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ADVISOR Simulation of Electric Vehicle Performance on Various Driving Cycles

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***Abstract*—ADVISOR software is used to perform simulation on determining if the combination of ultracapacitor with lead acid battery in an Electric Vehicle (EV) would improve its overall performance. Two vehicle templates are developed to represent: 1) EV with only batteries (EVBT), and 2) EV with combination of batteries and ultracapacitors (EVBTUC). The performances of both vehicles running on the United States' Environmental Protection Agency (EPA) Federal Test Procedure Driving Cycles are then compared.**

***Index Terms*—ADVISOR, Electric Vehicle (EV), Lead Acid Battery, Ultracapacitor, EPA Federal Test Procedure.**

I. Introduction

THERE are several problems which are associated with the EV technology at the moment. The most prominent one revolves around the main energy source of the EV, which is the battery. In this paper, the battery type discussed is the lead acid battery.

The battery has a characteristic of slow charging and discharging of current. This particular characteristic leads to inefficiency in recapturing the regenerative power from the wheels of EV back into the battery pack. As a consequence, this inefficiency produces more heat to accumulate at the battery pack area and prolonged battery operation under such high temperature circumstances would shorten the battery's lifespan.

Hence, it is proposed that the integration of ultracapacitor along with the Battery pack of the EV would improve:

1) The charging and discharging efficiencies of the EV;
2) The driving cost of the EV; and
3) The travel distance of the EV.

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II. Research Methodology

A. ADVISOR

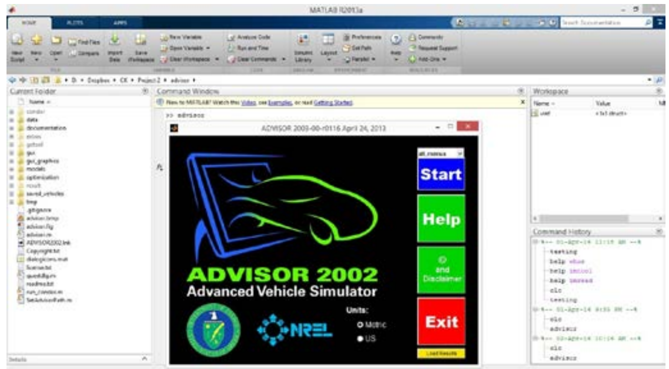

Fig. 1. ADVISOR in MATLAB Environment

The ADVISOR software is initially developed by the United States' National Renewable Energy Laboratory (NREL) and subsequently released to the public. As of April 2014, ADVISOR is an open-source software available for download.

ADVISOR is a software used to perform comprehensive analysis of performances of a wide range of vehicles. By using ADVISOR, two vehicles are developed: 1) EV with only lead acid batteries (EVBT), and, 2) EV with combination of lead acid batteries and ultracapacitors (EVBTUC). Subsequently, both vehicles are then made to run on the EPA Federal Test Procedure driving cycles, and their performances compared.

B. EPA Driving Cycles

The Federal Test Procedure was created by the United States' EPA for fuel economy testing and emission certification of light-duty vehicles in the United States.

The rationale of choosing the EPA Federal Test Procedure is because it is a Transient Cycle as compared to the Modal Cycles such as the New European Driving Cycle (NEDC) and the Japanese 10-15 Mode Driving Cycle.

Transient Cycle gives better representation of real-life driving behavior as opposed to the straight acceleration and constant speed profiles of the Modal Cycle.

The EPA Federal Test Procedure Driving Cycles tested in this paper are:

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1) FTP-75 City Driving Cycle
2) HWFET Highway Driving Cycle
3) SFTP-US06 Supplemental Test

C. Total Energy Consumption of an EV

The total power required to complete the task is determined by the road load equation:

$$P = mav + mgv\sin\alpha + C_{RR}mgv\cos\alpha + \frac{1}{2}\rho C_D A v^3 \quad (1)$$

where

P = traction power (kgm²/s³ = Js^{-1} = W)
v = velocity (ms^{-1})
a = acceleration (m/s²)
α = slope angle (100 sin α = % slope)
m = mass (kg)
g = acceleration due to gravity (m/s²)
Crr = coefficient of rolling resistance
ρ = density of air (kg/m³)
Cd = coefficient of aerodynamic drag
A = frontal area of vehicle (m²)

The road load equation is separated into four main parts:

- (m a v), where the acceleration factor is taken into consideration,
- (m g v sin α), is the hill climbing factor of an electric vehicle,
- (Crr m g v cos α), takes into account the rolling resistance, and
- (½ ρ Cd A v³), is where the aerodynamic drag is considered into the calculation.

