

Application of Electric and Hybrid Electric Buses in Macau

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Summary

Being a city with small geographical size limiting the travel range of vehicles, Macau has great potential for EV implementation. Due to the expansion of tourism and limited land space, Macau has been faced with problems of road congestion due to rapid growth in vehicle population. Air pollution is also another important concern. Electric buses provide a solution for low emission urban transportation. Researchers and engineers have concentrated on the improvement of EV performance through the advances in batteries, motors, converters, controllers and relevant auxiliaries, with enormous successes. Now, it comes to the stage of commercialization! Before adapting EVs, it is important to understand their performances in Macau. Several projects were launched to investigate the performance of EV, specifically for sub-tropical environment of Macau. Due to the high temperature and humidity, performance of EVs operated in Macau was yet to be understood. Previous experimental studies conducted in the US, Europe or Japan might not reflect the actual local real-road driving conditions. This paper aims to analyse the performance of electric and hybrid electric buses and compared with internal combustion engine powered buses. Viability of electric and hybrid electric buses will be simulated using real driving data in Macau.

Keywords: bus, emissions, environment, simulation, vehicle performance

1. INTRODUCTION

Electric vehicles (EVs) and hybrid electric vehicles (HEVs) have been substituted for conventional internal combustion engine (ICE) vehicles and to contribute to the sustainable development of the public transportation sector worldwide, e.g. reduction of greenhouse gas and particle emissions [1], [2] and [3]. With increasing economic growth in Macau, harmful environmental effects such as emissions come into the picture, out of which public / private buses contribute to a major portions. There is a pressing need for reduction in vehicular emissions with increasing demand on EVs. With an urbanized city and limited land space (30.3 km²), Macau has been faced with problems of road congestion and rapid growth in vehicle population. Total length of public roads in Macau was 424km, and the vehicle density was 592 vehicles per kilometer, Macau has great potential for EV implementation [4], [5], [6], [7] and [8].

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operated in Macau was yet to be understood. Previous experimental studies conducted in the US, Europe or Japan might not reflect the actual local real-road driving conditions. Vehicles are designed considering several factors such as: vehicle operating range, accelerations/decelerations, maximum speed, power output at various stages and factors as such which are directly represented by a driving patterns. Hence a driving pattern is essential to design the components for an EV / HEV. A driving pattern was constructed based on actual speed-time data collected from Macau. Before adapting electric and hybrid electric buses, it is important to understand their performances in Macau [8].

This paper aims to analyze the performance of electric and hybrid electric buses and compared with the conventional ICE-powered buses. Viability of electric and hybrid electric buses will be simulated using both Federal Urban Driving Schedule (FUDS) in Fig. 1 and actual local real-road driving conditions for a public bus as shown in Fig. 2. The total length of one Macau Driving Cycle (MDC) cycle is approximately 9km, and it was real driving data of public buses.

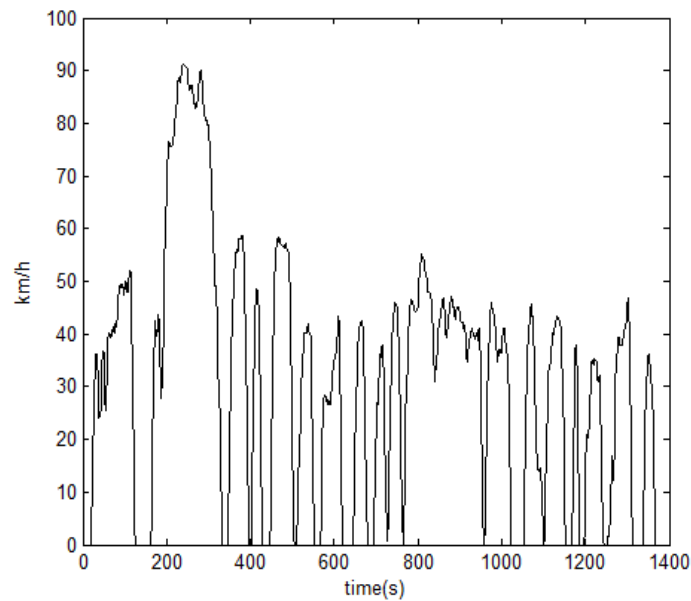


Figure 1: Federal Urban Driving Schedule (FUDS)

