Simulation and Evaluation of the Air-Conditioning System in Electric Vehicles

Nissan Leaf as a case study

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Abstract: In this work, it was implemented a model in AVL Cruise in order to simulate an electric vehicle as close as possible to Nissan Leaf 2013 with the information published for the vehicle. After modelling and calibrating the components in AVL Cruise it was included KULI software from MAGNA as an interface to implement the air-conditioning system to the model in AVL Cruise which is not possible without an external interface.

Range and consumption were evaluated for driving schedules such as New European Driving Cycle (NEDC), Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Driving Schedule (HWFET), Supplemental Federal Test Procedure for Aggressive driving style (US06), Supplemental Federal Test Procedure for air-conditioning testing (SC03) and Worldwide harmonized Light vehicles Test Cycle (WLTC) and the results with and without air-conditioning system were compared to those found in literature.

In general, the results obtained were close to those found in literature without A/C using AVL Cruise and with A/C using AVL Cruise with KULI. It was found that air-conditioning system can reduce the vehicle range from 12 % to 25 % in extreme conditions.

Keywords: Air-conditioning, Electric Vehicle, AVL Cruise, KULI, Simulation.

1. Introduction

In the last decades, the concerning about pollution has been growing. With the increase in population and in a need for transportation and mobility, the number of vehicles used in the world rapidly increased. With that grown, quickly came the concern for the human being in terms of hazardous emissions, namely CO_2 which contributes to global warming and NO_x gases which are toxic to the human being, among others such as CO, SO_x and soot.

Electric vehicles were developed in the last years and today almost every brand have presented, for example Nissan, BMW, VW, Renault, Tesla, or intend to present, for example Mercedes-Benz [1], Audi [2], a full electric vehicle. The main objective of electric vehicles is, first of all, to create a sustainable way of mobility in order to decrease the levels of pollution emitted by the transportation sector in all world. And second, with the increasing concern about pollution, the European Commission introduced the World harmonized Light vehicle Test Procedure (WLTP) as the necessary procedure to homologate new vehicles after 1st September 2019 and electric and hybrid vehicles may be the only option to consider by manufactures to complete successfully the test procedure.

Battery Electric Vehicles (BEV) undergo a series of challenges. The goals for electric vehicles are range, energy efficiency, comfort and easy maintenance and the main restrictions are weight and cost. Battery in electric vehicles is one of the main issues and the most important, and yet to be developed, component. Its efficiency for extreme temperatures need to be accounted as well as battery life vs n^{er} of cycles or battery life vs Depth of Discharge (DoD). Besides these factors, there are few battery external factors that influence battery and consequently vehicle range, which are driving style, vehicle coasting and auxiliary vehicles components. One of this components, which can be the main auxiliary consumer in a BEV is the air-conditioning compressor.

Air-conditioning system can have a huge impact in BEV decreasing its range in extreme conditions by 13 % [3]. Besides that, air-conditioning can be harmful for the environment. In 2012 EPA and NHTSA [4] estimated that in U.S.A. the air-conditioning system was responsible for 3.9 % of the total greenhouse gas emissions of cars and light trucks. However measures have been taken about air-conditioning system leakages and it is mandatory in European Union [5] since January 2017 that the refrigerant fluid has a Global Warming Potential (GWP) below 150. One of the solutions found was to use R1234yf, which GWP is 4, as a refrigerant fluid. However, many vehicles in the market still use R134a, which GWP is above 1300.

The objective of this work is to simulate the influence of the air-conditioning system in electric vehicles using Nissan Leaf as a case study. In this work it was implemented a model in order to simulate an electric vehicle as close as possible to Nissan Leaf 2013 with the information published for the vehicle and available from the literature. The differences in range and consumption for vehicle model and data published with and without air-conditioning module were discussed for driving schedules such as New European Driving Cycle (NEDC), Urban Dynamometer Driving Schedule (UDDS), Highway Fuel Economy Driving Schedule (HWFET), Supplemental Federal Test Procedure for Aggressive driving style (US06), Supplemental Federal Test Procedure for Air-conditioning Testing (SC03) and Worldwide harmonized Light vehicles Test Cycle (WLTC).