III. RESULTS AND DISCUSSION

A. FTP-75 City Driving Cycle

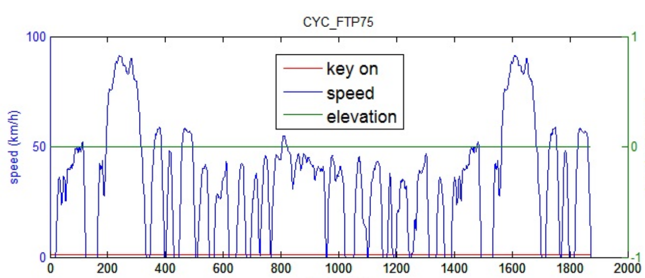

Fig. 2.FTP-75 City Driving Cycle

Both vehicles have to travel a distance of 17.77km in 1874s in the FTP-75 City Driving Cycle. It has an average speed of 34.12km/h and maximum speed of 91.25km/h.

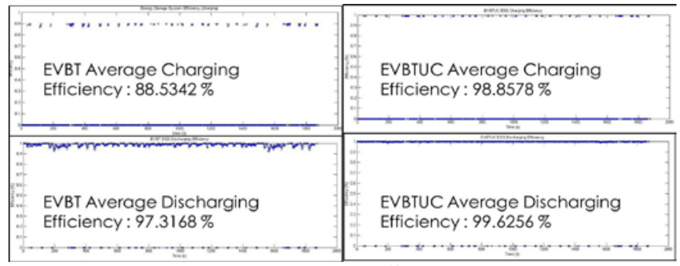

Fig. 3.Average Charging and Discharging Efficiencies

From Figure 3, it can be seen that EVBTUC is more efficient than the EVBT in terms of charging and discharging operations. This can be attributed to the fast charging and discharging characteristic of the ultracapacitors in helping the lead acid batteries to capture and absorb the regenerative power.

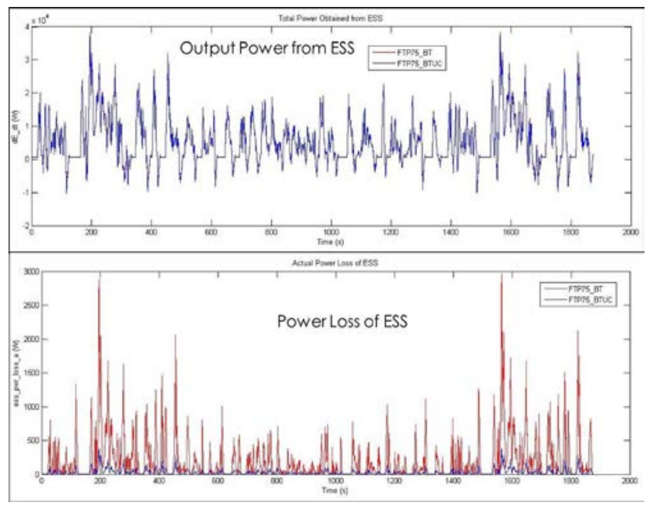

Fig. 4.Output Power and Losses of ESS

Figure 4 shows the total amount of output power from the ESS and its losses. The graph at the bottom represents the power losses in the ESSs of both vehicles.

The red line represents the losses of EVBT while the blue line represents the losses of EVBTUC. The lead acid batteries in EVBT have significantly more losses than the lead acid batteries and ultracapacitors combination because of the high internal resistance value of the lead acid batteries. The current will meet more resistance when it is being charged or discharged by the batteries and in turn, producing more heat to accumulate at the battery pack area.

