Artificial Driving Cycles for the Evaluation of Energetic Needs of Electric Vehicles

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***Abstract*—This article presents a novel method to simulate artificial driving cycles that have the same significant characteristics as measured driving cycles. The driving cycles are based on only two different easily accessible parameters namely mean velocity and mean positive acceleration as well as their standard variations. Those parameters allow to adapt the driving cycles to different cycle types (urban, extra urban, highway), length and duration. Other than know drive cycle simulators, the approach is based on normal distribution of velocities and accelerations, thus needing to analyze only few cycles for the initialization.**

I. INTRODUCTION

Electric and hybrid vehicles are the most promising answers to meet the demands of using sustainable energy. They are at the same time able to answer to our needs of personal transport, the limitation of fossil energy resources and global warming. Even if the technological development of those kind of vehicles has advances very quickly during the last years [1]–[4], there are still important questions that have to be solved.

Electric vehicles using electrochemical batteries as energy source still suffer from their limitation in autonomy [5]. The autonomy is bound to two factors: the energy needed by the system and the energy stored inside the battery. Intensive analysis on the battery based energy storage are carried out at the moment [6]–[8]. On the other hand the evaluation of the energy needed inside the vehicle has not developed equally. This work shows an approach toward the evaluation of the energy needs of an electric vehicle.

The evaluation of the energy needs can be separated into two major parts, the need for propulsion and the need for auxiliaries. The propulsion energy can be evaluated using the Newton Law [4], [9], which shows that the energy needs depend on several factors (vehicle mass, front surface, aerodynamic and rolling resistance) but mainly the driving cycle defined by velocity and hight profile. On the other hand there is the auxiliary power, whos influence seems to increase compared to the propulsion energy. This has two reasons, firstly the reduction of the propulsion energy as electric vehicles are smaller and lighter than all purpose vehicles as they are often adapted to urban applications and secondly to the fact that more and more electrically driven equipments are installed inside vehicles (for example entertainment and information electronics). Moreover, the climatisation has to be based on electrical energy.

There are different standardized driving cycles available (EUDC, NEDC, US driving cycle, Japan driving cycle) [4], [10]. Those driving cycles have been developed to be used mainly as baseline to evaluate the fuel consumption and exhaust emissions of internal consumption engine vehicles. Those driving cycles are well adapt for these applications, as they are very well defined and repeatable. However, some of them are purely artificial and do not at all represent the real life driving patterns (mean positive acceleration, length of driving phases, stop times etc.). Extensive series of driving cycle measurements have been affected throughout the European funded project ARTEMIS [11], [12], by Ericsson et al. [13], [14] or also by Toyota Europe [15], but those studies have still been aimed mainly at the evaluation the fuel consumption and the emission of pollutants of internal combustion engine vehicles. Ericsson [13], [14] described that different drivers show different driving pattern and ARTEMIS studies [11] describe different types of drivers according to their driving habits (acceleration and mean velocity). Despite this incertainties those analysis help to identify representative driving cycles. But using only one specific driving cycle to dimension the components of an electric vehicle will not answer to the real world needs, as the same vehicle is often used as well for urban commution (weekdays) and for long distance trips (weekends) for example.

The need for a driving cycle generator, that is capable to create a multitude of driving cycles has been identified and different solutions have been presented: Sometimes a Marcov chain based driving cycle generator is used, either to define a new driving cycle [16], or to reorganize existing driving cycles [17]; a non specified driving cycle generator was used in order to simulate all cycles that have been done over the vehicle lifetime [18]; Ravey et al. [19] presented a special purpose driving cycle simulator based on normal distributions. Until now all known driving cycle generators suffer from the fact that they are based on a very small number of measurements.

The presented driving cycle generator is based on normal distributions and parametrized using the results of the ARTEMIS project for different cycle types. Due to its easy parametrization it can be adapted to different conditions or driving patterns.

