Performance Evaluation of Electric Vehicles in Macau

Tze Wood Ching [1], Wenlong Li [2], Tao Xu [3], and Shaojia Huang [4]

[1] *Department of Electromechanical Engineering, University of Macau, twching@ieee.org*
[2] *Department of Electrical & Electronic Engineering, University of Hong Kong, wlli@eee.hku.hk*
[3] *Department of Electromechanical Engineering, University of Macau*
[4] *Department of Electromechanical Engineering, University of Macau*

Abstract
Being a city with small geographical size limiting the travel range of vehicles, Macau has great potential for implementation of electric vehicles (EVs). With an urbanized city and limited land space, Macau has been faced with problems of road congestion due to rapid growth in car population. Air pollution is also another important concern. EVs provide 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 analyze the performance of EVs and compared with internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs). Viability of EVs will be simulated using both Federal Urban Driving Schedule (FUDS) and Macau Driving Cycle (MDC).

Keywords
electric vehicles, Macau driving cycles, Federal Urban Driving Schedule, hybrid electric vehicles, performance evaluation

1. INTRODUCTION
With the growing concerns on price fluctuation, depletion of petroleum resources, global warming, environmental and health, there is fast growing interest in electric vehicles (EVs) in Macau and also a pressing need for researchers and power utilities to develop various infrastructures [Ching, 2010; 2011] for EVs and strategies [Ching, 2011] for adapting EVs. Being a city with small geographical size (29.9 sq.km) limiting the travel range of vehicles, Macau has great potential for EV implementation [Ching, 2011; 2012], [Ching et al., 2012].

With an urbanized city and limited land space, Macau has been faced with problems of road congestion and rapid growth in car population. Number of vehicles in the city is shown in Table 1, while the total length of public roads in Macau was 417 km, and the motor vehicle density was 546 vehicles per kilometer.

Air pollution is also another important concern. EVs provide low emission urban transportation. Even taking into account the emissions from power plants needed to fuel the vehicles, the use of EVs can reduce carbon dioxide (CO_2) emissions significantly [Chan and Wong, 2004; Chan, 2007; Wong et al., 2010; Ching, 2011]. Thus, EVs are promising green vehicles

Table 1 Growth of vehicles in Macau

Year	Total	Light Vehicles	Heavy Vehicles	Motor Cycles
2006	162,874	71,726 (44.1%)	5,780 (3.5%)	85,368 (52.4%)
2007	174,520	76,117 (43.6%)	6,107 (3.5%)	92,296 (52.9%)
2008	182,765	78,753 (43.1%)	6,288 (3.4%)	97,724 (53.5%)
2009	189,350	80,499 (42.5%)	6,285 (3.3%)	102,56 (54.2%)
2010	196,634	83,879 (42.7%)	6,363 (3.2%)	106,420 (54.1%)
2011	206,349	88,581 (42.9%)	6,570 (3.2%)	111,198 (53.9%)
2012	217,335	95,063 (43.7%)	6,649 (3.1%)	115,623 (53.2%)
2013	227,937	101,547 (44.6%)	6,937(3.0%)	119,453 (52.4%)

that can reduce both energy consumptions and CO_2 emissions [Chan and Wong, 2004; Chan, 2007; Ching, 2011].

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 [Wong et al., 2010; Ching, 2011].

Before adapting EVs, it is important to understand their performances in Macau. This paper aims to analyze the performance of EVs and compared with internal combustion engine vehicles (ICEVs) and hybrid electric vehicles (HEVs). Viability of EVs were simulated using both Federal Urban Driving Schedule (FUDS) and Macau Driving Cycle (MDC) [Ching et al., 2014] as shown in Figures. 1-2

