Fuel Consumption Analysis Regarding Different 48V Topologies Application in a Flex Fuel Vehicle on Brazilian Emission Homologation Drive Cycles

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ABSTRACT

Research on 48-volt hybrid vehicles have been conducted throughout the last years, however the benefits of such vehicles in the Brazilian market, that is, assess energetic efficiency based on the Brazilian homologation drive cycles (FTP75 and HWFET) and the implications of ethanol in a hybrid powertrain have not been studied deeply. Given the context above, the present paper investigates the improvement in terms of fuel consumption (energetic efficiency) of a 48-volt hybridization of a vehicle with a turbo direct injected engine under several hybrid topologies: P0, P2, P3 and P4. In addition, this work is focused on the impact of the usage of ethanol in these vehicles running the Brazilian homologation drive cycles. 1-Dimensional numerical simulation using GT-Suite was chosen as the methodology for this study. Fuel consumption results through the energy consumption minimization strategy (ECMS) were obtained for the respective topologies and for 2 types of fuels, E22 and E100. A brief analysis of the energetic efficiency benefits was done to compare homologation drive cycle results from Europe and Brazil.

INTRODUCTION

It is noticeable the growing global interest regarding environmental concerns specifically with climate change and global warming. To address those issues, efforts to reduce fossil fuel emissions are being made. Governments and entities are proposing new policies and legislations in order to strict GHG emissions, and to assure the improvement of energy efficiency in vehicles. In this context, researchers have investigated a couple of distinct ways to fulfill these requirements, such as improvements in the IC engines and the usage of alternative fuels like ethanol, methanol, CNG and others. However, these new combustion technologies might not be enough to reach the levels of energy efficiency required by the legislations. Consequently, electrified vehicles (xEV) are now viewed as the main option to comply such requirements [1,2].

Electrified vehicles, generically called xEVs, includes: Battery Electric Vehicles (BEVs), Hybrid Electric Vehicles (HEVs) and Plugin Hybrid Electric Vehicles (PHEVs). BEVs have no tailpipe emissions, but on the other hand their driving range and battery charging time depends on the battery size and the charging infrastructure. [3]

HEVs and PHEVs combine internal combustion engines with electric machines in a single powertrain taking benefits of both technologies. HEVs can be classified by their level of hybridization in order of acquisition cost: micro hybrids work with 12V powertrain system. Although it only offers a small amount of fuel economy, it has little cost associated with it. Mild 48V hybrids are a cost-effective powertrain system that allows relevant fuel consumption economy. Full hybrids may utilize 100-600V powertrain systems and may offer significant fuel consumption economy. [1]

According to studies of the Brazilian market, fleet electrification has not achieved the same market share as in the European market for a couple of reasons. To sum up, the clean energy matrix and the extensive usage of ethanol as a fuel in the Brazilian fleet, generates low contribution to Global CO2 emission, thus may delay electrification. In addition, it is possible to notice that Brazil might not be ready for high hybridization level vehicles in large scale, due to its current infrastructure and the high costs associated with these vehicles. As a result, researchers argue that Brazil might go through an intermediary phase of hybridization of its fleet, that is mild hybrids [4].

Generally, 48V mild hybrid systems have the following operation modes: start-stop, regenerative braking and torque assist. A brief description of each mode is presented below.

Start-Stop is one of the most impactful features in an electrified vehicle and can also be implemented in 12V micro hybrid vehicles. The system is responsible to turn-off the vehicle's engine when it is stopped and/or the engine is in idle position. In urban areas, where the average velocity is low and vehicle may stop more often than usual, this feature can save a significant amount of fuel.

Regenerative braking is a system that allow the vehicle to convert part of its kinetic energy into electricity to recharge the battery when braking or coasting the vehicle. The more energy the system recovers more charge the battery will dispose to the electric machine to assist the vehicle propulsion. Therefore, by maximizing the regenerative braking system, powertrain efficiency gets higher as well. [5]

Torque assist is defined as a mode where the electric machine provides additional torque to the vehicle with the following objectives: supply additional torque when the ICE is already on its maximum load and to deliver torque in order to shift engine operating points to a region of better efficiency. Besides that, with a 48V power grid, neither electric shock protection nor additional maintenance training are required.

The main topologies applied to 48V mild hybrids are P0, P1, P2, P3, P4 and all-wheel drive (AWD), although not widely used. The number associated with the topology is related to the position of the electric machine in the powertrain. In a P0 configuration the EM is coupled to the front accessory drive by a belt, for that reason, the power delivered by the EM is limited due to belt slip. In a P1 layout the EM is direct coupled directly to the engine crankshaft, (ISG). One of the most versatile topologies is the P2, where the EM is coupled between the engine and the transmission separated by at least one clutch, on the other hand, in a P3 layout the EM can be mounted integrated to the transmission or parallel to the transmission. Lastly, in a P4 configuration the EM is coupled in a separate axle, alongside the rear differential [6]. All the topologies described above, can be seen in Figure 1.

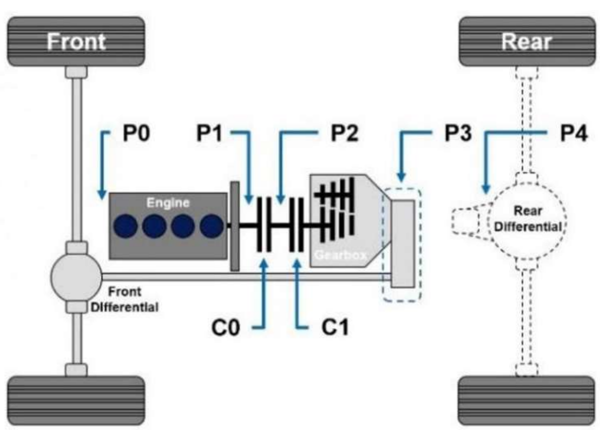

Figure 1 - 48V mild hybrid topologies [7].

