ACCREDITED TESTING OF ENERGY CONSUMPTION OF ELECTRICAL VEHICLES ACCORDING TO E-SORT PROTOCOL

G. S. Milushev, K. S. Kirilova-Blagoeva

Abstract: The main aim of the SORT (Standardised On Road Test cycles) methodology is to provide the European bus sector with a standardized way of comparing the energy consumption of different buses. The purpose of the "E-SORT" project is to measure, in a reproducible way the energy consumption and the Zero Emissions range of a bus. The requirements of these two papers play a role of main standardized documents for defining the parameters of the consumption of electrical buses. Even limited to traction energy only, the compliance with the requirements of SORT and E-SORT is hard and depends on the specifics of local testing conditions. The present report describes a real and successful E-SORT test of a fully electrical bus with a super-cap Rechargeable Energy Storage System (RESS). The obtained results were documented and certified by an independent accredited inspection body.

Key-Words: Electrical Vehicles, Electrical Energy Consumption, DC Electrical Energy, Energy Efficiency, Charging Stations, Rechargeable Energy Storage System.

1. Introduction

The methodology adaptation of the SORT procedure, documented in the UITP (Union Internationale de Transport Publique/ International Association of Public Transport [4]) E-SORT project paper consist of 2 sequenced testing methodologies:

1) Usable energy measurement of the RESS: the difference between SOCM (Maximum level of State of Charge - SOC) and SOCW (warning SOC corresponds to the minimum level allowed by the manufacturer during a normal operation).

2) Energy consumption measurement – the object of the present paper – aiming to determine the energy consumption of the bus on a given SORT cycle.

Both tests may be carried out in any order. By combining results from both tests we can calculate, for a given SORT cycle, the energy consumption and the maximum range for traction [1].

The present report presents real results obtained during tests according the mentioned above methodology under requirements of [1] and [2]. The conclusions at the end provide recommendations related to the limitations and boundaries of the approaches suggested in the both normative documents.

The inspection team has advance experience on the same type of Supercap busses in the years [3]. Unlike to the former tests [3], done under the supervision of TUF, in 2018 the team makes the Conformity Assessment as a National Inspection Body, accredited by BAS [5], recognized under EA MLA [6].

2. Methodology

The methodology is strictly based on [1] and [2]. Measurement conditions are fixed for the all SORT testing cycles e.g.: auxiliaries switched off with the exception of those systems that are required for the normal functioning of the vehicle; the temperature of the RESS carefully noted in the test Protocol; several SORT cycles form each type 1, 2 or 3;

2.1. Measurement general requirements

The energy to and from the RESS is measured as close as possible to the RESS. All measurement devices used are calibrated by an independent laboratory, proven by certificates. The on-board energy values are stored by a data acquisition system (energy analyzer), with a global accuracy of at least +/- 2 %, and a frequency of at least 20 Hz [1].

2.2. Energy consumption measurement

Aiming to determine the energy consumption of the bus on a given SORT cycle [1, 2]:

1. Calibrated analyzer is directly switched to measure current and voltage on each cable from/ to the RESS;
2. Vehicle passes the test track according the SORT speed/acceleration profiles - fig. 1
3. The vehicle driveline (engine, motors, RESS, retarder,..) T° are within reference ranges
4. SOC at the beginning of given SORT cycle allows for full regenerative braking capacity, because the test track is over 3-4 km away from the charging station;
5. The bus driver follows the specifications

of $SORT_i$ (I = 1, 2 or 3) cycles, on a preliminary measured distance (di) and the energy flow between RESS and vehicle (E_i) is duly registered;

6. Repeat until convergence condition according to SORT protocol (the consumption measurements for each respective cycle have to be repeated until 3 measurements lie within an accuracy requirement of 2 %)

The maximum deviation between the SORT consumption values, **as provided by the manufacturer**, and the result from the control test, may not exceed 5% [2].

This deviation margin of 5% takes into account [2]: 1) Accuracy of measurement; 2) Tolerance of the complete driveline (transmission efficiency, engine performance, tyre influence, etc.); 3) External test conditions (external temperature, air pressure, humidity, wind speed, state of the track surface, etc.).