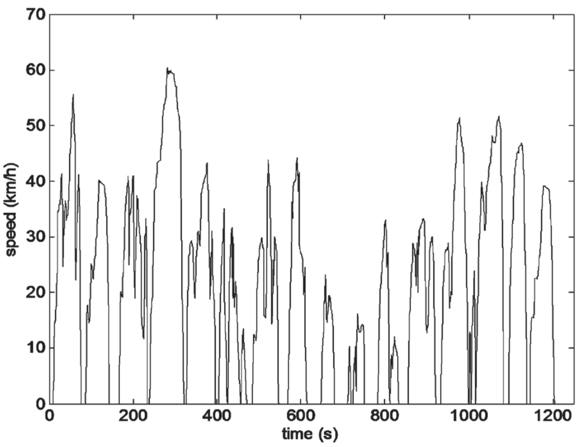


Fig. 1 Macau Driving Cycle (MDC)

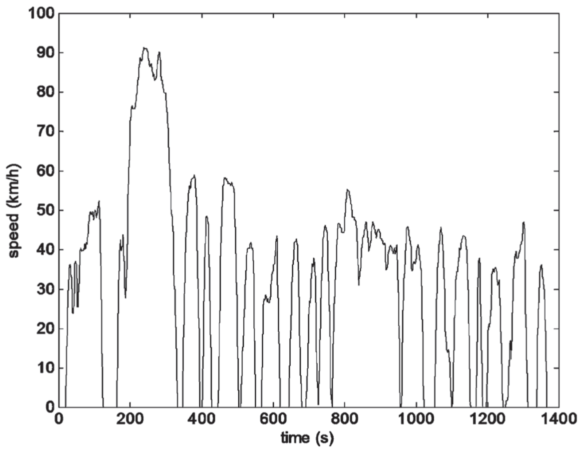


Fig. 2 Federal Urban Driving Schedule (FUDC)

2. PERFORMANCE EVALUATION

The concept of local driving conditions using 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. In evaluating with different driving cycles, the total travel distance (S) of each driving cycle can be calculated using (1),

$$S = vtdt \qquad (1)$$

Moreover, evaluations were also conducted and compared with FUDS, among all three sample vehicles, namely ICEV, EV and HEV. Two driving cycles being used for evaluation as shown in Figures. 1-2.

The computational models of feed forward simulation for the three kinds of vehicles are shown in Figure 3, while the parameters of the three sample vehicles are shown in Tables 2-4.

For simulating of ICEVs, as in Figure 3 (a), first of all,

Table 2 ICEV for evaluation

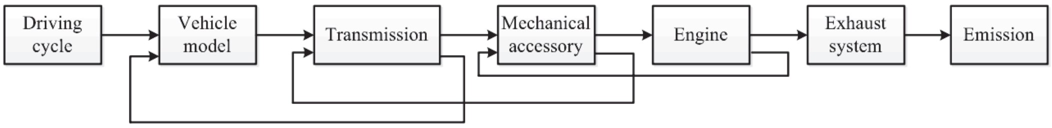
Engine displacement	1L
Fuel tank capacity	60 L
peak engine power	41 kW
Maximum torque	80.9 Nm @3479 rpm
Curb weight	984 kg

Table 3 EV for evaluation

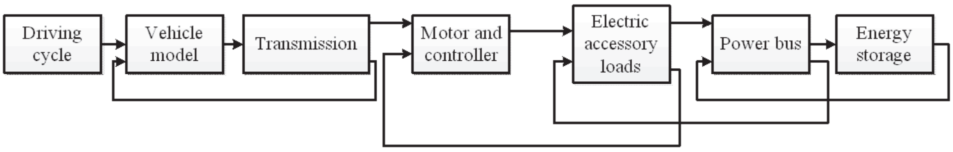
Motor type	Synchronous
Motor maximum power	150 kW
Maximum torque	225 Nm
Battery type	NiMH
Battery capacity	1500 Ah
Curb weight	1189 kg

