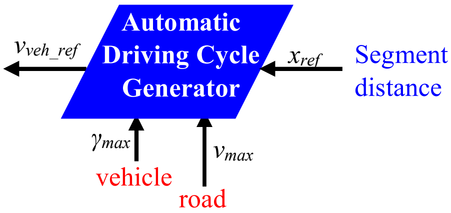

Figure 3: driving cycle generator

The generator can be resumed in three main parts (Fig. 4). The velocity limitation calculate the maximal velocity on the road and depends on the position of the car. The maximal acceleration is defined by the acceleration limitation block according to the maximal velocity and limit from the car and the electric machine. This maximal acceleration is transformed in velocity with an integral function.

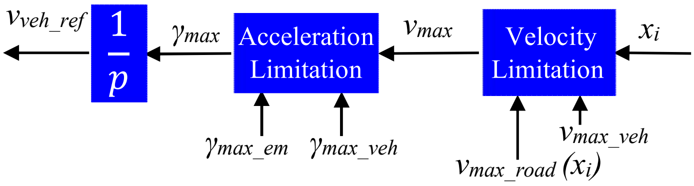

Figure 4: Simplified structure of the driving cycle generator

In more details, the trip is cut in different segments. The velocity limitations and the position of the end of each segment is known. This position are between 0 and the length of the trip called x_{ref}. The actual position of the car x_{mes} is calculated by the integration of the vehicle velocity. This position is compared with the position of the end of the segment x_i and the braking distance x_{brake} (7).

$$v_{max}=\begin{cases} v_{max\_road}(x_{ref}) \ if \ x_{ref}-x_{mes}>x_{brake} \\ v_{max\_road}(x_{ref}+1) \ if \ x_{ref}-x_{mes}\leq x_{brake} \end{cases} \quad with \ x_{brake}\geq 0 \qquad (7)$$

When the vehicle is not braking, the road limitation $v_{max\_road}(x_i)$ of the current segment is applied. When the position is between the braking position and the end of the segment, the next velocity $v_{max\_road}(x_{i+1})$ is applied. Then, the velocity is limited by the maximal velocity of the vehicle. And that becomes the maximal velocity v_{max}

The velocity is transformed in acceleration with a P. controller. This acceleration is limited by the maximal acceleration of the vehicle and the maximal acceleration due to the electric machine. In fact, the torque of the machine is limited as a function of the machine speed. The maximal acceleration is integrated to define the reference velocity applied to the vehicle (Fig.5).

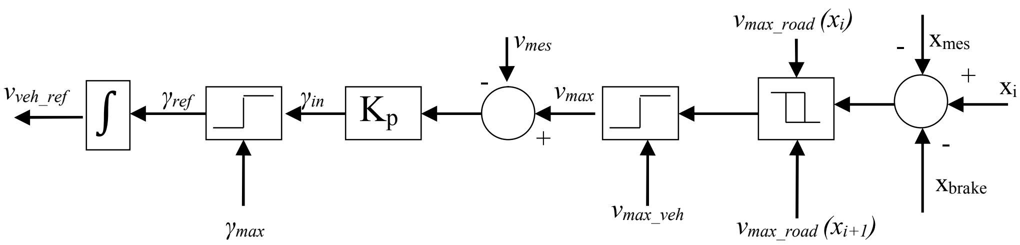

Figure 4: Simplified structure of the driving cycle generator

3 Urban driving cycle without stops

The studied trip is a 14 km urban trip. It consists in a round trip between University of Lille and Lille downtown (Fig. 4). The routing data, distances and maximal velocities, is provided by OpenStreetMap.org [16] and using the Graphhopper API [17]. First, no stop is considered by the driving cycle generator. Random conditions, such as traffic jam, are thus not considered. The velocities applied to the vehicle are the limitations of the different segments of the road (30 km/h and 50 km/h) (Fig. 5). The traveling time is 20 min. The energy consumption of this trip (Fig. 6) is 1.98 kWh.