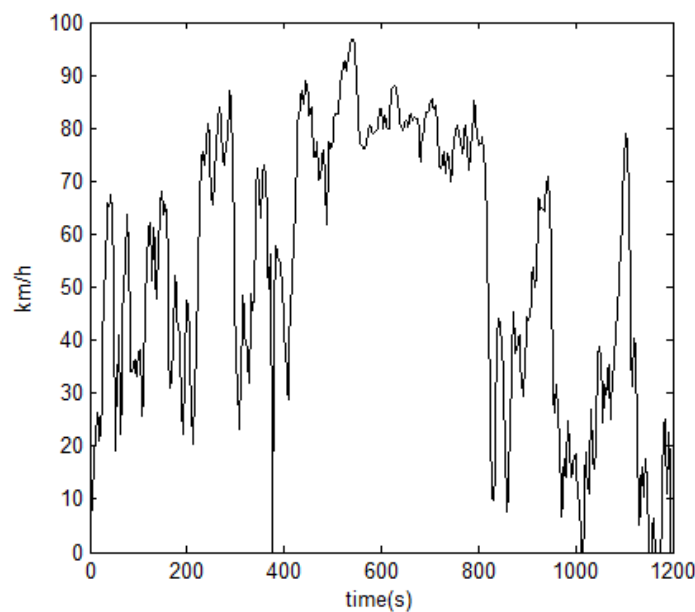


Figure 2: Macau Driving Cycle (MDC) for buses

2. Performance Evaluation

The concept of local driving conditions using Macau Driving Cycle (MDC) is emphasized in this evaluation rather than collecting data synthesized from simulated conditions using a chassis dynamometer in the laboratory, as it would not have been the real driving conditions. Moreover, evaluations were also conducted and compared with Federal Urban Driving Schedule (FUDS), among all three sample buses, namely ICE-Buses, electric buses (E-Buses) and hybrid electric buses (HE-Buses).

The computational models of feed forward simulation for the three kinds of vehicles are shown in Fig. 3, while the parameters of the three sample buses are shown in Tables 1-4.