2. State of the art

In 2012, EPA (Environmental Protection Agency, United States) and NHTSA (National Highway Transportation Agency) [4] estimated that 95% of new cars and light trucks in U.S.A. were equipped with mobile air-conditioning systems (MAC).

Air-conditioning system energy consumption depends on many factors. Shete [6] in his study about air-conditioning load on engine defined some factors that can contribute to an increase of energy consumption such as climatic conditions, cabin conditions and the contribution of both to thermal load, compressor speed and the overall efficiency of the A/C system.

The air-conditioning system in a vehicle is considered the most significant in terms of auxiliary loads on engine. In a study about fuel used by air-conditioning systems in U.S. [16] and supported by NREL, Johnson pointed that in U.S., every year, it is consumed by vehicle air-conditioning systems 27 billion litres of gasoline, equivalent to 10 % of U.S. imported crude oil. From the works done so far, it is inconclusive on how much the air-conditioning system affects emissions because that depends on a many factors such as type of vehicle, external and internal load, driver’s profile and many others mention above. In EPA and NHTSA [4], it is discussed that air-conditioning system contributes mainly in two forms of pollution. First, there are leakages in the system which may occur in components such as seals, gaskets, and can increase due to the wear of these components and also in accidents, which can contribute to a major fluid leakage. The second form is related to the extra load that air-conditioning system does on the engine, thus emissions are done by the additional fuel that is consumed when the air-conditioning system is running. So the amount of pollutants is related to the amount of fuel used. Knowing the load that A/C system does on the engine and knowing the engine, the amount of fuel and pollutants can be determined. EPA [4] collected data from 2012 to 2016 and stated that the load of the A/C system on the engine contributed indirectly to 3.9 % of the total greenhouse gas emissions from cars and light trucks in United States of America. In BEV, only leakages contribute to harmful emissions from A/C system in a tank to wheel analysis.

Heat, Ventilation and Air-Conditioning system (HVAC) in electric vehicles is one of the major contributors to reduce vehicle range and increase vehicle consumption. In battery electric vehicles (BEV) the compressor of the air-conditioning system is powered by the high voltage battery which means that it is dependent from battery performance, namely its temperature and SOC. Thus, in electric vehicles the battery undergoes a series of challenges from the need of power to vehicle movement through the electric machine, to power other devices such as the air-conditioning compressor. Every component that it is powered by the battery can impact greatly vehicle performance as well as the battery life time. Also, in electric vehicles, there is no heat generated by the engine to be used for heating, thus power is consumed from the battery by heating coils which has a major impact in power consumption [3]. This impact is greater for lower temperature and can reduce vehicle range by values around 13 %. In Faruque and Vatanparvar's work [3] it is pointed that a Tesla Model S with 60 kWh can have a range loss of 13 % due to the HVAC system at the ambient temperature of -20 ºC, it has the shortest range loss (4 %) at the ambient temperature of 10 ºC and the range loss increases to around 12 % for an ambient temperature close to 45 ºC, which means that in extreme temperatures, HVAC system can have a huge impact.

Faruque [3] also presents a comparison between BEV and internal combustion engine vehicles (ICEV) and states that power consumption of HVAC system can reach 20 % which is more significant than in ICEV where it can be up to 9 %. This factor, together with all electric devices in the vehicle (such has lamps, radio, monitors, gadgets) can lead to an increase of battery stress and then decrease State-of-Health (SoH) and consequently decrease the total range available over time.