As pointed out earlier, the Brazilian market has its particularities, such as the substantial utilization of ethanol in the fuel mixture. Flex-Fuel technologies allows vehicles to run with a diverse type of fuels, ranging from E22 (22% ethanol content) to E100 (100% ethanol content). This feature is not widely employed across the world. Hence, hybrid vehicles must go through modifications in Brazil to allow them to function with this wide spectrum of fuels.

Given the circumstances above, the present work investigates fuel consumption/energy efficiency benefits of 48V flex-fuel mild hybrid vehicles, in the P0, P1, P2 and P4 topologies, using the homologation drive cycles and methodology in the Brazilian legislations. In addition, the paper investigates the impact of the usage of ethanol in a hybrid powertrain.

VEHICLE MODELS

Two commercial softwares were used in this work, first GT-Suite (by Gamma Technologies) was used to perform the powertrain simulations, alongside MATLAB (by Mathworks) that was responsible for the HEV control strategy system. A conventional ICE vehicle was modeled in GT-Suite to serve as a reference when comparing fuel economy benefits across all simulated topologies. The base vehicle model is a 1.0L turbo direct inject compact car. The engine data was obtained through a chassis dynamometer test, within Robert Bosch Brazil installations, for two types of fuels, E22 and E100.

Four hybrid topologies were simulated in this paper, P0, P2, P3 and P4. Most of the vehicle parameters were identical throughout the simulations. The models consist in the following GT-Suite template blocks: ICE, transmission, electric machine, 48V and 12V batteries, DC/DC converter, Vehicle body, Vehicle control unit, and the driver, according to Figure (2). It is important to emphasize that the objective is to compare as fair as possible the fuel consumption benefits of vehicle electrification to the conventional vehicle model.

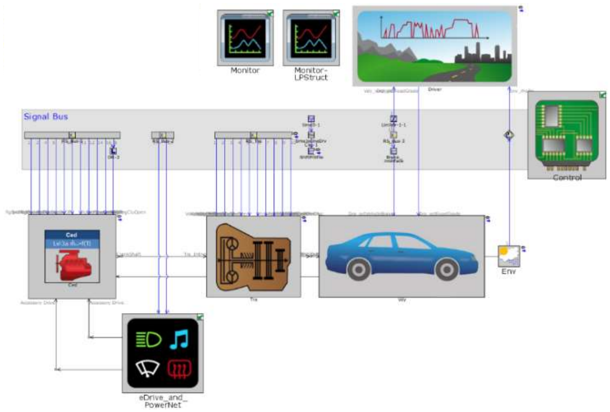

Figure 2 - Conventional ICE vehicle model.

The baseline vehicle has 1220 kg, with a 6-gears automatic transmission. A detailed parameters display is presented in Table 1, below. Vehicle mass is increased in 50 kg due to the addition of the battery, electric machine, DC/DC converter and cables in the powertrain to all the hybrid topologies.

Table 1 - Vehicle parameters.

		ICE Vehicle	mHEV
Vehicle	Vehicle Mass (Kg)	1220	1270
	Drag coefficient	0.334	0.334
	Frontal area (m²)	2.21	2.21
	Tire rolling resistance	0.01	0.01
	Tire rolling radius (mm)	306	306

Engine parameters is presented in Table 2. It is possible to note that all the parameters are the same regardless of the fuel used in the simulation.

Table 2 -Engine parameters.

		E27	E100
Engine	Engine displacement (cm³)	999	999
	Numbers os cylinders	3	3
	Compression Ratio	10.5	10.5
	Fuel Injection Type	DI	DI
	Engine Idle Speed (RPM)	950	950

The electrical system for each topology has its specificities. Electric machine varies from 3-20 kW according to the simulated topology. Due to a more efficient position in the powertrain, topologies such as P3 and P4 have the possibility to use a more powerful electric machine. In this case, a 20 kW electric machine was implemented. On the other hand, in the P2 configuration a 15 kW EM was used, and in the P1 a 12 kW EM was installed. The conventional ICE model uses a starter motor, which is focused solely on the engine start and not on propulsion purposes, therefore electric machine does not have to be oversized, as seen in Table 3. It is worth to mention that besides the conventional ICE vehicle model, which has a 12V power grid, all hybrid models have 48V power grid.

It is important to address the reason why different electric machines are used for distinct hybrid topologies. As stated above, P0 configuration has losses due to the usage of a belt, consequently an adequate electric machine is chosen because no additional gain is expected by using a more powerful EM. On the other hand, P3/P4 topologies have smaller losses due to the powerline, therefore a more powerful EM may be utilized with high efficiency. P2 is the middle term, it has reasonably less losses than P0 but higher than P4, with that in mind, the chosen electric machine is a 15 kW. In addition, the electric machine sizes were chosen based on current hybrid vehicles benchmark. [1,5]

Table 3 - Electrical system parameters.

		Conventional	P0	P2	P3	P4
Electric System	Nominal Voltage (V)	12	48	48	48	48
	Max Power Emachine (kW)	3	12	15	20	20

All vehicles have a 6 gears automatic transmission with similar gear ratios and gear-shift strategy.

HEV CONTROL STRATEGY

As known, hybrid vehicles combine electric motors with an internal combustion engine to propel the vehicle. In this scenario, the vehicle control unit (VCU) has the function to determine, through the usage of algorithms, the highest efficiency combination of the EM and ICE in order to minimize fuel consumption. Mainly, there are 2 different types of control strategies: global optimization and local optimization. Global control strategies determine the best optimization possible. However, this technique can only be used in simulations. Local optimization determines the instantaneous best scenario, consequently it is possible to be implemented in a real time control loop [8,9].