Table 4 HEV for evaluation

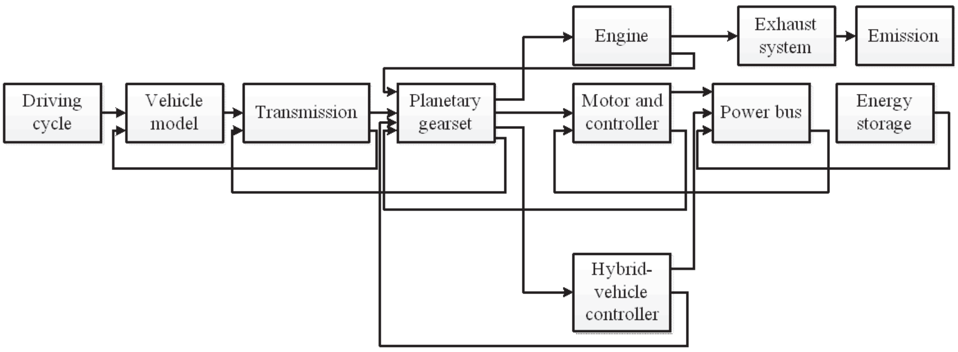
Fuels	Gas & Batteries
Engine displacement	1.5 L
Fuel tank capacity	45 L
Peak engine power	43 kW
Maximum torque	102 Nm@4000 rpm
Motor type	Synchronous
Motor maximum power	31 kW
Motor maximum torque	305 Nm
Battery type	NiMH
Battery capacity	6 Ah
Single-charge range	594.9 km
Curb weight	1332 kg



(a)



(b)



(c)

Fig. 3 Computational Models for: (a) ICEV; (b) EV; and (c) HEV

the MDC and FUDC 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 EVs and HEVs are similar to ICEV and are shown in Figure 3 (b) and Figure 3 (c) respectively.

3. SIMULATED RESULTS

Simulated results for EV, for both MDC and FUDS, of

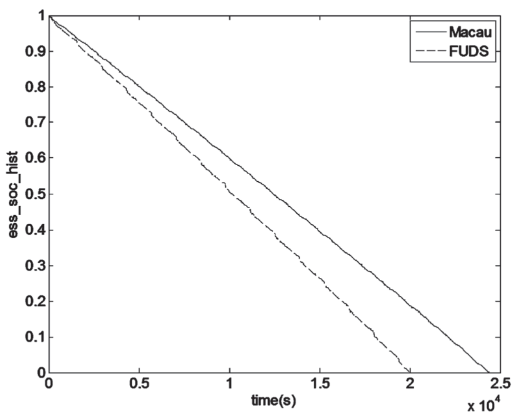
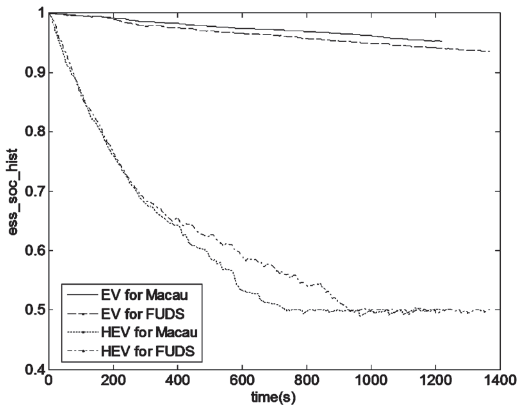
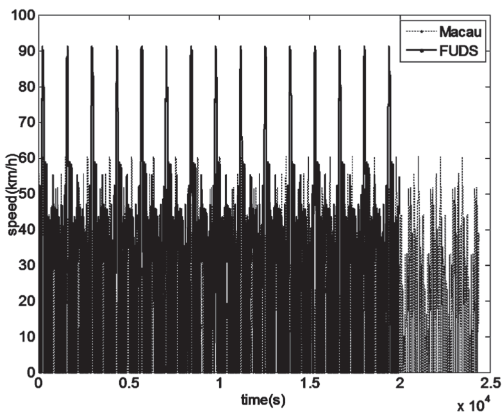


Fig. 4 Simulated results for EV: State-of-charge for batteries



(a)



(b)

Fig. 5 (a) Simulated results for EVs and HEVs; (b) Driving patterns

Table 5 Driving range for one-full charge/ one-full-tank using MDC

	EV	ICEV	HEV
Distance (km)	144.9	447.2	526.3
Gasoline equivalent (L/100 km)	2.5	11.9	7.6

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

	EV	ICEV	HEV
Distance (km)	175.6	611.0	754.7
Gasoline equivalent L/100 km)	2.0	8.9	5.3