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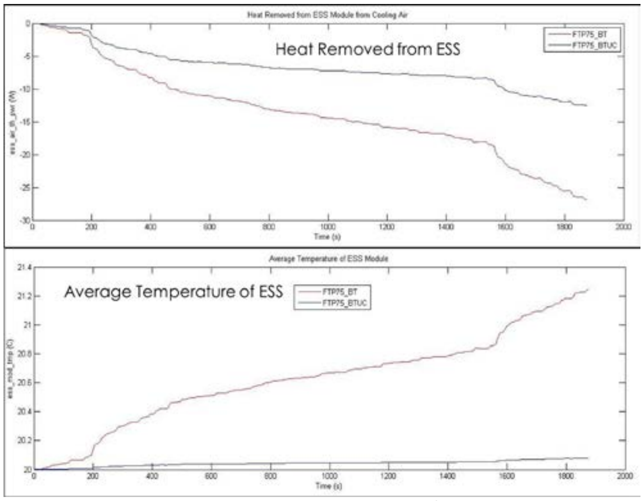

Fig. 5.Heat Removed and Average Temperature of ESS

In Figure 5, from the graph at the top, it can be clearly seen that the EVBT dissipates more heat, as it represents the amount of heat removed from the ESS by a 20^{o}C cooling air as coolant. On the other hand, the graph at the bottom shows that the ESS of EVBT has a higher temperature as compared to the ESS of EVBTUC. If an ESS is continuously operated under high temperature conditions, its lifespan will be shortened.

In terms of the driving cost of both EVs, the total amount of energy consumption by both EVs in performing the FTP-75 is determined and multiplied by the domestic tariff rate charged by the Tenaga Nasional Berhad (TNB) of Malaysia. As of April 2014, the tariff rate for the first 200 kWH per month for domestic consumers is at RM 0.218/kWH

For EVBT,

$$3.432\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.75$$

For EVBTUC,

$$3.104\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.68$$

From the two simple calculations, it can be said that EVBT consumed more energy, because of more losses, to perform the entire driving cycle as compared to EVBTUC. Hence, the EVBT costs more than the EVBTUC to run on the FTP-75 Driving Cycle.

B. HWFET Highway Driving Cycle

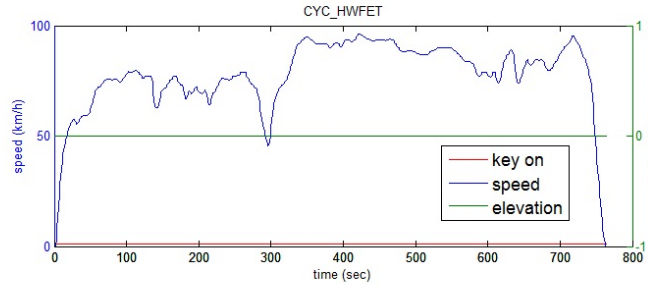

Fig. 6.HWFETHighway Driving Cycle

The HWFET Highway Driving Cycle has a distance of 16.51km. Both vehicles have to perform the driving cycle in 765s at an average and maximum speed of 77.58km/h and 96.4km/h respectively.

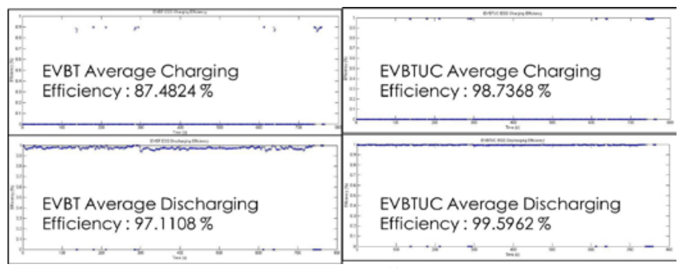

Fig. 7.Average Charging and Discharging Efficiencies

Figure 7 shows that for highway driving behavior such as the HWFET Highway Driving Cycle, EVBTUC is also more efficient than EVBTUC in charging and discharging operations.

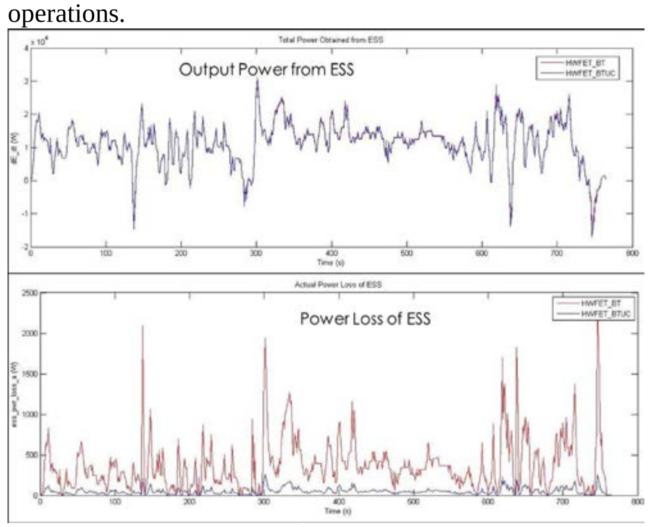

Fig. 8.Output Power and Losses of ESS

Similarly from Figure 8, it clearly shows that the ESS of EVBT, which is represented by the red line on the bottom graph, has more losses as compared to the ESS of EVBTUC, which is represented by the blue line on the bottom graph.