3. Results treatment

The calculation takes into account also the Usable Energy measurement of the RESS $E_C{}^{Max}$ - energy measured downstream the charging station, as mentioned above.

3.1. Energy consumption on $SORT_i$ [2]

$$C_i = \left[\frac{kW.h}{100.km}\right] = \frac{100.E_i}{d_i} \qquad (1)$$

C_i = energy consumption on $SORT_i$ [kW.h/100 km]
E_i = energy measured on $SORT_i$ [kW.h]
d_i = distance measured on $SORT_i$ [km]

3.2. Maximal range on $SORT_i$ [2]

$$d_i^{Max} = \frac{100.E_c^{Max}}{C_i} = \frac{E_c^{Max}}{E_i}\, d_i \qquad (2)$$

$E_C{}^{Max}$ = energy measured downstream the charging station [kWh]
C_i = energy consumption on $SORT_i$ [kW.h/100 km]
E_i = energy measured on $SORT_i$ [kW.h]
d_i = maximum range on $SORT_i$ [km]

4. Test realization

In view of the existing conditions is selected an optimally applicable length of the track 520/920/1450 m to SORT 1,2 and 3. At the ends of the track there are roundabouts with areas of unacceptable stay. This specificity is compensated by the driver's experience and does not affect the consumption dynamics. The

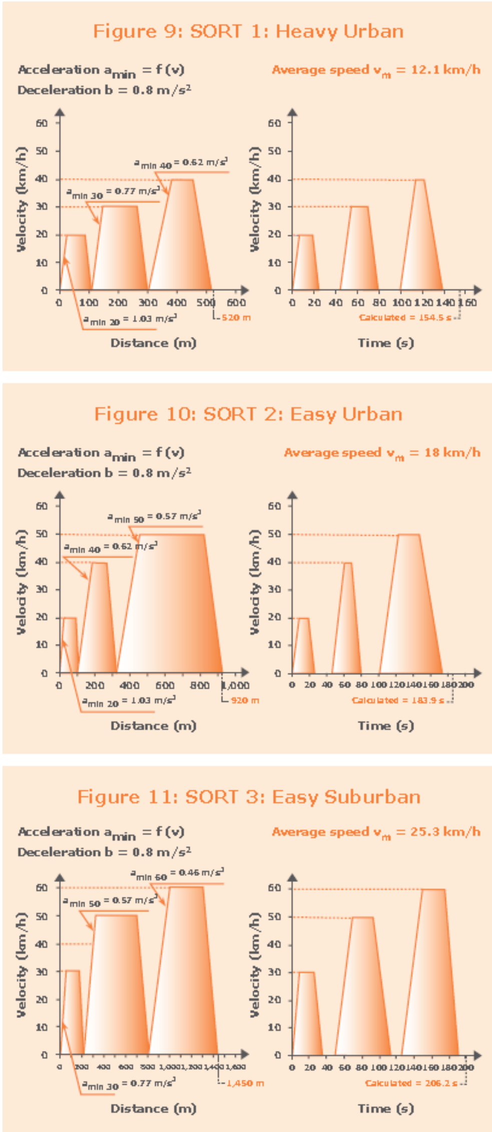

Fig. 1 Sort cycles according UITP SORT 2014, source UITP PROJECT SORT [2]

trapezoidal baseline velocity profiles are achieved over a straight section.

4.1. Connection Scheme

Connection to the closest point to the Rechargeable Energy Storage System (RESS): Voltage - directly to the power voltage, Current - with DC clamps to the main power line – fig 2.

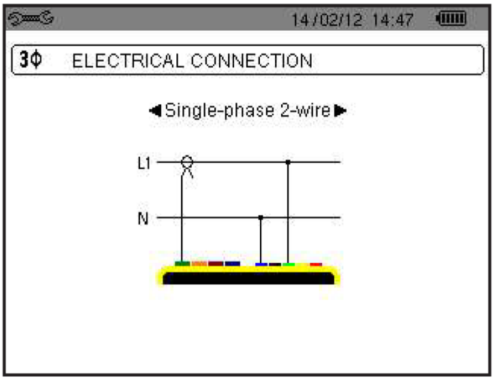

Fig. 2 Connection chosen by the analyzer menu.