The equivalent consumption minimization strategy (ECMS) is a local control strategy that intends to minimize the total equivalent fuel consumption. The total equivalent fuel consumption is the sum of the real engine fuel consumption and the equivalent fuel consumption relative to the power utilized by the electric motors. At each time step the ECMS determines the next operating point (Torques and angular velocity) for both EM and ICE to which fuel consumption is minimized. Mathematically, in the optimal control problem, the Hamiltonian, J(x,u,t), Equation (1), must be minimized due to certain constrains.

$$\boldsymbol{J(x,u,t)} = \int_0^{t_f} \boldsymbol{H(x,u,t)dt} \quad (1)$$

Where, one can demonstrate the following [9].

$$\boldsymbol{H}(\boldsymbol{x},\boldsymbol{u},\boldsymbol{t}) = \boldsymbol{P}_{fuel}(\boldsymbol{u},\boldsymbol{t}) - \boldsymbol{\lambda}(\boldsymbol{t})\frac{1}{Q_{batt}}\boldsymbol{I}_{batt}(\boldsymbol{x},\boldsymbol{u},\boldsymbol{t}) \quad (2)$$

And $\boldsymbol{P}_{fuel}(\boldsymbol{u},\boldsymbol{t}) = \boldsymbol{Q}_{lhv}\dot{\boldsymbol{m}}_f(\boldsymbol{u},\boldsymbol{t})$

Note that λ(t) might be interpreted as an equivalent factor when substituted for s(t) in equation (2). In other words, s(t) can be understood as a weighting factor that converts battery power into fuel power. Thus, this factor is responsible to make both power sinks into one equivalent factor, according to Equation (3).

$$\boldsymbol{H}(\boldsymbol{x},\boldsymbol{u},\boldsymbol{t}) = \boldsymbol{P}_{fuel}(\boldsymbol{u},\boldsymbol{t}) + \boldsymbol{s}(\boldsymbol{t})\boldsymbol{P}_{ech}(\boldsymbol{x},\boldsymbol{u},\boldsymbol{t}) \quad (3)$$

The s(t) factor it is an important variable to track. If the equivalent factor is too high the ECMS tends to recharge battery at every opportunity. However, if is too small, chances are that the vehicle tends to run in electric drive mode whenever it is possible. Because of this, special attention must be given to s(t). In this work, the parameter s(t) was determined experimentally through simulations and determined based on the fact that the battery SOC in the beginning of the drive cycle must be close to the battery SOC at the end of the drive cycle. Consequently, one can assure that charge sustaining phase is correct and the vehicle is not charging battery too much nor using it too little either.

$$\boldsymbol{SOC}_{initial} \approx \boldsymbol{SOC}_{end}$$

SIMULATED DRIVE CYCLES

As stated earlier, the present work is focused on homologation drive cycles used in Brazil, that is FTP75 and HWFET, as seen in Figure (3) in appendix 1. Simulations with WLTC were also ran, in order to have a reference to the obtained results. In addition, it is important to observe the characteristics of each drive cycle, so it is possible to grasp what to expect from the results.

The federal test procedure (FTP-75) is a drive cycle that intends to emulate driving condition within urban areas. The FTP-75 may be divided into 3 distinct phases: a cold start transient segment that represents a suburban driving condition (0-505 s); an urban stabilized phase where the engine warms up to the default temperature (506-1372 s); a hot phase that despite being similar to the first segment the vehicle is now fully warmed. [10].

The Highway Fuel Economy Test (HWFET) is a drive cycle developed by the US EPA with the objective to determine fuel consumption in highway conditions. Because vehicle velocity is maintained fairly constant the test is shorter than the others, 765 s, with an average velocity of 77.7 km/h.

The Worldwide harmonized Light vehicles Test Cycles (WLTC) is a drive cycle within the Worldwide harmonized Light vehicles Procedure (WLTP) that is now replacing the European NEDC. WLTC is composed of 4 different phases: low, medium, high, and extra-high. It is worth to mention that average velocity of each phase increases sequentially. According to the vehicle category max velocity of the drive cycle may change. Vehicle category is defined by power-to-mass ratio (PMR) which is the rated power (W) divided by the curb mass (kg), as seen in Table 4 [11].

Table 4 - WLTP PMR vehicle categories [9].

Category	PMR, W/kg	v_max, km/h	Speed Phase Sequence
Class 3b	PMR > 34	v_max ≥ 120	Low 3 + Medium 3-2 + High 3-2 + Extra High 3
Class 3a		v_max < 120	Low 3 + Medium 3-1 + High 3-1 + Extra High 3
Class 2	34 ≥ PMR > 22	-	Low 2 + Medium 2 + High 2 + Extra High 2
Class 1	PMR ≤ 22	-	Low 1 + Medium 1 + Low 1

WLTP also presents special cases for xEVs: OVC-HEVs (off-vehicle chargeable hybrid electric vehicles); NOVC-HEV (not off-vehicle chargeable hybrid electric vehicles); and PEV (pure electric vehicles). However, since the scope of this paper is on 48V hybrid vehicles (non-chargeable and only operates in sustaining mode) these categories are not relevant.

A comparison between drive cycles can be seen below, Table 5.

Table 5 - Comparison between FTP-75, HWFET and WLTC3a.