However, as compared to the FTP-75 City Driving Cycle, it is obvious that the losses incurred during the HWFET Highway Driving Cycle are lesser than the losses recorded during the FTP-75 City Driving Cycle. This is because for highway driving behavior, the vehicle would be in "cruising" state and would not require much current from the ESS as opposed to the "Stop-and-Start" driving of the vehicle in city driving behavior, which requires more current to propel a vehicle at rest due to heavy traffic condition or stopping for traffic light.

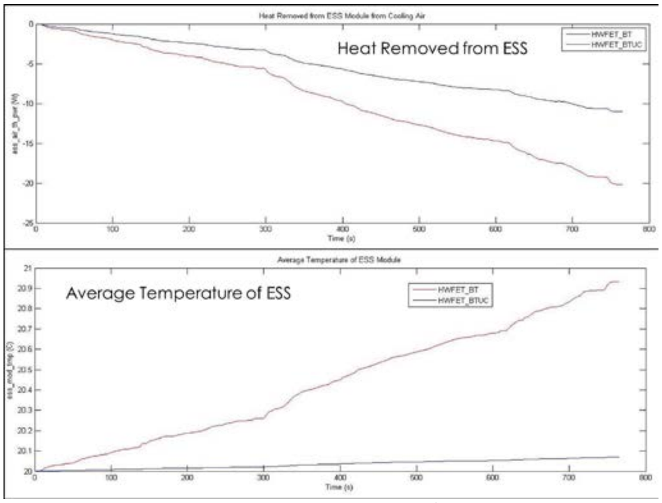

Fig. 9.Heat Removed and Average Temperature of ESS

Due to the higher internal resistance value in the lead acid batteries, more heat is produced during charging and discharging operations as can be seen in Figure 9. Also, the ultracapacitors have a characteristic of maintaining its temperature at a relatively low temperature throughout its charging and discharging operations.

For this HWFET Highway Driving Cycle, the driving cost of both EVs is also calculated.

For EVBT,

$$2.727\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.59$$

For EVBTUC,

$$2.446\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.53$$

In "cruising" state, both EVs did not consumed a lot of energy, but EVBTUC still recorded a cheaper driving cost as compared to EVBT.

C. SFTP-US06 Supplemental Test

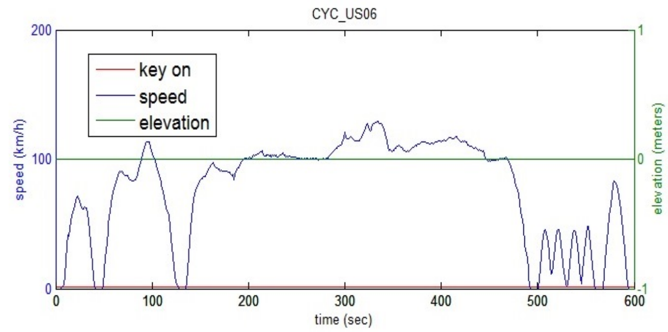

Fig. 10.SFTP-US06Supplemental Test Driving Cycle

The SFTP-US06 Supplemental Test Driving Cycle consists of both city and highway driving behavior. It is to supplement the shortcomings of both the FTP-75 City Driving Cycle and HWFET Highway Driving Cycle. Moreover, the SFTP-US06 is also a representation of aggressive driving behavior as it contains sharp accelerations and high speed profile.

The SFTP-US06 spans over 12.89km in 600s and has an average and maximum speed of 77.2km/h and 129.23km/h respectively.