In the next section, the theoretic approach of artificial driving cycle generation is presented. The parameters to represent different cycle types are developed thereafter. The artificial

driving cycle generator is validated against a measured driving cycle including sections of urban, extra urban and motorway driving. This approach is used to evaluate the power and energy needs of the reference driving cycle and it can be shown that the results of the artificial driving cycle represent the real world needs with a high degree of viability. The artificial driving cycle can thus be used to predefine the sizes of different components of an electric vehicle. The article ends with conclusions and perspectives.

II. Approach of artificial driving cycle generation

The artificial driving cycle is generated by a succession of driving phases. Each driving phases is defined by its duration in seconds and its final velocity, while the initial velocity is defined by the former step. In order to facilitate the creation of the driving cycle some assumptions have been made. The main assumptions are:

- acceleration and deceleration values are constant,
- no differences in altitude,
- the vehicle is not doing any backtracking.

The driving cycle is constructed as follows; as long as the driving cycle is not finished, driving phases are created by defining the duration and the final velocity of the next step, therefore a normal distribution of velocity and duration is used. Each phase is tested with regard to its compliance to the maximum velocity. Thereafter, the (constant) acceleration value is evaluated as well as the distance covered during this phase. The main data (time, velocity, distance and acceleration) are stored in the output vector. The generation process of the driving cycle is also shown in figure 1.

The driving cycle generator is initialized using the distance of the total driving cycle. It includes the possibility to define the length of different road types and foresees, furthermore the possibility of stops as encountered at red lights for example.

The driving cycle generator, as it is presented here, does not show the possibility of constant speed driving. Observations of measured driving cycles have shown, that real life driving cycles do not show any constant speed driving either. Furthermore, the evaluation of ambient data like outside temperature and light conditions are not presented here.

In order to adapt the driving cycle generator to different road types, only some input parameters have to be adapted as presented in the following section.

III. Parametrization of driving cycle generator

Profound driving cycle studies have been effected inside the European funded project ARTEMIS and have been presented by André et al. [11]. Analysis of those studies show characteristic values for different driving conditions, which can be directly used by the driving cycle generator. The main parameters are the mean velocity and the mean acceleration. The parameters found by the Artemis project as well as the values that can be obtained using the proposed driving cycle generator are presented in table I. The initialization parameters, in order to obtain those results, are given in table II.

Table I
Characteristics of different road types [11]

	v_{mean}		$a_{positive}$	
	meas	gen	meas	gen
urban	28	27.4	0.72	0.70
extra urban	73	70.8	0.6	0.52
motorway 110	115	110.23	0.53	0.18
motorway 130	130	128.6	0.38	0.2

IV. Validation of the driving cycle generator

In order to validate the driving cycle generator a cycle has been chosen that includes portions of urban, extra-urban and motorway driving. In order to have a comparable database three drivers have been driving the described cycle several times. Their cycle has been measured using a GPS based positioning device with a acquisition frequency of $5\ \mathrm{Hz}$. The cycle is composed of the following parts; (1) urban driving $1.4\ \mathrm{km}$, (2) extra urban driving $1.3\ \mathrm{km}$, (3) motorway driving $16.5\ \mathrm{km}$ speed limitation changing from $130\ \mathrm{km\ h^{-1}}$ to $110\ \mathrm{km\ h^{-1}}$ after $7.0\ \mathrm{km}$, (4) extra urban driving $1.6\ \mathrm{km}$.

The comparison between a measured and an artificial driving cycle is presented in figure 2(a). It can be seen that the artificial driving cycle is in excellent accordance with the measured driving cycle with regard to the time needed to fulfill the different parts of the driving cycles as well as the velocities. The artificial driving cycle proposes stops, namely while urban driving, representing the same effect that is occurring in the real driving cycle. The observation of the velocity profile versus the drive time (figure 2(b)) shows that the accelerations in the artificial driving cycle are slightly more important than the accelerations in the real driving cycle. At the same time it can be seen that the artificial driving cycle provokes stops less often as the real driving cycles.