3. Methodology

AVL Cruise developed by AVL was selected to simulate a pure electric vehicle (or battery electric vehicle BEV). First the vehicle, based on Nissan Leaf, was set without the air-conditioning module. The implementation parameters are described below and those were validated comparing with INL Document [7], which is for a 2013 Nissan Leaf Vehicle test and supported by U.S. Department of Energy in Vehicle Technologies Program. It was conducted a series of tests in the dynamometer and in track. For calibration of the model, test and validation one run those tests which include driving cycle runs (UDDS, HWFET, US06 and SC06, which belong to EPA Driving tests and described further in this text). And track tests such as acceleration and maximum speed.

After the calibration and validation without A/C, validation took place for A/C integration. One simulated and validated A/C system using a software named KULI, from MAGNA. KULI is an "automotive thermal management software" [8] which has an interface with AVL Cruise and allows the user to set the A/C system in KULI and obtain results in AVL Cruise with the model designed for the vehicle previously.

3.1 Vehicle specifications

The vehicle specifications were based on the Nissan Leaf 2013, which has the characteristics described in table 1. Almost all data was collected from [7], except NEDC range and energy consumption and other data elements which were collected from Nissan Portuguese Website [9].

Table 1 - Nissan Leaf 2013 Specifications

Vehicle Specifications	
Type	Battery Electric Vehicle (BEV)
Class	Midsize Car
EPA Energy Consumption [kWh/100km]	16.8/21.1/18.6 (City/Highway/Combined)

NEDC Energy Consumption [kWh/100km]	15 [9]
EPA Range	135 km (84 mi) [7]
NEDC Range	199 km (120 mi) [9]
Vehicle Maximum Speed	144 km/h [9]
Tire and Wheels	205/55R16 [9]
Electrical Machine [9]	
Type	Permanent Magnet AC Synchronous
Max. Power	80kW (3008 – 10 000 rpm)
Max. Torque	254 Nm (0 - 3008 rpm)
Maximum Speed	10 500 rpm
Transmission [7]	
Type	Automatic Fixed Gear
Final Drive Ratio	7.9
Traction	FWD
Battery [7]	
Type	Lithium-Ion (LiO)
Number of Cell	192
Cell configuration	2 Parallel, 96 Series
Nominal Cell voltage	3.7 V
Nominal System Voltage	364.8 V
Rated Pack capacity	66.2 Ah
Rated pack Energy	24 kWh
Weight of Pack	290 kg
Weights [7]	
Design Curb Weight	1486 kg
Delivered Curb Weight	1498 kg
Dimensions	
Wheelbase	2700 mm [9]
Height	1550 mm [9]
Ground Clearance	160 mm [7]
Aerodynamics	
Cd for 16'' tire	0.29 [9]

3.2 Simulation software

The vehicle model for simulation was implemented in two phases. First it was only used AVL Cruise and it was calculated all data without considering air-conditioning system. In the second phase, an air-conditioning model from Magna's KULI was integrated with AVL Cruise which has an interface that enables the processing of data between the two software and presents the final data in AVL Cruise.

3.2.1 AVL Cruise

AVL Cruise is a software from AVL that allows to perform multiple calculations in terms of consumption, emissions, vehicle performance and components performance and in this case it was used to simulate the consumption and range for driving schedules. The model used is represented in fig. 1 and in black rectangles are the modules added for air-conditioning system integration.

One will present the method used to determine driving resistance using wheels modules. For wheels modules AVL Cruise has incorporated a calculation task which has as inputs tire dimensions, in this case 205/55R16, and calculates static and dynamic rolling radius and respective circumferences. To define rolling resistance, it was used SAE Coastdown method which is a procedure defined by SAE Standard J2263 and consists in the determination of the road load applied to the vehicle while travelling from 115 km/h to 15 km/h with transmission in neutral [10]. In Nissan Leaf, the constants were obtained in the track tests done by INL [11] and then used for dynamometer testing. With the methodology used by AVL Cruise, these constants originated unrealistic results, usually consumption values three times greater. To determine the most accurate values to input, one used the calculation task presented in AVL Cruise named Brake/Coast/Thrust, set the parameters of SAE Standard 2263 [10], with velocity starting at 115 km/h until 15 km/h and as a result AVL calculated the resistance constants A, B and C.