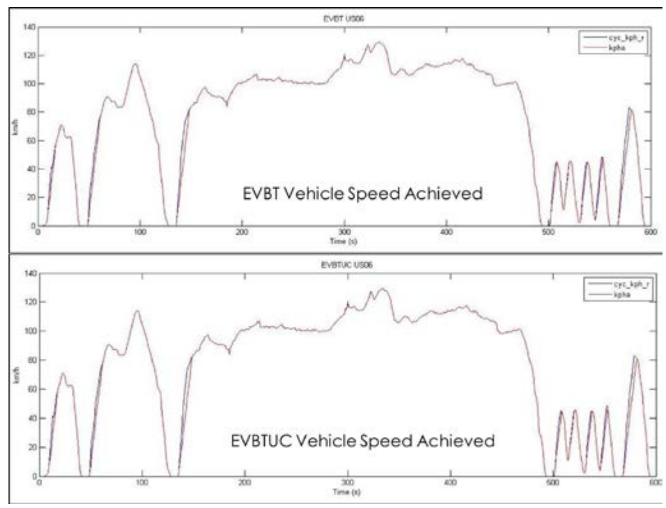

Fig. 11.Vehicle Speed Achieved

Figure 11 illustrates the vehicle speed achieved by both EVs. It can be seen that there some small chunks at the lines. These small areas depict the inability of both EVs to achieve the requested speed by the SFTP-US06.

For EVBT, it is because of the slow charging and discharging capability of the lead acid batteries. As for the case of EVBTUC, the extra weight of the ultracapacitors in the ESS of EVBTUC is the major cause.

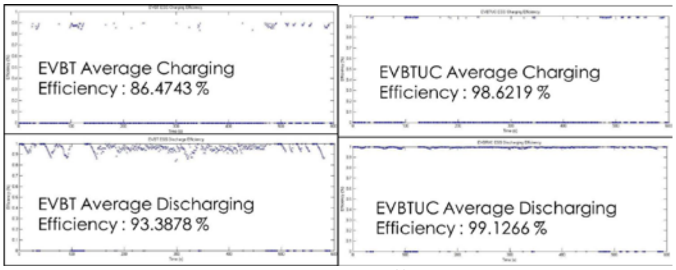

Fig. 12.Average Charging and Discharging Efficiencies

From Figure 12, it is obvious that for demanding situations such as the sharp acceleration of SFTP-US06, the lead acid batteries are not efficient at both charging and discharging operations. On the other hand, the ESS of EVBTUC still manages to maintain a considerable charging and discharging efficiencies.

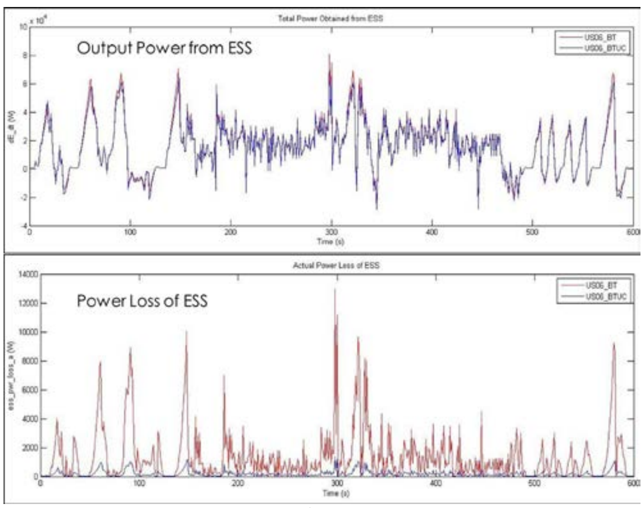

Fig. 13.Output Power and Losses of ESS

In SFTP-US06, again it can be seen that the losses suffered by the ESS of EVBT is significantly more than the ESS of EVBTUC. Due to the demanding acceleration of SFTP-US06, more current is discharged to supply to the motor, but because of the high internal resistance value, more heat is produced and accumulate at the ESS area which leads to more losses incurred.