Table 7 Energy Consumption for both MDC and FUDS

	MDC	FUDS
EV	20337kJ (100 %)	28065kJ (100 %)
ICEV	28968kJ (142 %)	53919kJ (192 %)
HEV	27946kJ (137 %)	34571kJ (123 %)

Table 8 Emissions for using MDC

	HC (g/km)	CO (g/km)	NO_x (g/km)
EV	0	0	0
HEV	1.017	1.047	0.134
ICEV	0.59	3.542	0.404

Table 9 Emissions for using FUDS

	HC (g/km)	CO (g/km)	NO_x (g/km)
EV	0	0	0
HEV	0.614	0.653	0.111
ICEV	0.716	2.186	0.908

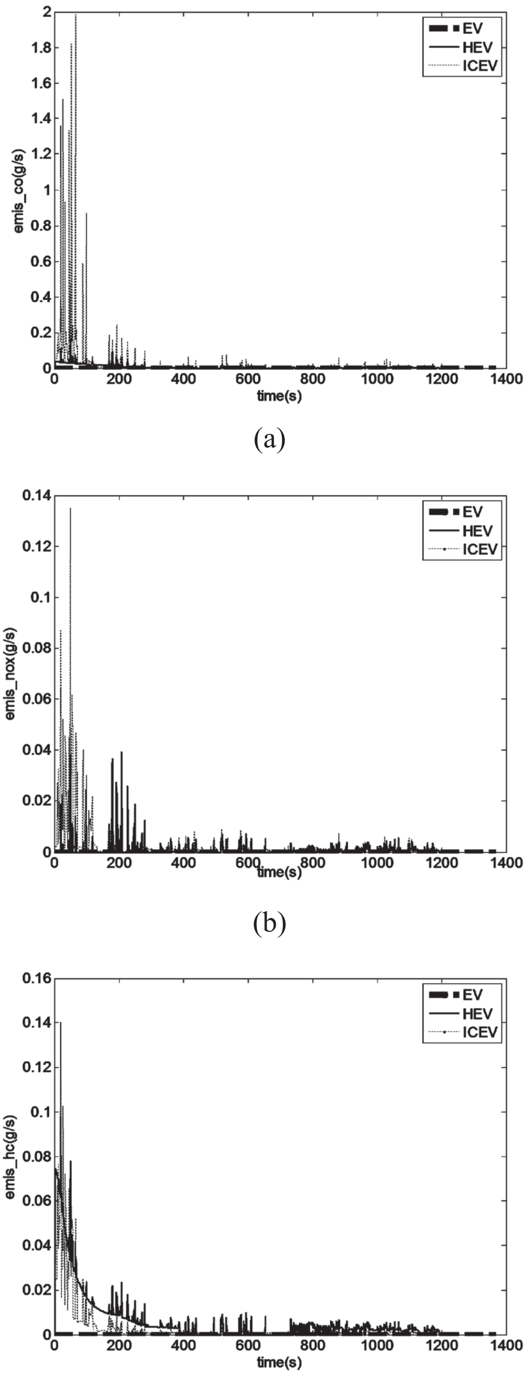


Fig. 6 Emissions for MDC: (a) CO; (b) NO_x; (c) HC

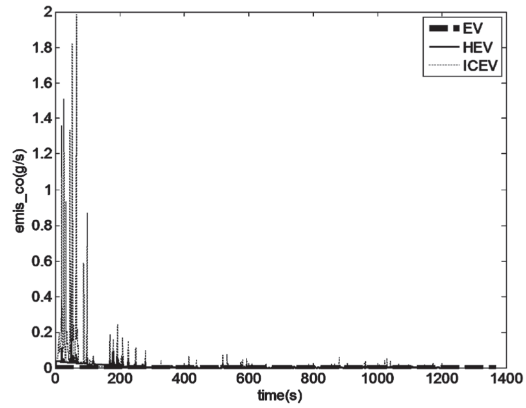
one full-discharge were shown in Figure 4. Similarly, simulated results for HEV are shown in Figure 5 (note that the batteries of HEV are not allowed to discharge to less than its 50 %). Other results are summarized in Tables 5-7 and emission data are shown in Tables 8-9 and Figures 6-7.