3.2.2 KULI

KULI is a software developed by MAGNA and the main goal is energy management optimization. It can simulate vehicle cooling systems and allows to calculate components temperature, heat losses, power losses, etc. It can predict the influences of vehicle heat exchangers such as engine oil cooler, air-conditioning condenser, transmission air cooler amongst others, which can impact vehicle performance and passenger comfort inside the cabin.

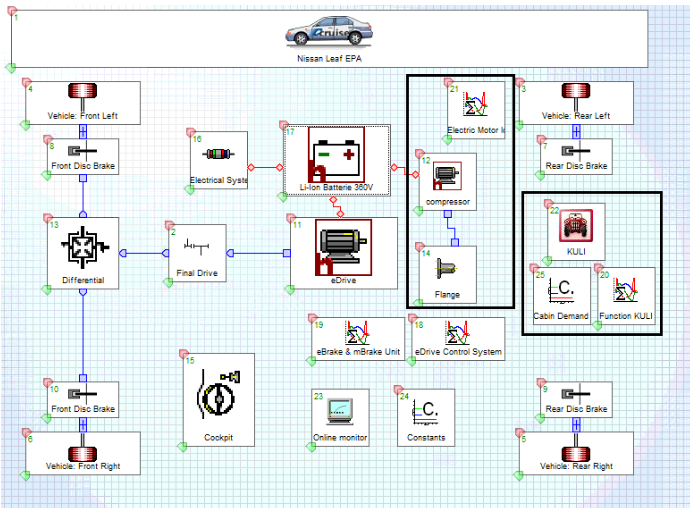

Figure 1- AVL Cruise Model with all components used for KULI interface

In this work the main objective was to incorporate a model of vehicle air-conditioning system and determine how much it influences vehicle range and consumption.

KULI is a very complex software and to run a simulation starting from zero, many parameters are necessary and about Nissan Leaf air-conditioning system there was almost no public data available at the time. To overcome this difficulty, one decided to use a KULI example model which is represented in figure 2 with some modifications.

To simulate the results obtained by INL [9] the first main objective was to set the target temperature to 22.2 ºC (72 ºF) because in the air-conditioning test the conditions were ambient temperature at 35 ºC (95 ºF) with a solar load of 850 W/m^2 and the air-conditioning set to auto at 22.2 ºC (72 ºF).

The air-conditioning model is the green circuit in fig.2 and contains the evaporator, compressor, condenser and expansion valve. Each COM represented in fig. 2 are defined by the user and represent data in KULI that are inputs or outputs. In this models the inputs (data that comes from AVL Cruise) are vehicle speed (8.COM), ambient temperature (9.COM) and compressor Speed (2.COM). For outputs in KULI model there are A/C status on/off (6.COM),