Drive Cycle	Duration (s)	Stop Duration (s)	Idle (%)	Distance (Km)	Max Velocity (Km/h)	Average velocity (Km/h)	Max Acceleration (m/s²)
FTP75	1874	416	22,2	17,77	91,25	34,06	1,48
HWFET	765	0	0	16.45	96,4	77,57	1,46
WLTC3b	1800	242	14,21	23,19	131,3	46,51	1,67

It is important to address that for Brazilian fuel consumption homologation a weighting average must be done between the fuel consumption in the FTP-75 and HWFET, as seen in Equation (4).

$$\boldsymbol{FC}_{weighted} = \mathbf{0.45} * \boldsymbol{FC}_{HWFET} + \mathbf{0.55} * \boldsymbol{FC}_{FTP75} \quad (4)$$

Where, FC is the Fuel consumption, and the subscript refers to the drive cycle.

BASELINE VEHICLE MODEL VALIDATION

The first part of this project is to model the conventional vehicle in GT-Suite. The results obtained from this model is set as the baseline vehicle, consequently, fuel economy benefits due to electrification will be accounted in respect to this model.

However, in order to validate the baseline vehicle, chassis dynamometer tests were conducted, in which the real vehicle went through FTP-75 and HWFET drive cycles. A comparison between the fuel consumption obtained through chassis dynamometer and virtual simulation is compiled in Table 6. On the other hand, data regarding energetic efficiency and CO2 emissions are presented in Table 7.

Table 6 - Comparison table between fuel consumption in chassis dynamometer tests and virtual simulations.

	Drive Cycle	Fuel Type	Fuel Consumption (km/L)	Fuel consumption weighted (km/L)	Fuel consumption error (%)
Real measurements (Chassis dynamometer)	FTP75	E22	13,40	15,767	-
	HWY	E22	18,66		
	FTP75	E100	9,18	10,832	-
	HWY	E100	12,85		
GT-Suite (Conventional) Alternator: 3 kW - 12V	FTP75	E27	13,96	16,197	2,65%
	HWY	E27	18,93		
	FTP75	E100	9,80	11,389	4,89%
	HWY	E100	13,33		

Table 7 - Comparison table between CO2 and energy efficiency in chassis dynamometer tests and virtual simulations.

	Drive Cycle	Fuel Type	Energetic Effiециency (MJ/Km)	Energetic Effiency Weighted (MJ/Km)	CO2 (g/Km) Tail pipe	CO2 (g/Km) Weighted	CO2 Error (%)
Real measurements (Chassis dynamometer)	FTP75	E22	2,215	1,934	162,00	141,30	-
	HWY	E22	1,590		116,00		
	FTP75	E100	3,233	2,817	156,30	136,68	-
	HWY	E100	2,310		112,70		
GT-Suite (Conventional) Alternator: 3 kW - 12V	FTP75	E27	2,126	1,875	165,66	147,25	4,04%
	HWY	E27	1,568		124,74		
	FTP75	E100	3,028	2,667	155,03	137,57	0,65%
	HWY	E100	2,226		116,23		

It is possible to notice that fuel consumption error for both E27(most common gasoline blend in Brazil) and E100 were below 5% margin, consequently it is secure to assume that the conventional vehicle model represents reality. One may observe that HWFET results were more precise than the FTP-75 due to the simplicity of the drive cycle, where vehicle velocity does note varies significantly with time.

Although chassis dynamometer tests were conducted in E22 fuel and the simulations were run with E27, it is possible to infer that the conventional vehicle model is still satisfactory.

The comparison in table 7 corroborates to the fuel consumption analysis. It is possible to infer that for CO2 emissions and energetic efficiency results were satisfactory as well.

With the conventional vehicle model validated, its results will serve as the reference data to compare with the simulated hybrid vehicle results.

RESULTS

As stated in the earlier sections of this paper, models for conventional, P0, P2, P3 and P4 topologies were built and simulated through FTP-75, HWFET and WLTP drive cycles with 2 different types of fuels, E27 and E100. In order to simplify visualization, the results were stratified into 4 graphs.

Fuel economy was determined for several distinct scenarios. To begin with, WLTC fuel consumption results are shown, in Figure (4), below. P0 topology presented up to around 6% of fuel consumption benefit. The P2 vehicle obtained gains up to approximately 14%. P3 and P4 presented similar performance on fuel efficiency, each configuration was able to save up to 17% of fuel. This behavior can be explained by the fact that in P4 HEV the electric machine is installed in a separate axle, alongside the rear differential, and in P3, the EM is parallel to the transmission. Consequently, mechanical losses in the powertrain of P3 and P4 are close to each other since there are not many additional equipment between these power lines.

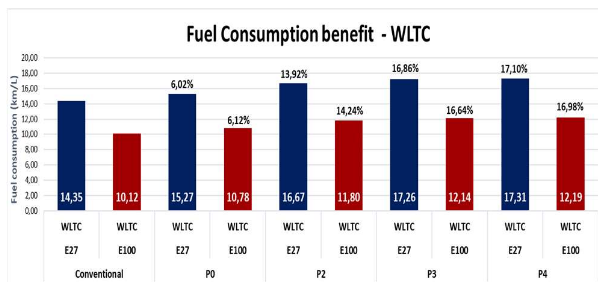

Figure 4 - Fuel consumption results in WLTC for E27 and E100. The benefits given in percentages values are in respect to the conventional vehicle model.

An equivalent type of analysis can be done for Brazilian homologation drive cycles, that is FTP-75 and HWFET. From Figure (5), it is possible to observe that P0 can save up to approximately 7% of fuel for E27 and E100. For the P2 configuration, one may notice savings up to around 11%. Analogous to the WLTC results, P3 and P4 have similar performance. In both configurations, fuel consumption may save up to approximately 14,30%.