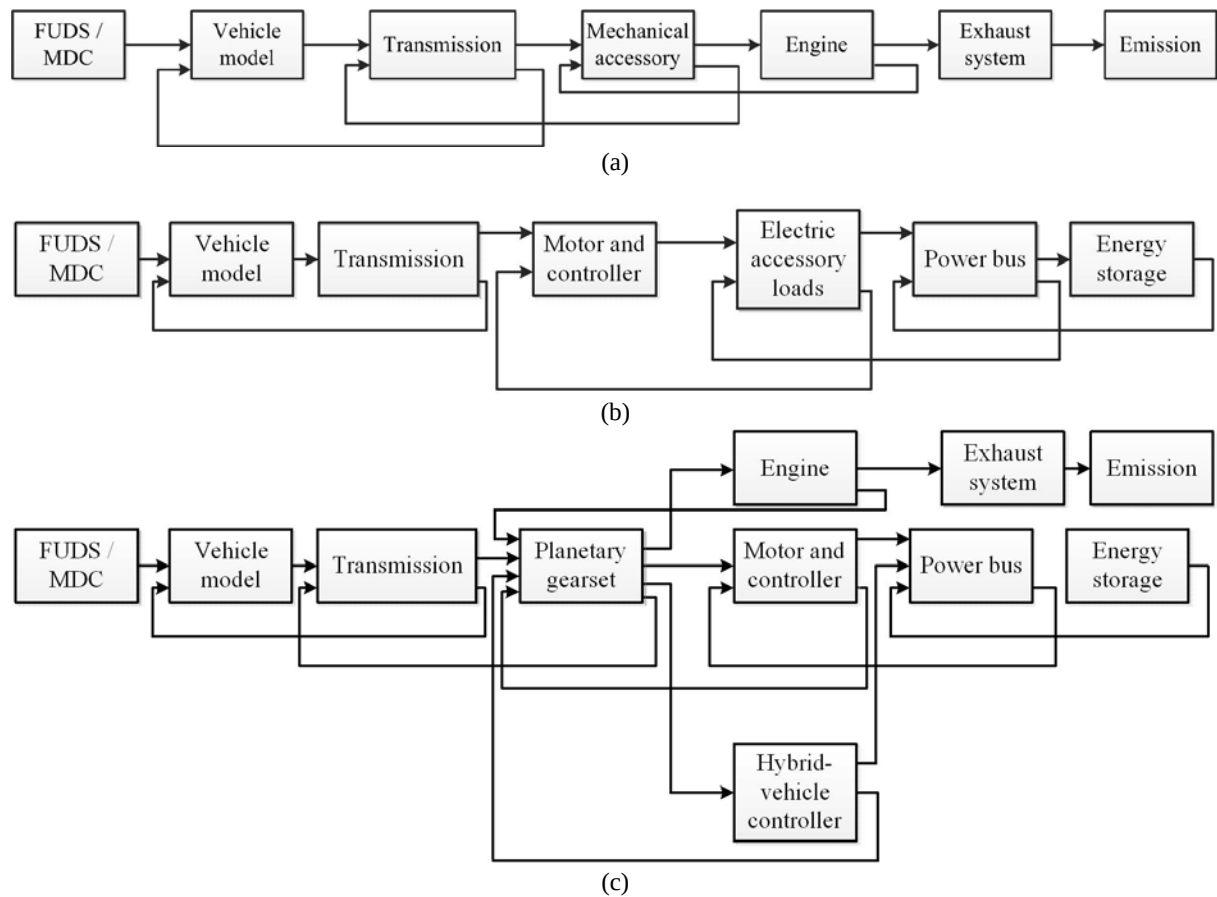


Figure 3: Computational Models for: (a) ICE-Bus; (b) E-Bus; and (c) HE-Bus

Table 1: Parameters of buses

Parameter	Value
Coefficient of drag	0.56
Frontal area	6.3m ²
Centre-of-gravity above the road	0.725m
Wheelbase	6.3m
Cargo mass	3500kg

Table 2: ICE-Bus for evaluation

Parameter	Value
Engine displacement	2L
Fuel tank capacity	180L
Peak engine power	92kW (Magnify to 200kW)
Maximum torque	300Nm@4200rpm
Curb weight	1660kg

Table 3: E-Bus for evaluation

Parameter	Value
Motor type	Air cooled induction motor
Motor maximum power	150kW
Motor torque	220Nm
Battery type	NiMH
Total battery capacity	1179V
Number of Modulus	88
Curb weight	1873kg

Table 4: HE-Bus for evaluation

Parameter	Value
Fuels	Diesel & Battery
Engine displacement	2.2L
Fuel tank capacity	180L
Peak engine power	92kW
Maximum torque	300Nm@4200rpm
Motor	Traction motor
Motor maximum power	139kW
Motor maximum torque	400Nm
Battery type	NiMH
Battery capacity	60Ah
Modules of battery	20
Curb weight	1463kg

For simulating of ICE-Bus, as in Fig. 3(a), first of all, the MDC and FUDS are input to the vehicle model, driving patterns are then processed by the transmission and mechanical accessory model, the required velocity and torsion will be feed into the engine model. At the same moment, the engine will provide its output parameters (lambda, engine torsion, etc.) to the aforementioned input model to control the overall process. A subroutine for modelling the exhaust system will also evaluate the corresponding emissions for that particular driving pattern. The algorithms for simulating E-Bus and HE-Bus are similar to ICE-Bus and are shown in Fig. 3(b) and Fig. 3(c) respectively.

3. Simulation Results

In evaluating with different driving cycles, the total travel distance (S) of each driving cycle can be calculated as in (1),

$$S = \int v dt \quad (1)$$

Moreover, evaluations were also conducted and compared with FUDS, among all three sample vehicles, namely ICE-Bus, E-Bus and HE-Bus. The gasoline equivalent ($mpgge$) reflects the fuel consumption for a certain vehicle. During this evaluation exercise, the gasoline equivalent is calculated by a vehicle travelling from full charge until the fuel was exhausted. For a certain driving cycle, as in (2):

$$mpgge = \frac{S(42600)(749)}{V H \rho} \quad (2)$$

Where S is the total distance calculated from (1) and V represents the gasoline consumption. H and ρ denote the lower heating value and the density of a fuel respectively.

For evaluating an E-Bus, the equation for gasoline equivalent is determined by (3),

$$mpgge = \frac{S}{\frac{E}{\eta} H \rho} \quad (3)$$

Energy consumption (E) is calculated by integrating the total power output of the energy storage system while considering the columbic losses (η) during a recharge.

Simulated results for E-Bus, for both MDC and FUDS, of one full-discharge were shown in Fig. 4(a). Similarly, simulated results for HE-Bus for one driving cycle are shown in Fig. 4(b). Note that the batteries state of HE-Bus is starting from 70%. This is due to the limitation of simulation, and as the cycle continues, the battery will be charged during driving; therefore the setting of initial state of charge is 70%.