Technical tools used for inspection are Energy Analyser type C.A 8335 and DC Current clamps PAC 93.

4.2. Inspection Point

The inspection point is in the rear left compartment of the electrical bus (Fig. 3), next to the disconnectors of RESS in an isolated protected section with a thick lid (Fig. 4).

Fig. 3 Inspection point.

Fig. 4 connection to the RESS.

The energy analyzer is placed inside the bus on a seat next to the inspection point (Fig 5). A constructive hole between the public compartment and the condenser cooler is used to pass the probe cables.

Fig. 5 Analyzer fixed next to the inspection point.

4.2. Energy consumption

For rows in the straight and reverse directions, recorded results are used, from 3 cycles selected in accordance with the E-SORT requirements for repeatability of the registered energy consumption within the minimum deviation of the consumed energy, according chapter 6 of UITP SORT.

The calculations were made in accordance with the methodology in Ch. 6 of UITP SORT 2014 using the net energy records. Profile example for energy consumption under SORT 1 is shown on fig. 6.

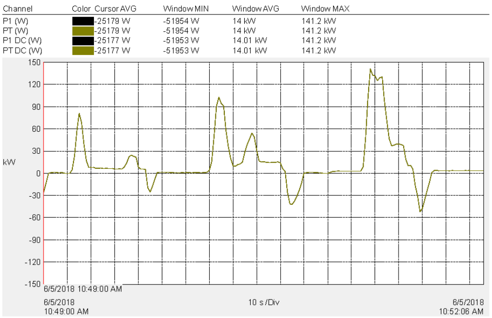

Fig. 6 SORT 1 Power Profile

Profile example for energy consumption under SORT 2 is shown on fig. 7.

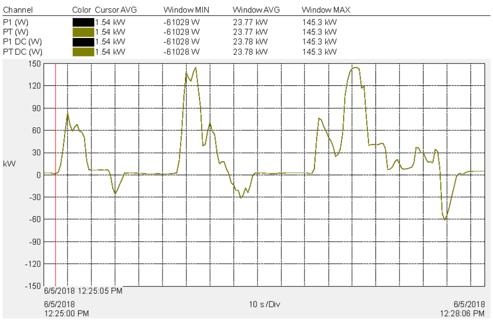

Fig. 7 SORT 2 Power Profile

The time for each SORT cycle is recorded as a start and end in the energy record for the corresponding SORT cycle – Fig. 8.

4.3. Test results

A very important criterion for the reliability of the average results is the average speed achieved during the tests. It should be very close to the references form SORT 2014 [2]. The average speeds from the test are presented in Table 1

The following tables (Tables 2, 3 and 4) show the averaged (according SORT 2014 [2]) data respectively for SORT 1, SORT 2 and SORT 3.

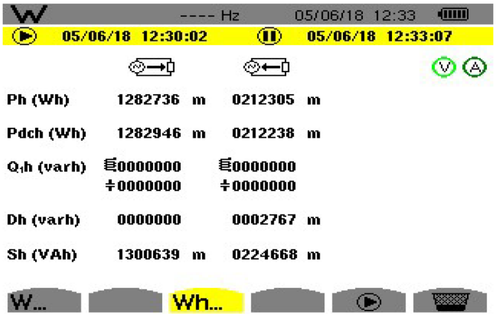

Fig. 8 Energy Record for a SORT cycle

5. Conclusions

1) More or less, the circular test track gives significant deviations in the both directions and the statistical data shall be grouped according the direction;

2) The respect of the requirement for minimum mileage of 20 000 km is very difficult, because the buses under test are always new models for the producers;

3) The experience of the bus driver is dominant for the successful and repeatable tests.