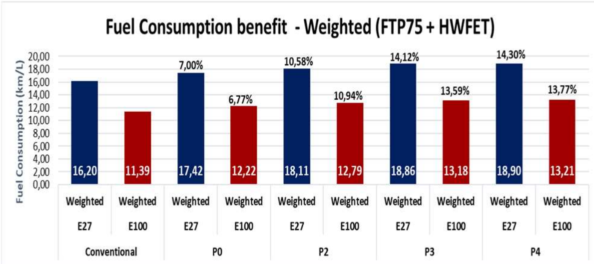

Figure 5 - Weighted fuel consumption results for E27 and E100. The benefits given in percentages values are in respect to the conventional vehicle model.

In general, fuel benefits increase as the electric machine moves towards the drive shaft, therefore, P4 is the most efficient topology, and consequently delivers the lowest fuel consumption of all models. On the other hand, P0 topology is the least efficient of all xEV models.

One important feature to notice is that, for this vehicle and the topologies simulated, fuel benefits do not change significantly with the fuel type. However, it may be important to analyze if the hybrid vehicle running on E27 and E100 have similar operating modes, if not, it may be relevant to understand the differences in the propulsion control system of these vehicles. To illustrate this point Table 8, compiled the amount of energy transfer in and out of the electric machine for 2 hybrid topologies, P0 and P4, for both types of fuel and for the Brazilian homologation drive cycles.

Table 8 - Energy transferred in/out of the electric machine for E27 and E100, separated by operating modes and drive cycles.

Topology	Fuel	Operating Mode	FTP-75 Energy (Wh)	HWFET Energy (Wh)
P0	E27	Torque Assist	199,613	34,087
		Electric Mode only	-	-
		Engine load shift	-	-
		Decceleration	-450,013	-89,651
	E100	Torque Assist	202,751	34,146
		Electric Mode only	-	-
		Engine load shift	-	-
		Decceleration	-449,905	-89,837
P4	E27	Torque Assist	300,939	102,548
		Electric Mode only	120,674	9,623
		Engine load shift	16,356	32,69
		Decceleration	-679,749	-147,147
	E100	Torque Assist	299,374	102,186
		Electric Mode only	113,651	9,565
		Engine load shift	14,044	32,97
		Decceleration	-679,081	-146,912

A few points can be highlighted from the table above. First, it is possible to observe that despite the operating mode the energy transfer for both types of fuel are similar. In addition, it is clear that P4 topology is able to assist the ICE more than the P0 configuration. Besides, one can notice that P4 can also recuperate energy better than the P0 topology, from the deceleration row in the Table 8.

To continue the analysis, a relevant point to highlight is the fuel consumption for FTP-75 and HWFET independently. Data is represented in Figure (6) and Figure (7), as seen below. At first look, it is possible to notice that gain in fuel efficiency in FTP-75 drive cycle is higher than comparing to HWFET. This behavior is justified by several reasons. First, urban drive cycles have several engine idle regions, thus it allows start-stop to function. As stated, the feature turns off the vehicle engine when it is in idle, therefore fuel is saved. Simulations showed evidence that for FTP-75 drive cycle start-stop on its own may save up to 5% in fuel consumption. In addition, urban drive cycles provide the vehicle more opportunities to utilize regenerative braking, which increases vehicle efficiency.

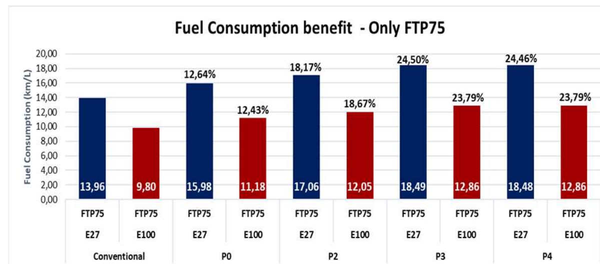

Figure 6 - Fuel consumption results regarding only FTP-75. The benefits given in percentages values are in respect to the conventional vehicle model.

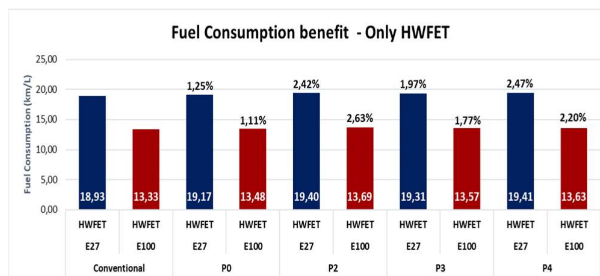

Figure 7 - Fuel consumption results regarding only HWFET. The benefits given in percentages values are in respect to the conventional vehicle model.

From Figure (6), it is noticeable that 48V hybrid vehicle are most efficient in urban scenarios. P0 topology presented benefits up to approximately 12,60% for both types of fuel. P2 can save up to 18,70%. P3 and P4 showed improvements in fuel efficiency up to around 24,50%. Again, it is relevant to state that fuel type does not impact fuel benefits for this specific vehicle and with these types of hybrid topologies.

On the other hand, it is possible to observe that in highway conditions, 48V hybridization does not increases vehicle efficiency remarkably. To begin, HWFET does not have engine idle regions. In addition, in this situation, engine load and angular velocity are high, hence ICE is already running in a high efficiency zone and EM assistance may be limited. To illustrate this point, Figure (8), in the appendix, shows the output torque delivered by the electric machine during the FTP-75 drive cycle in P0 configuration (Figure (8.a)) and P4 (Figure (8.b)). Figure (9)), in the appendix, presents the torque delivered by the electric machine for HWFET in P0 (Figure (9.a)) and P4 (Figure (9.b)).