Another comparison based on the velocity and acceleration distribution over the entire driving cycle can be seen in figure 3. Also in this respect, the artificial driving cycle is in good accordance with the measured data. The artificial driving cycle proposes a slightly higher fraction of very high velocities and a slightly lower fraction of very low velocities. The distribution of mean velocities is respected accurately. With regard to the acceleration distribution a majority of small accelerations can be observed. The artificial driving cycle suggests slightly more low accelerations around zero, but slightly less extreme accelerations.

V. Using of artificial driving cycle generator to predefine components of electric vehicles

Based on the driving cycle and the vehicle characteristics presented in table III, moreover the propulsion and regeneration efficiency has been taken into account. The mean power, the maximum power as well as the energy needed for this cycle are calculated [9]. It can be seen in figure 4, that the power distributions of artificial and real driving cycles are highly comparable. They lead to mean powers of $11.7\ \mathrm{kW}$ for the artificial driving cycle and $9.6\ \mathrm{kW}$ for the real driving cycle respectively. The maximum power of the artificial driving

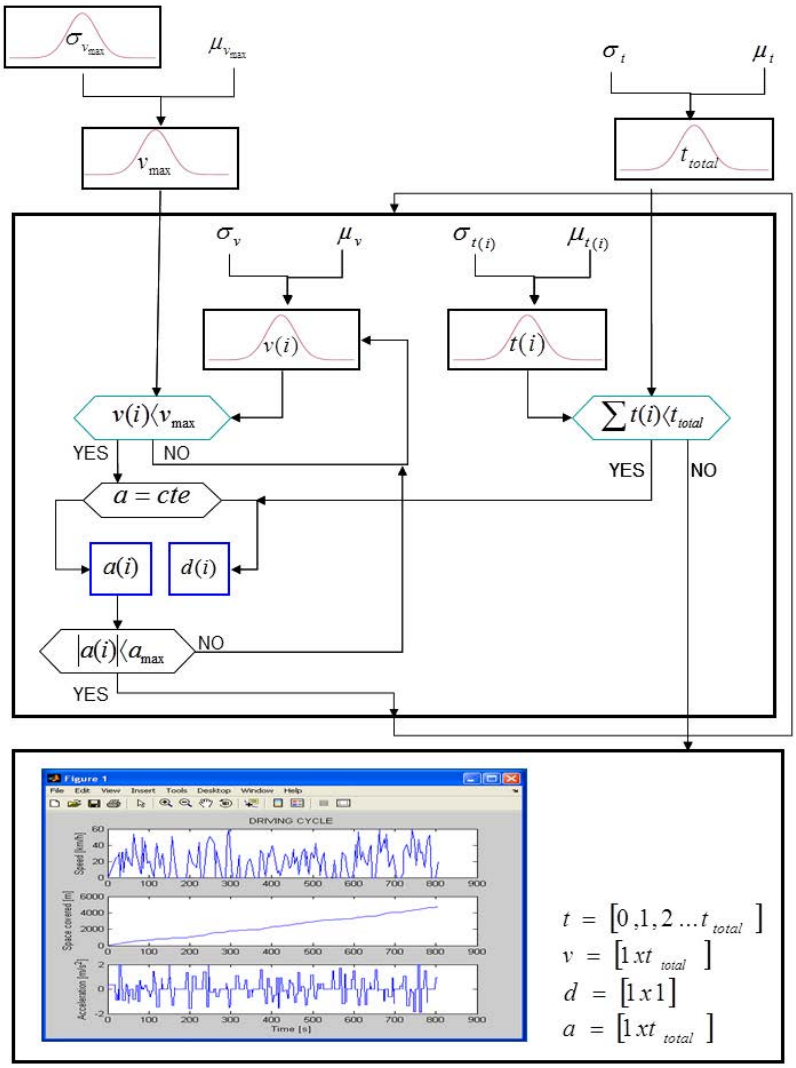