Fig. 5 showed the driving patterns for both MDC and FUDS. The comparison of state of charge for E-Bus and HE-Bus for using both cycles was shown in Fig. 6. Other results are summarized in Tables 5-7 and emissions are shown in Figs. 7-8 and Tables 8-9.

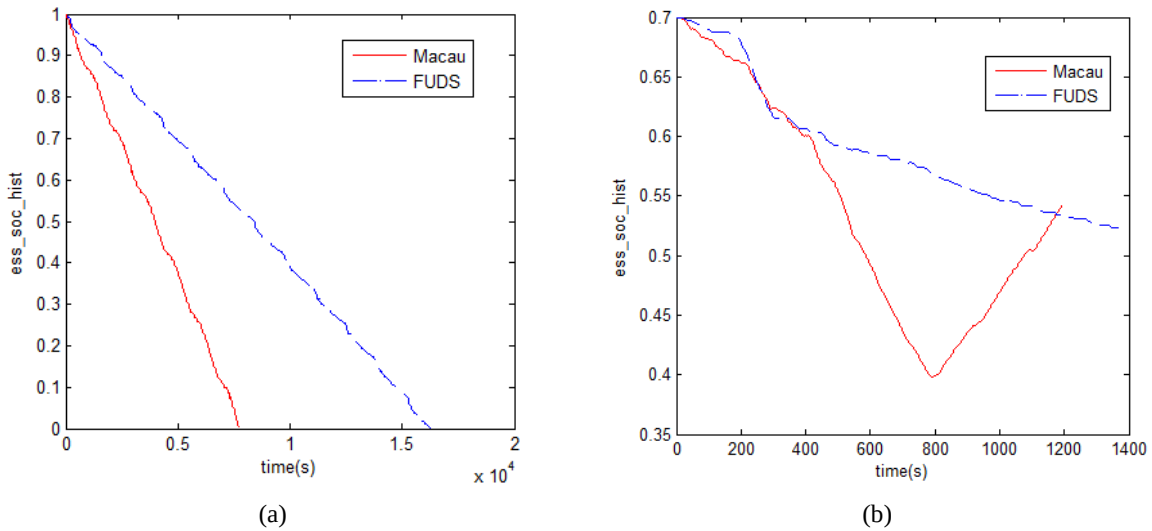


Figure 4: Simulated results state-of-charge for batteries (one driving cycle): (a) E-Bus; (b) HEV bus

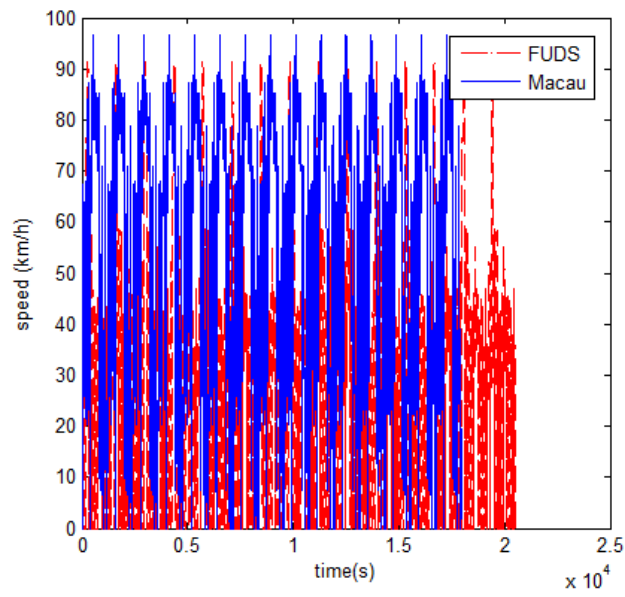


Figure 5: Driving patterns

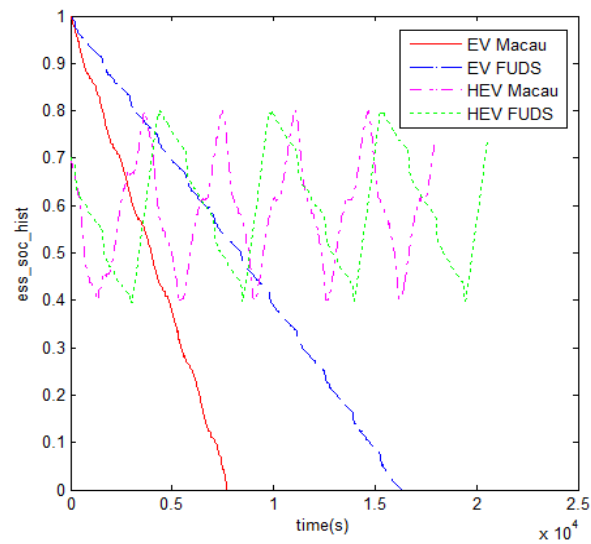


Figure 6: State-of-charge for different buses and driving patterns

Table 5: Simulated driving range for one-full charge / one-full-tank using MDC

	E-Bus	ICE-Bus	HE-Bus
Distance (km)	115.4	252.3	268.1
Gasoline equivalent (L/100km)	10.3	22.1	16.3