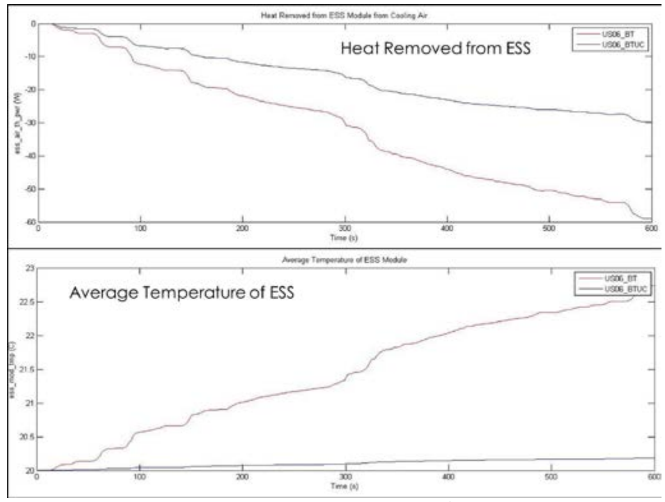

Fig. 14.Heat Removed and Average Temperature of ESS

Throughout the SFTP-US06 Supplemental Test Driving Cycle, the ESS of EVBT produces more heat and recorded a higher average temperature than the ESS of EVBTUC as can be seen in Figure 14.

As for the driving cost of both EVs after completing the SFTP-US06:

For EVBT,

$$3.244\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.71$$

For EVBTUC,

$$2.817\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 0.61$$

From the driving cost of both EVs, again it is proved that the EVBTUC consumes lesser energy as compared to EVBTUC.

IV. CASE STUDY

For this section, a case study is carried out. A driving cycle which represents a real-life route in Malaysia is approximated. Moreover, an additional parameter is added into the driving cycle of this case study, which is the elevation profile.

The elevation data for every route can be extracted from the Google Earth software. The Google Earth is a free software which can be downloaded easily with internet access.

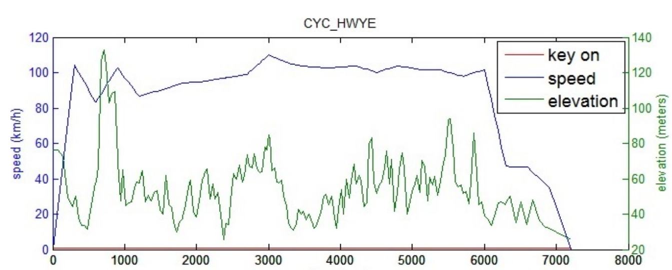

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Fig. 15.UTAR KL Campus to UTAR Kampar Campus

This driving cycle is to approximate the route between two University Tunku Abdul Rahman (UTAR) campuses. Due to the lack of raw data, the speed profile of the driving cycle is from estimation.

The route consists of 176km of highway driving to be completed in 7200s and has an average and maximum speed of 87.99km/h and 110km/h respectively.

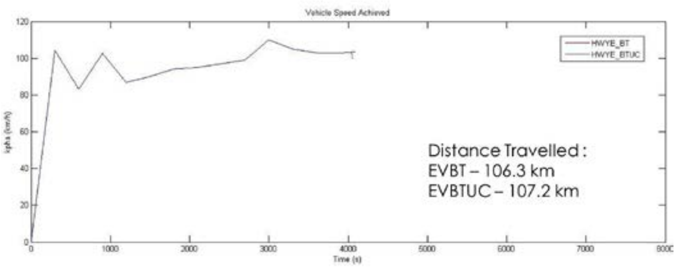

Fig. 16.Distance Travelled

Figure 16 illustrates the distance travelled by both EVs. It is apparent that both vehicles did not manage to complete the entire distance of 176km. However, it can be seen that EVBTUC managed to travel a slightly longer distance of 107.2km as compared to the travel distance of EVBT of only 106.3km.

For this particular driving cycle, there was no regenerative braking occurred. This is because there was neither sharp deceleration nor stops made throughout the driving cycle.

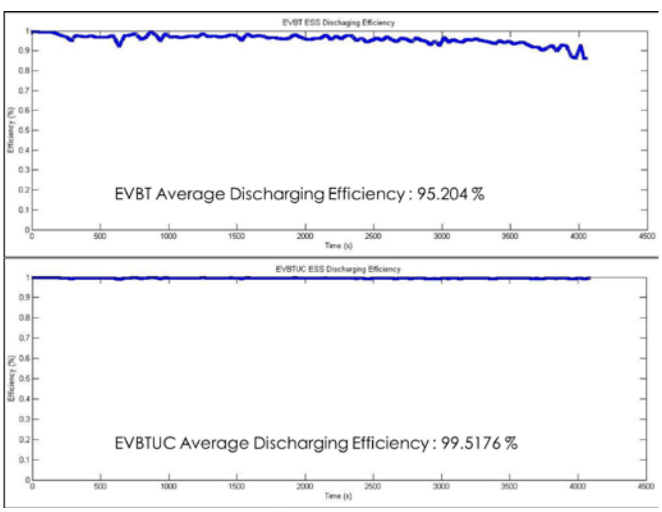

Fig. 17.Average Discharging Efficiencies

As for the average discharging efficiency of both vehicles, from Figure 17, it can be seen that, again, EVBTUC is more efficient in its discharging operation as compared to its EVBT counterpart.