Figure 1. Working principle of the driving cycle generator

Table II
INITIALIZATION PARAMETERS FOR DRIVING CYCLE GENERATOR

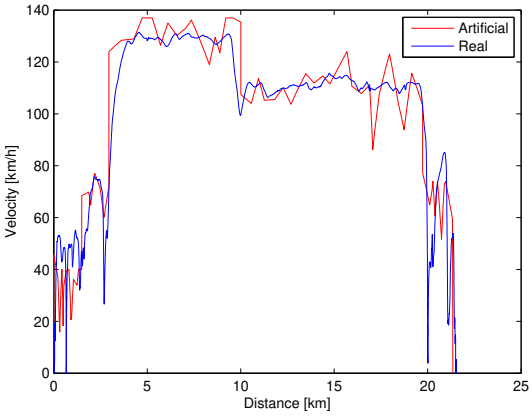
	phase duration [s]		mean velocity [km h^{-1}]		maximum velocity [km h^{-1}]	
	mean value	standard derivation	mean value	standard derivation	mean value	standard derivation
urban	10	5	35	30	60	30
extra urban	6	5	70	15	77	15
motorway 110	13	3	110	27	115	27
motorway 130	13	3	130	27	135	27

cycle is 40.3 kW, while 40.6 kW for the real driving cycle. Based on this, the energy needed to fulfill this cycle can be evaluated to be 2.84 Wh for the artificial driving cycle and 2.69 kWh for the real driving cycle. Those observations underline the representability of the artificial driving cycle with regard to power and energy needs.

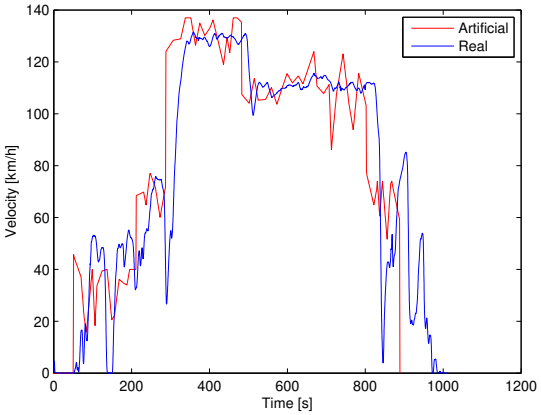
A detailed analysis of 1000 artificial driving cycles with regard to the mean power, maximum power and energy need is presented in figure 5. The results of several measurements of the real driving cycle are also integrated in the figure. It can be seen that the variation of the mean power of the artificial driving cycle is overestimated by 3 kW with regard to the

Table III
CHARACTERISTICS OF THE EVALUATED VEHICLE

mass	865	kg
frontal area	2.03	m^2
drag coefficient	0.337	
rolling resistance	0.01	
propulsion efficiency	80	%
recovery efficiency	30	%