In these scenarios it is possible to perceive that the levels of assistance by the electric machine is radically higher during the urban area comparing to the levels of those in highway scenarios, one can observe again from Table 8. In addition, it is possible to infer that most of the assistances occur during low speeds accelerations. It is important to note that the negative torque displayed in the figures is relative to the regenerative braking, and as presented earlier, urban driving presented more opportunities to use this feature than in highway.

An important point to address is the differences in torque delivered by the different topologies. Figure (8) and Figure (9) represents the electric machine output torque for 2 distinct topologies, P0 and P4 respectively. One can notice that the most relevant difference between the output torques is the magnitude of the torque itself. The electric machines are utilized approximately at similar times for both topologies, however, due to losses intrinsic to the powertrain, the P4 configuration allows the electric machine to utilize more torque consequently shifting the engine operation region to a more efficient zone, thus saving fuel.

One may perceive that fuel benefits from electrification through Brazilian homologation drive cycles are different than the fuel benefits result for the European drive cycle. Is important to remember that homologation in Brazil utilizes equation (4), that is considered almost equally highway and urban area fuel consumption in an weighted average. In addition, it was seen that HWFET does not present signifcant fuel benefits for 48V hybrids. On the other hand, WLTP has only 33% of its length in highway areas, therefore one can argue that the impact of highway scenarios, for fuel consumption assessment is larger in Brazil than in European Homologation methods. Consquently, higher gains are expectd for for WLTP than FTP-75+HWFET, specially for P2, P3 and P4 48V hybrids..

CONCLUSIONS

48V Flex-fuel hybrid vehicles are a cost-effective intermediary solution in order to initiate Brazilian fleet electrification until the infrastructure and the market are well stabilished and developed. As seen, it is possible to obtain significantly saving regarding fuel economy without the high costs associated with full hybrid vehicles.

A conventional ICE compact 1.0L direct inject engine vehicle was modeled in GT-Suite to serve as a reference model to compare its results to the 48V HEV models. The baseline vehicle was validated through the usage of chassis dynamometer data test performormed at Robert Bosch Brazil.

With the baseline vehicle model validated, it was possible to build the 48V hybrid topologies virtually. In this paper one could see that benefits in fuel economy for urban areas were the most significant, ranging from up to 12,64%, for P0, and up to 23,79% for P4. On contrast, highway drive cycle have less impactful benefits from 48V hybridization. Due the characteriscts of the drive cycle, the electric machine offers limited assistance, besides that the cycle does not have engine idle regions where start-stop can be applied.

It was seen that for this specific vehicle running in these hybrid configurations fuel type does not impact fuel economy remarkably. Results for E27 and E100 were similar within 3% difference between them. However, additional studies must be conducted to understand the role of the ECMS and other optimal control algorithms for different fuel types in hybrid vehicles. Besides that investigations on optmize ICE for ethanol in hybrids is also a field for future works.

Combined results from Brazilian homologation drive cycles were obtained. Fuel benefits found ranges from up to 7,00%, for P0 and up to 13,77% for P4. Results for WLTP has showed to be different than for FTP-75 + HWFET, mainly due to the characteristics of the drive cycle. In WLTP, the vehicle goes through less time in highway scenario, which has less benefits from hybridization. Consequently, WLTP presented better fuel economy benefits, ranging from up to 6,00% for P0, up to 17,00% in P4.

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DEFINITIONS & ABBREVIATIONS

In the order of appearance in the text.

ECMS	Energy consumption minimization strategy
E22	Fuel blend of 88% gasoline and 22% ethanol
E100	Hydrous ethanol
GHG	Greenhouse gases
ICE	Internal combustion engine
CNG	Compressed natural gases
xEV	Electrified vehicles
BEV	Battery electric vehicle
HEV	Hybrid electric vehicle
PHEV	Plug-in hybrid electric vehicle
EM/EMachine	Electric machine
ISG	Integrated starter generator
Flex-Fuel	Term used to describe vehicles moved by gasoline (E22), hydrous ethanol (E100) or any mixture of the two
DC	Direct current
VCU	Vehicle control unit
SOC	State-of-charge
EPA	U.S Environmental Protection Agency
OVC-HEV	Off-vehicle charging hybrid electric vehicle
NOVC-HEV	Not-off-charging hybrid electric vehicle