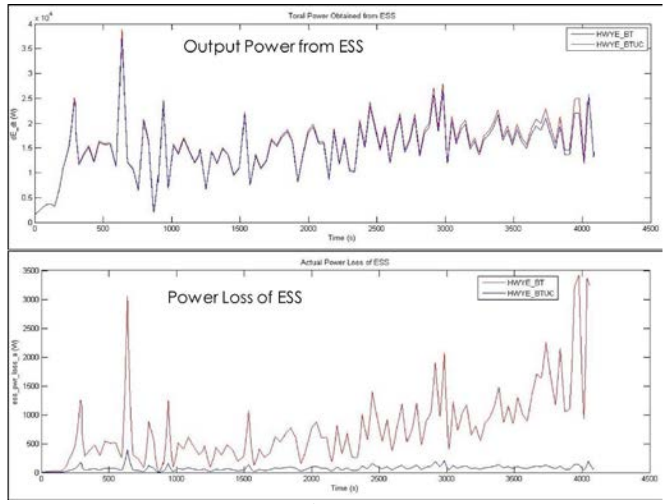

Fig. 18.Output Power and Losses of ESS

The high internal resistance of the ESS of EVBT again played its part in generating more heat, and as a result more losses incurred, as compared to the ESS of EVBTUC.

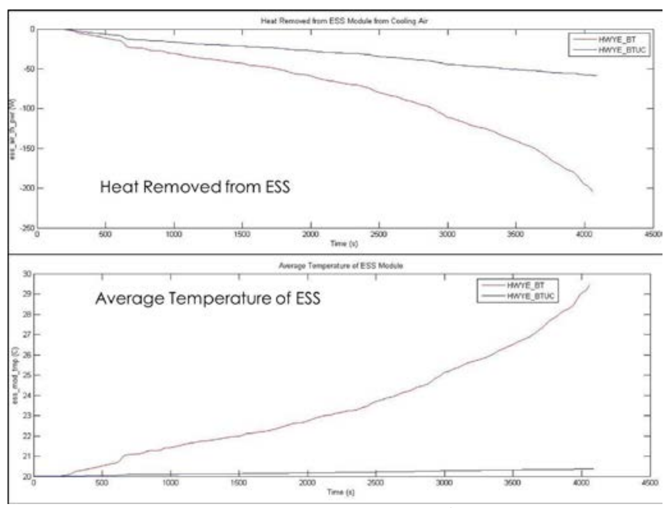

Fig. 19.Heat Removed and Average Temperature of ESS

From Figure 19, it can be seen that the ESS of EVBT dissipates more heat and recorded a higher average temperature as compared to the ESS of EVBTUC.

The calculation of the driving cost of both EVs is as follow:

For EVBT,

$$19.703\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 4.30$$

For EVBTUC,

$$17.441\ kWH \times \frac{RM\ 0.218}{kWH} = RM\ 3.80$$

From the calculation, it is obvious that because of more losses incurred, EVBT consumed more energy than the EVBTUC in performing the driving cycle of this case study.

V. CONCLUSION

From the three EPA Driving Cycles and an additional case study, a conclusion can be reached. Simulation results showed that the integration of ultracapacitors along with the lead acid batteries in an EV would:

1) Improve the charging and discharging efficiencies of the EV;
2) Lessen the driving cost of the EV; and
3) Prolong the travel distance of the EV.

With future work in the pipeline such as, determining the optimum ratio between the sizing of lead acid batteries and ultracapacitors to decrease overall weight of EV, and collection of raw data for the speed profile of the case study to further enhance the accuracy and precision of the driving cycle, is it believed that the integration of ultracapacitors would bring a greater impact and more obvious effect on the overall performance of an EV.

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