(a) Velocity vs distance



(b) Velocity vs drive time

Figure 2. Comparison of real and artificial driving cycle

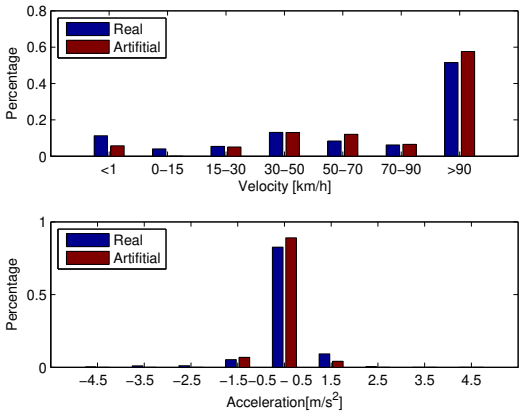


Figure 3. Distribution of velocities and accelerations

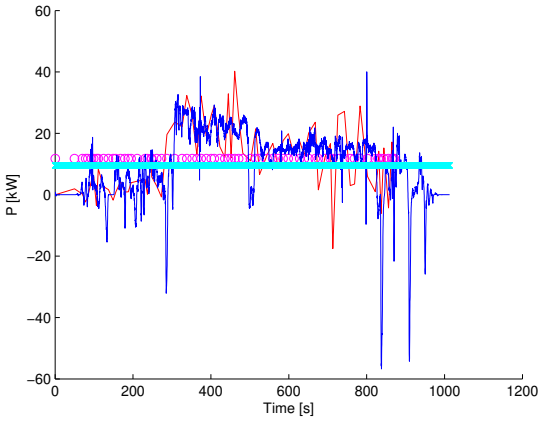


Figure 4. Power need during cycle

measurement data. The maximum power is well predicted to be around 50 kW. With regard to the energy needed to fulfill the cycle the energy needs are overestimated of around 1 kWh. This might be explained by the fact, that the test drivers have not been bound always to take the exact same roads, thus leading to the fact that some measured driving cycles might have varying fractions of urban, extra-urban and motorway driving, thus explaining the differences. More evaluations have to be done to improve this point.

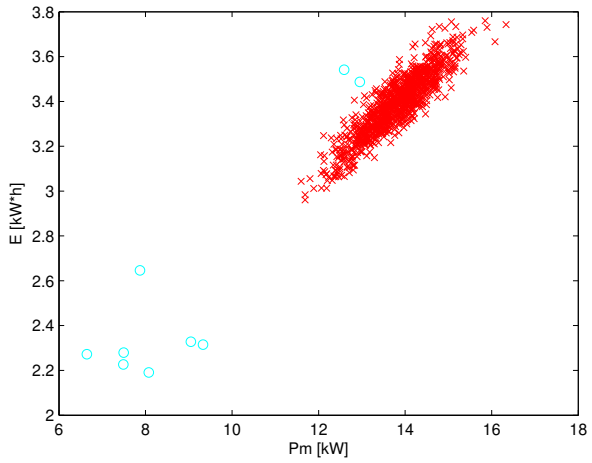
The same approach can be used to evaluate the energetic needs of hybrid vehicles with the approach presented by Chrenko et al. [9].

VI. Conclusions and Perspectives

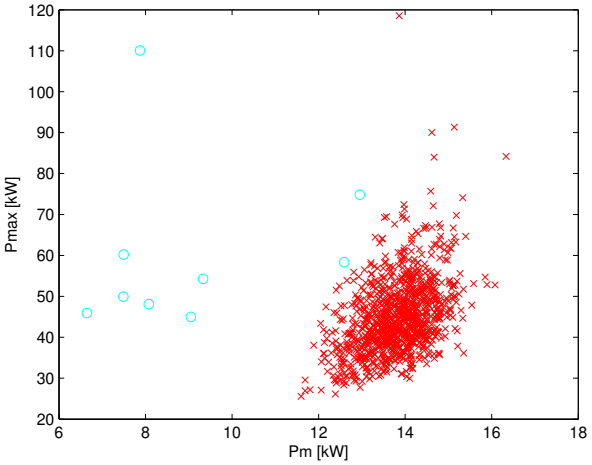
This article presents an approach of artificial driving cycle generation. Each driving cycle is created by a large number of driving phases based on normal distributed speed and duration functions, to describe constant accelerations and decelerations respecting maximum speed and maximum acceleration. The driving cycle can be adapted to different road types as defined by the ARTEMIS project, therefore only six input parameters have to be adapted, which is done automatically.

Based on this approach a driving cycle including sections of urban, extra urban and motor way driving has been reproduced and the approach is validated against measurement values. It is shown that the artificial driving cycle is in good accordance width the real driving cycle not only with regard to the instantaneous velocities or velocity and acceleration distribution, but also with regard to the power profile and the energy needed to fulfill the cycle. This conclusion has been used to create a large number of artificial cycles, classifying them with regard to the mean power, maximum power and energy need, thus giving interesting results with regard to the size of the electrical motor and energy source in an electric vehicle.

In the future this approach can be extended to create the driving cycles during longer periods, for example between recharging. It would be helpful to integrate difference in altitude and it could also be interesting to add auxiliaries



(a) Mean Power and Energy Need



(b) Mean Power and Maximum Power

Figure 5. Overview of 1000 artificial urban driving cycles

consumption for light, climatisation or infotainment to the driving cycle generator in order to evaluate their influence on the autonomy of electric vehicles.

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