APPENDIX

DRIVE CYCLES

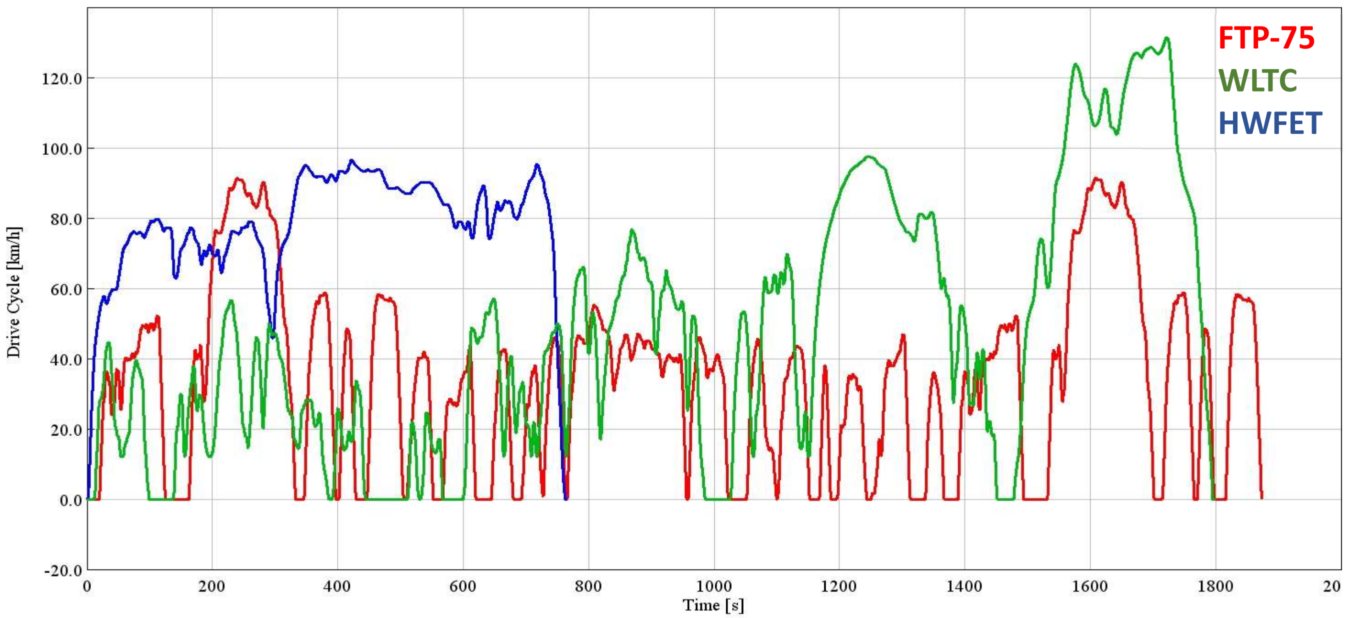
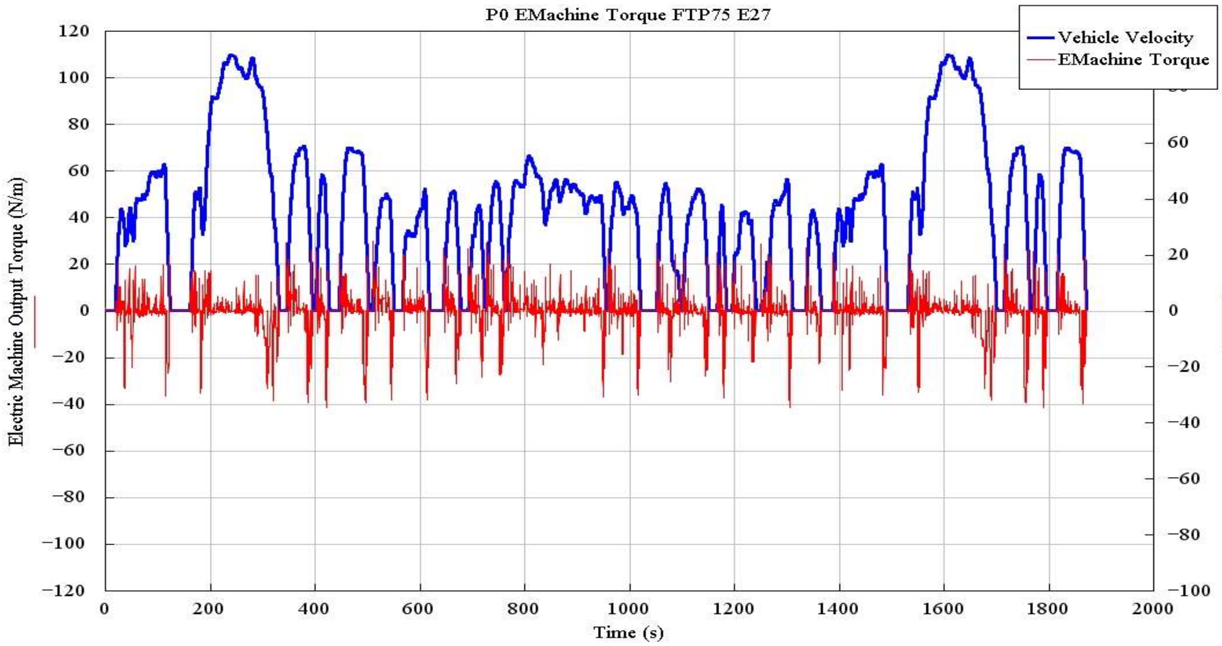


Figure 3 - Drive cycles used in this work. In red FTP-75, in green WLTP cycle and in blue HWFET.