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):

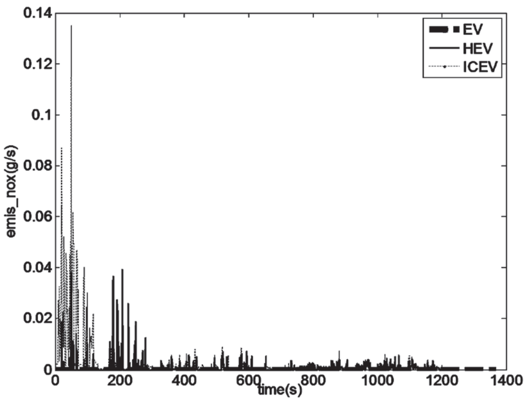
$$mpgge = \frac{S(42600)(749)}{V H \rho} \qquad (2)$$

where S stands for 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.

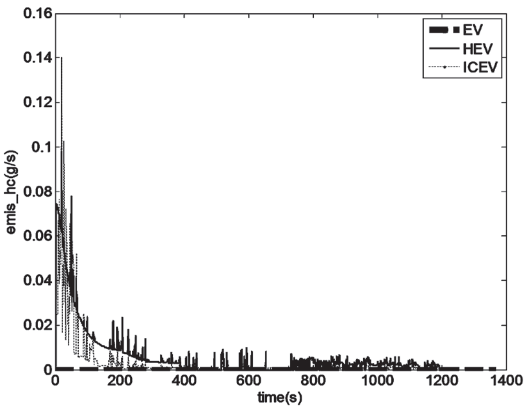
For evaluating an EV, the equation for gasoline equivalent is determined by (3),



(a)



(b)



(c)

Fig. 7 Emissions for FUDS: (a) CO; (b) NO_x; (c) HC

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

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.

4. CONCLUSION

From simulated results shown in Tables 5-7, EVs are most efficient for both MDC and FUDS, but with shortest driving range. However, for Macau, such a small city, one full charge can meet the daily driving range for most typical vehicle users [Ching, 2011]. Furthermore, simulated results from Figures. 6-7 shows that the zero local emission is a definite advantage of EVs.

EVs are clean due to their zero local emissions, but 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 [Ching, 2011].

Acknowledgements

This work was supported by the Research Council, University of Macau under MYRG041(Y1-L1)-FST12-TWC.

References

Chan, C. C., and Y. S. Wong, Electric vehicles charge forward, *IEEE Power & Energy Magazine*, Vol. 2, 25-33, 2004.

Chan, C. C., The state of the art of electric, hybrid, and fuel cell vehicles, *Proceedings of the IEEE*, Vol. 95, 704-708, 2007.

Ching, T. W., Electric vehicle charging station in Macau, *World Electric Vehicle Journal*, Vol. 4, 677-684, 2010.

Ching, T. W., Design of electric vehicle charging station in Macau, *Journal of Asian Electric Vehicles*, Vol. 9, No. 1, 1199-1206, 2011.

Ching, T. W., Road testing of electric vehicle in Macau, *Journal of Asian Electric Vehicles*, Vol. 9, No. 2, 1491-1495, 2011.

Ching, T. W., Application of electric vehicles in Macau, *Proceedings of the International Conference on Electrical Engineering (ICEE2011)*, 2011.

Ching, T. W., Cost analysis of battery-powered electric vehicles in Macau, *Journal of Asian Electric Vehicles*, Vol. 10, No. 2, 1619-1623, 2012.

Ching, T. W., K. Lai, and L. Iong, Performance study of battery-powered electric vehicles in Macau, *Proceedings of the 26th International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium*, USA, 2012.

Ching, T. W., T, Xu, W. Li, and S. Huang, Evaluation of electric vehicles in Macau, *Proceedings of the International Conference on Electrical Engineering (ICEE2014)*, 2014.

Wong, Y. S., W. F. Lu, Z. Wang, and Y. Liu, Life cycle cost analysis of different vehicle technologies in Singapore, *Proceedings of the 25th World Battery, Hybrid and Fuel Cell Electric Vehicle Symposium*

& Exhibition, 2010.

(Received May 12, 2014; accepted May 30, 2014)