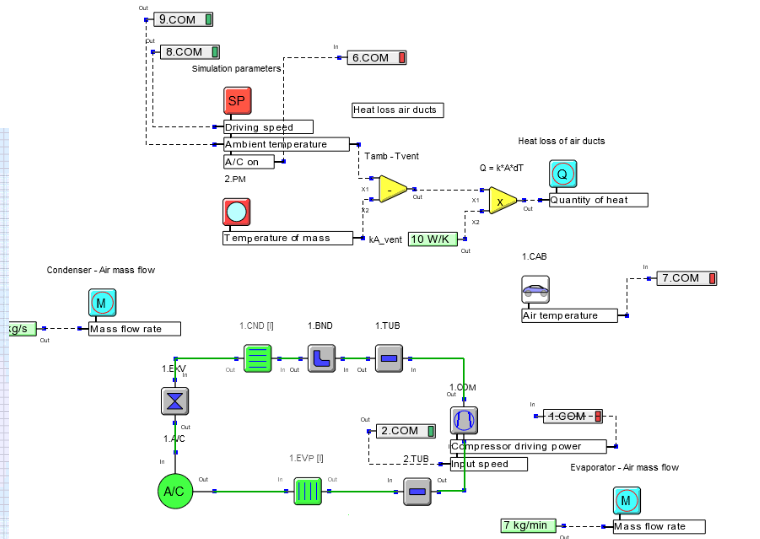

Figure 2 - KULI model used for air-conditioning system and all its components

cabin temperature (7.COM) and compressor driving power (1.COM). For the compressor it was assumed a constant speed of 2000 rpm which is an input from AVL Cruise. KULI then calculates the compressor driving power necessary to lower the temperature which is then sent to AVL Cruise and allows the calculation of torque and consumption in Cruise model.

4. Results and Discussion

4.1 Calibration

In terms of vehicle calibration, it was used vehicle top speed test and vehicle full throttle acceleration test. Performance for full throttle acceleration test is presented in fig. 3. From 0 to 60 mph, the time was 11.58 s. This value is close to the obtained by INL [7] of 10.6 s and it is below their performance goal which was 13.5 s.

Acceleration test allows also to calibrate battery in terms of peak power during full throttle acceleration.

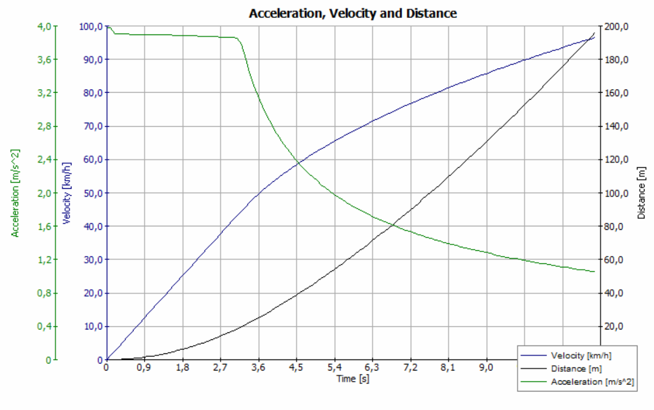

Figure 3 - Acceleration, velocity and distance profile for full throttle acceleration from 0 to 60 mph (0 - 96.6 km/h).

Figure 4 represents the maximum reached output power (as red) and its negative due to a convention used for "work" done by battery current. The peak for battery output power is 89.06 kW and it is close to the peak power from the battery obtained in [7], which was 87.1 kW. There is a 2.2 % difference.

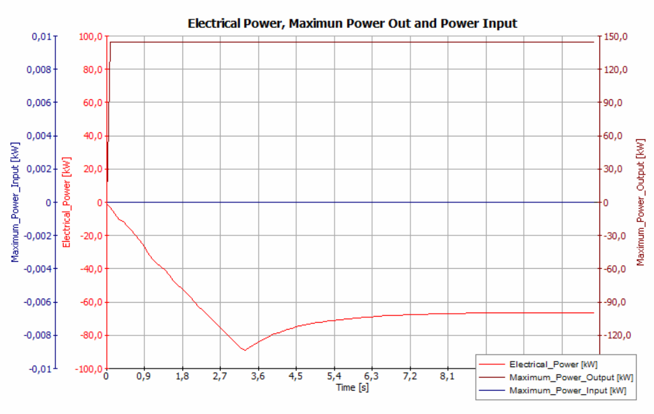

Figure 4 - Electric power output during full throttle acceleration from 0 to 60 mph.

Starting from rest, the maximum speed was reached before 1.61 km (1 mi) mark and was 146.69 km/h which is very close to the result obtained by INL [17] of 146.51 km. The difference is less than 0.2 %. For the speed trap at 402.34 m (1/4 mile) the velocity obtained with AVL was 118.12 km/h with a difference of 5.3 % when comparing with [7] which at a quarter mile mark the velocity was 124.78 km/h.