4) The strict requirement: 'the consumption measurements for each respective cycle must be repeated until 3 measurements lie within an accuracy requirement of 2 %' [1] highly depends on the available resources: trace, driver, time, weather, distance to charge etc. The study of the results shows that this requirement could be more easily satisfied on 'NET' (with recuperation) energy than the 'LOAD' energy (consumption only). As it is not fixed in the SORT documents the inspection team strictly follows this approach;

6. References

[1] **UITP PROJECT E-SORT**, Cycles for Electric Vehicles, International Association of Public Transport (UITP), Rue Sainte-Marie, 6 | B-1080 Brussels | Belgium, Legal deposit: D/2017/0105/9

[2] **UITP PROJECT SORT**, Standardised On-Road Test Cycles, New edition UITP 2014, International Association of Public Transport, Legal Deposit: D/2014/0105/1

[3] **G. S. Milushev, K. S. Kirilova, K. S.**

Table 1

E-SORT №	Item	Length	SORT Ref	Average speed
2.9	SORT 1 Cycle Average	520 m	12,4 km/h	11,990 km/h
2.9	SORT 2 Cycle Average	920 m	18,5 km/h	18,007 km/h
2.9	SORT 3 Cycle Average	1450 m	26,2 km/h	26,527 km/h

Table 2

E-SORT №	Item	Definition	Value	Unit
1.1	d_1	Total distance on SORT 1	0,520	km
1.2	E_1	Total energy consumption on SORT 1	0,74628	kW.h
1.3	/	Battery pack outside temperature at the beginning of the test	22,4	ºC
1.4	/	Battery pack outside temperature at the end of the test	23,6	ºC
1.5	$\mathbf{c_1}$	**Energy consumption on SORT 1**	$c_1 = 100 \times E_1 / d_1 =$ **143,494**	**kW.h/100 km**
1.6	$\mathbf{d_{1\,Max}}$	**Maximal range on SORT 1**	$d_{1\ Max} = 100 \times E_C^{Max}/c_1$ = **19,379**	**km**

Table 3

№ on E-SORT	Item	Definition	Value	Unit
1.1	d_2	Total distance on SORT 2	0,920	km
1.2	E_2	Total energy consumption on SORT 2	1,1605	kW.h
1.3	/	Battery pack outside temperature at the beginning of the test	23.5	ºC
1.4	/	Battery pack outside temperature at the end of the test	26.2	ºC
1.5	$\mathbf{c_2}$	**Energy consumption on SORT 2**	$c_2 = 100 \times E_2 / d_2 =$ **126,141**	**kW.h/100 km**
1.6	$\mathbf{d_{2\,Max}}$	**Maximal range on SORT 2**	$d_{2\ Max} = 100 \times E_C^{Max}/c_2$ = **22,0449**	**km**

Table 4

№ on E-SORT	Item	Definition	Value	Unit
1.1	d_3	Total distance on SORT 3	1,450	km
1.2	E_3	Total energy consumption on SORT 3	1,712	kW.h
1.3	/	Battery pack outside temperature at the beginning of the test	23.6	ºC
1.4	/	Battery pack outside temperature at the end of the test	26.8	ºC
1.5	$\mathbf{c_3}$	**Energy consumption on SORT 3**	$c_3 = 100 \times E_3 / d_3 =$ **118,081**	**kW.h/100 km**
1.6	$\mathbf{d_{3\,Max}}$	**Maximal range on SORT 3**	$d_{3\ Max} = 100 \times E_C^{Max}/c_3$ = **23,549**	**km**

Stanev, Method for Assessment of the Consumption of Electrobus Using Load Profile of the Charging Stations, Proceedings of XXV National Scientific Symposium with International Participation 'Metrology and Metrology Assurance 2015', Sozopol, 7-11 Sept. 2015

[4] http://www.uitp.org/ International Association of Public Transport, accessed on May 10th, 2018

[5] http://nab-bas.bg/bg/ 'Executive Agency 'Bulgarian Accreditation Service'

[6] http://www.european-accreditation.org/ mla-and-bla-signatories#1 European Accreditation, MLA & BLA Signatories, Testing

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