Table 6: Driving range for one-full charge/ one-full-tank using FUDS

	E-Bus	ICE-Bus	HE-Bus
Distance (km)	143.3	175.1	179.9
Gasoline equivalent (L/100km)	8.4	23.1	14.1

Table 7: Energy consumption for both MDC and FUDS (per km)

	MDC	FUDS
E-Bus	3015kJ (100%)	2510kJ (100%)
ICE-Bus	7065kJ (234%)	7370kJ (294%)
HE-Bus	5208kJ (173%)	4504kJ (179%)

Table 8: Emission for using MDC

	HC (g/km)	CO (g/km)	NO _x (g/km)
E-Bus	0	0	0
ICE-Bus	0.012	0.084	1.753
HE-Bus	0.233	0.585	0.336

Table 9: Emissions for using FUDS

	HC (g/km)	CO (g/km)	NO _x (g/km)
E-Bus	0	0	0
ICE-Bus	0.011	0.075	1.519
HE-Bus	0.072	0.314	2.559

4. Summary

From simulated results shown in Tables 5-7, E-Buses are most efficient for both MDC and FUDS, but with shortest driving range. However, for Macau, such a small city with flat roads, one full charge can meet the need for most conventional or public buses based on a regular route. Furthermore, simulated results from Figs. 6-7 shows that the zero local emission is a definite advantage of E-Buses, where most of the ICE-Buses are using diesel and produce significant emission of NO_x. Due to the increasing number of tourist in Macau in recent years, more public transports or city buses are required, therefore it might be a good timing to introducing E-Buses to the market.

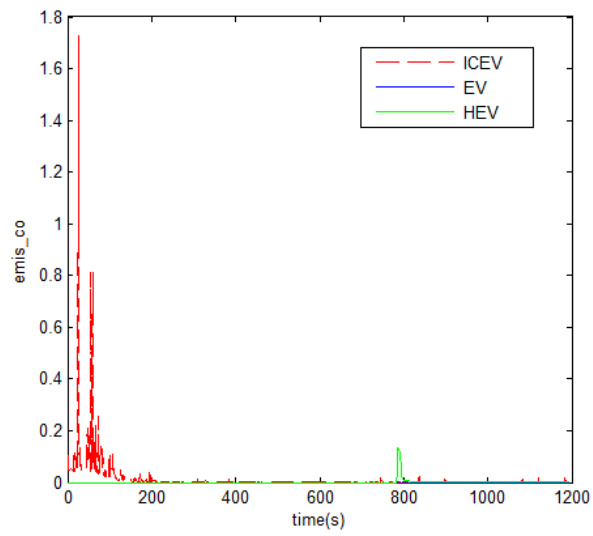
E-Buses are clean due to their zero local emissions, which will make a contribution to reducing the global emission. However the global emissions depend on how electricity is generated. Further global emissions reduction could be achieved when more renewable energy sources or non-coal electricity was used for the generation of electricity [2].