RESULTS



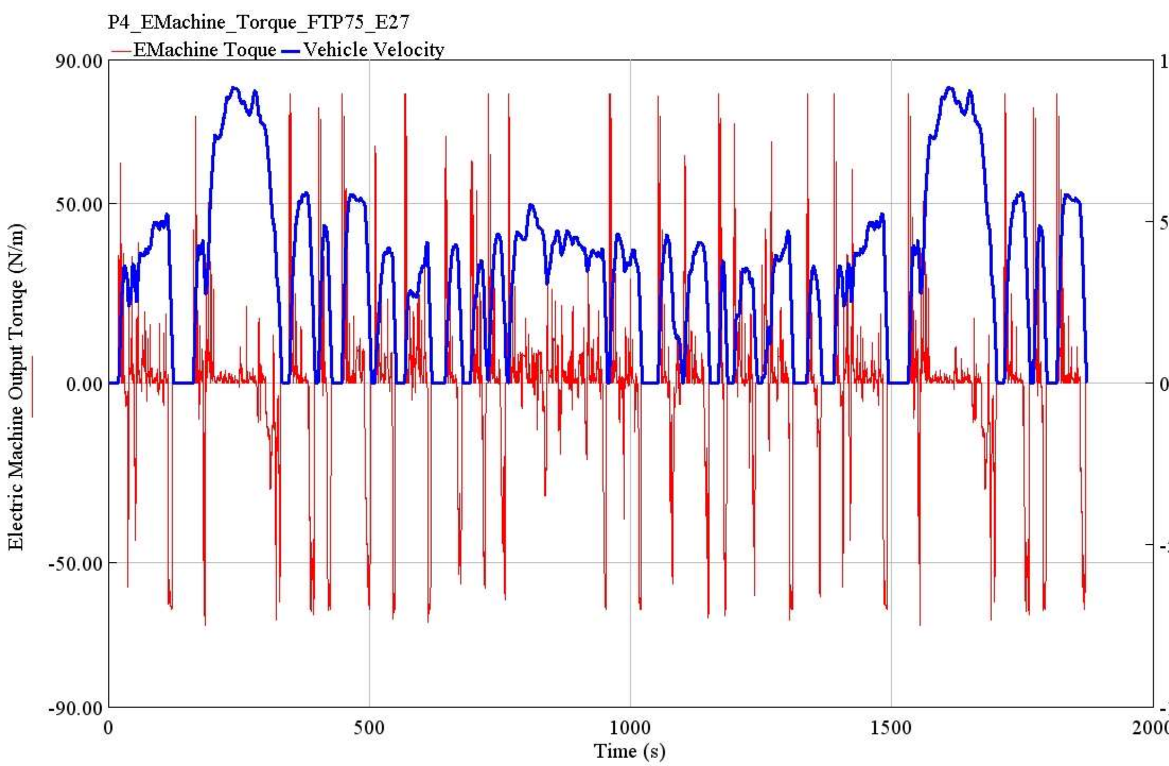


Figure 8 - P0 Electric machine torque during FTP75 (Fig. 8a) and P4 Electric Machine torque in FTP-75(Fig. 8b) drive cycle for E27 fuel.

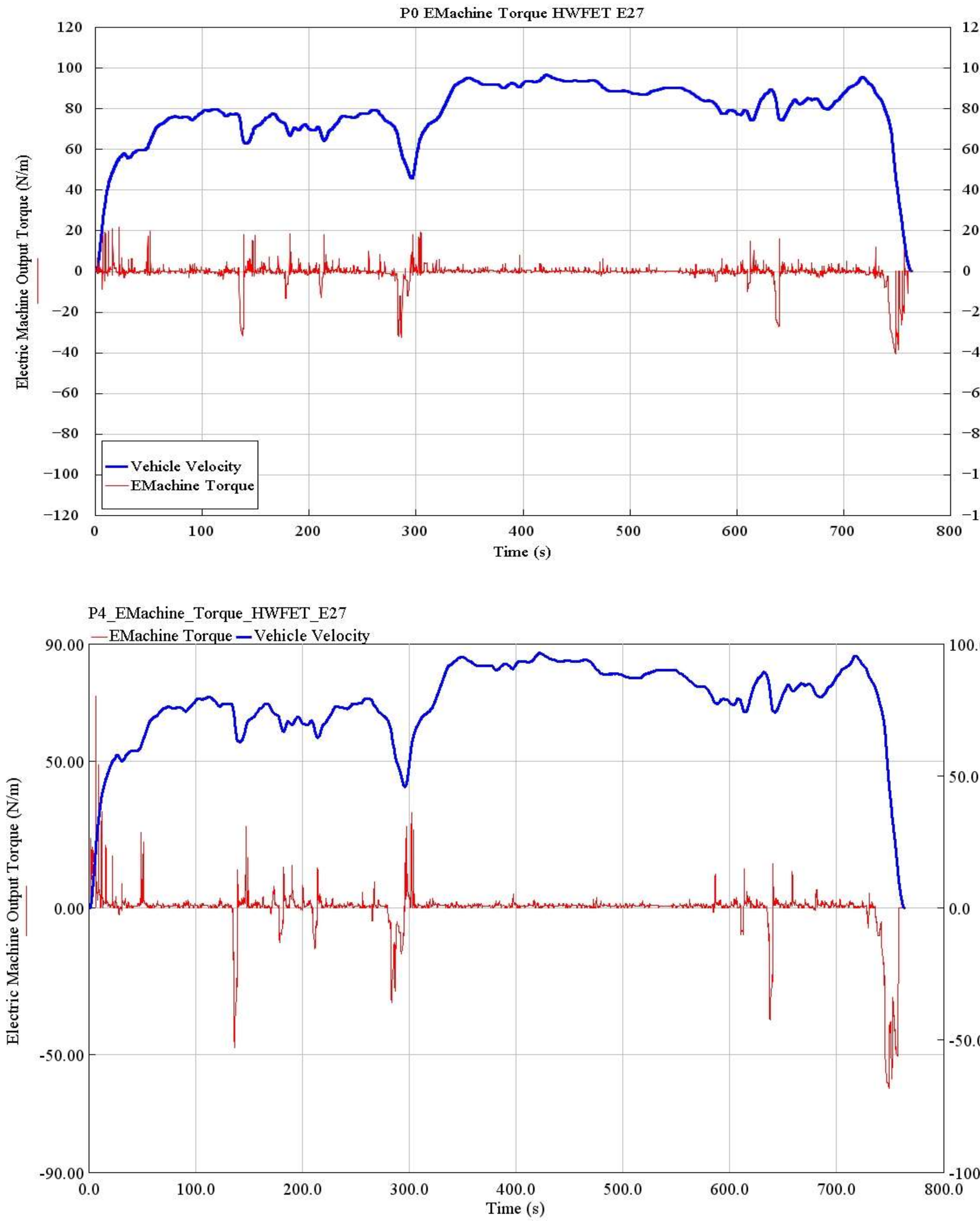


Figure 9 - P0 Electric machine torque during HWFET (Fig. 9a) and P4 Electric Machine torque in HWFET (Fig. 9b) drive cycle for E27 fuel.