Figure 4: Map of the considered trip

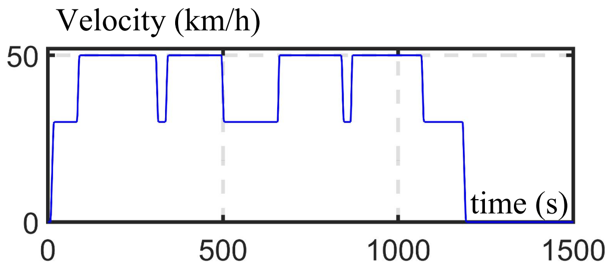

Figure 5: Velocity of the trip without stop

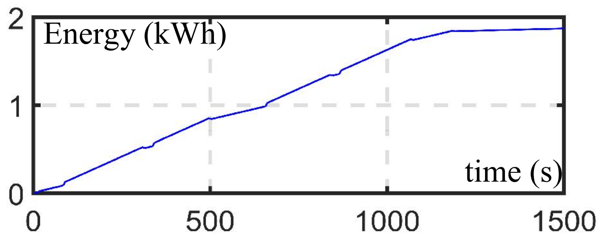

Figure 6: Energy consumed in the trip without stop

4 Urban driving cycle with stops

In this second case, the traffic lights and the cross stops are considered for the same trip. The vehicle is assumed to stop at every stop including all the traffic lights (30 in total). The other random conditions are not considered. The trip realized by the car contains more acceleration and deceleration (Fig 7). That leads to a larger traveling time, 37 min. Furthermore, the energy consumption is increased by 2.44 kWh (Fig 8).

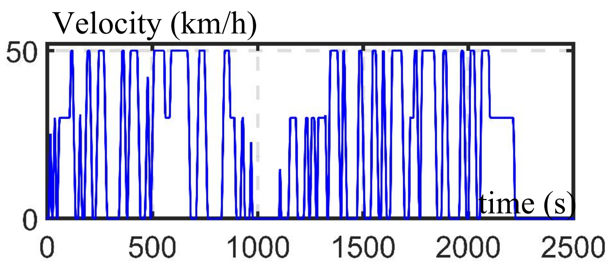

Figure 7: Velocity of the trip with stops

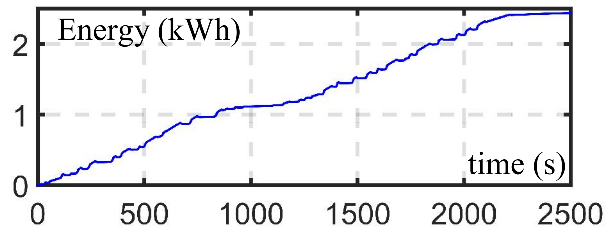

Figure 8: Energy consumed in the trip with stops

Table 2 summarizes the comparison between both cases. The full stop scenario is considered as the reference. The trip with all stop leads to the maximal traveling time and the maximal energy consumption. The trip with no stop leads to the minimal traveling time (-40%) and the minimal energy consumption (-20%). The real trip should lead to intermediate time and consumption. So it is important to take into account such random conditions to estimate the accurate energy consumption for an Electric Vehicle.

Table 2: Traveling time and energy consumption of the two trips

Stops	All stops	No stop	Difference
Traveling time (s)	37 min 5 s	19 min 55 s	46.3%
Energy consumption (kWh)	2.44 kWh	1.98 kWh	18.9%

5 Conclusion

A simulation tool has been developed to calculate the energy consumption of an Electric Vehicle. This tool is composed of an EV simulation tool and a driving generator tool. They are given by the driving cycle generator.

With this driving cycle generator, different traffic stop configuration can be studied. The difference between the all stops configuration and the no stop configuration is significant in terms of time (50%) and energy consumption (20%). In conclusion, it is important to take into account the stops on a trip to have an accurate energy consumption estimation.

Acknowledgment

This paper has been realized thanks to the funding of the University of Lille and the Region "Hauts-de-France" (Northern France) within the CUMIN program.

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