Acknowledgements

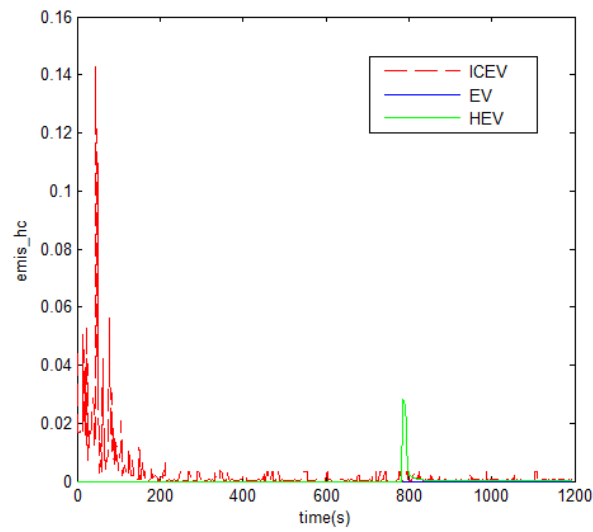
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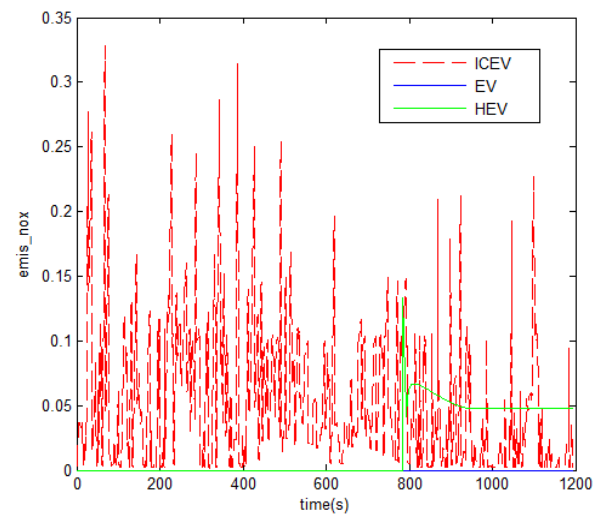
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(a)

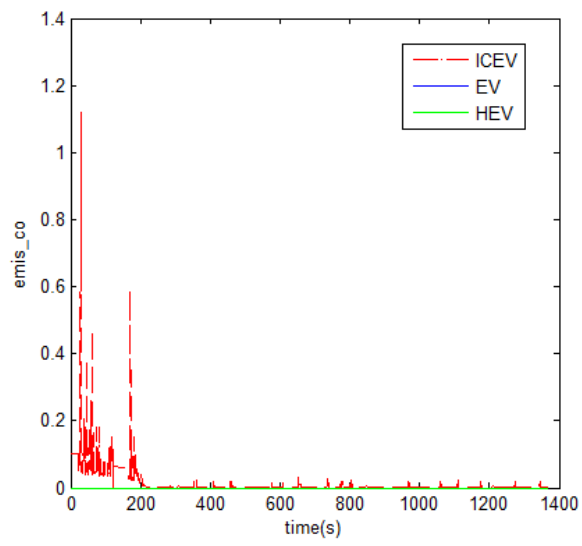


(b)

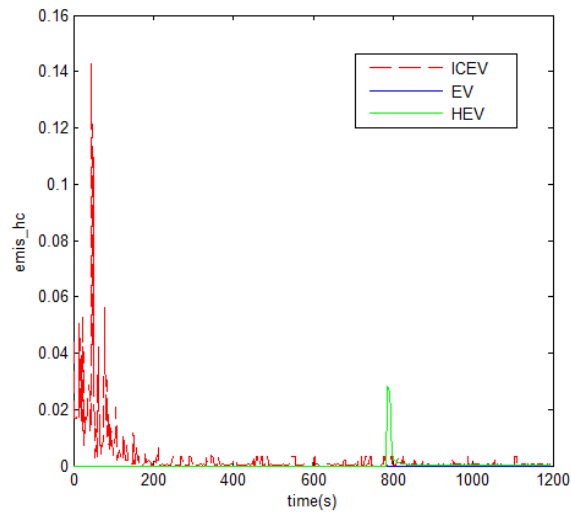


(c)

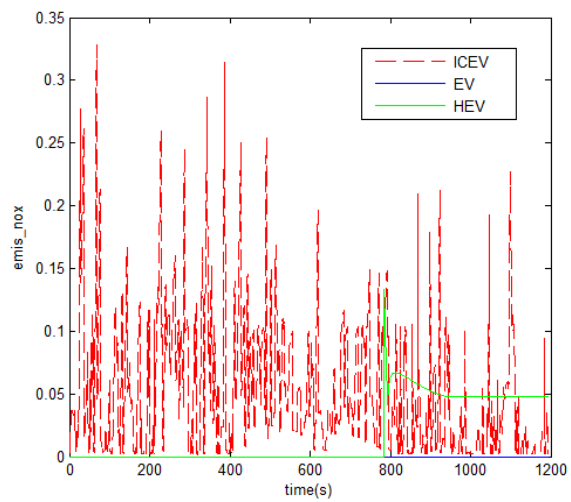
Figure 7: Emissions for MDC: (a) CO; (b) HC; (c) NO_x



(a)



(b)



(c)

Figure 8: Emissions for FUDS: (a) CO; (b) HC; (c) NO_x

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