4.2 Results

4.2.1 U.S. EPA Driving Schedules without A/C

The simulation cycles for EPA Driving Cycles are based in "Chassis Dynamometer Testing Reference Document" [11] which is based in SAE Standard J1634 from October 2012 and uses a Modified Multi Cycle Test

In this work it was used the expanded version of the MCT which includes the US06 cycle and the order is described in [11]. The calculation for driving range was done following the procedure presented and for an ambient temperature of 22.2 ºC (72 ºF).

Table 2 presents the results for each cycle consumption and the SOC initial and final for each cycle run. The cycles were simulated individually in AVL Cruise and the final SOC was set as the initial SOC of the following cycle.

Table 2 - Results for consumption and State of Charge following the Multi Cycle Test.

Driving Cycle	***Consumption [kWh/100 km]***	***Consumption [kWh]***	***Initial SOC [%]***	***Final SOC [%]***
UDDS #1 Cold Start	13.45	1.618	100	93.28
HWFET #1	15.36	2.528	93.28	82.70
UDDS #2 hot start	13.37	1.609	82.70	75.91
US06 #1	19.24	2.486	75.91	65.33
55 mph	17.24	3.569	65.33	50
US06 #2	19.20	2.480	50	39.20
UDDS #3 hot start	13.19	1.586	39.20	32.25
HWFET #2	15.25	2.511	32.25	21.16
UDDS #4 hot start	13.11	1.578	21.16	14.13
55 mph to SOC = 0%	17.23	3.145	14.13	0
Total	-	**23.11**	-	-

4.2.2 U.S. EPA Driving Schedules with A/C

The conditions used in all driving schedules in air-conditioning system simulation were those defined in [23], ambient temperature of 35 ºC (95 ºF), target temperature of 22.2 ºC and a solar radiation of 850 W/m^2.

For these schedules the multi cycle is done after 12h soaking period with the car at temperature conditions described previously. Air-conditioning testing includes in the MCT run, a SC03 test which is done twice and with a 10 minutes interval while the vehicle is exposed to radiant energy. Each simulation will be done individually and some of the final results (Final SOC and Final Cabin Temperature) will be the starting values for the next cycle run. The starting temperature will be 35 ºC in the cabin until it reaches 22.2 ºC (72 ºF). After that, temperature will stay constant with A/C on which means that compressor driving power will be constant. For simulation and to ease processes, compressor speed was assumed constant and equal to 2000 rpm. Values for consumption and range are presented in table 3.

Table 3 - Results for range in city, highway, aggressive and air-conditioning tests.

Cycle	**Consumption [kWh/100km]**	**Range [km]**
City (UDDS)	17.77	130.2
Highway (HWFET)	17.45	132.6
Aggressive (US06)	23.75	97.4
Air-conditioning (SC03)	18.47	125.2

4.3 Validation

The main goal in this sub-chapter is to understand if both models used present close results in terms of vehicle consumption and range in order to compare to the results obtained in the vehicle test by INL [7]. If those results are close enough, one can then compare which influence has the air-conditioning system in the electric vehicle.

For vehicle tests without A/C system, table 4 shows a comparison between consumption calculated results and data from [7]. Tables 5 represents a comparison in ranges.

Table 4 - Consumption comparison between data from INL and results from AVL Cruise.

Driving Schedules	**Consumption [7] [kWh/100km]**	**Consumption AVL Cruise [kWh/100km]**	**Diff (%)**
UDDS (Cold Start)	13.15	13.45	2.2%
UDDS (Hot Start)	12.51	13.22	5.4%
HWFET	14.96	15.31	2.3%
US06	19.98	19.22	(4)%

In terms of consumption, the results are close to those obtained by INL [7]. Nevertheless, in terms of cold start and hot start difference, the values differ only slightly, only two tenths of kWh/100km comparing with six tenths obtained by INL. This fact may seem negligible but there is a reason for this error. During the simulation, one was unsuccessful to simulate the influences of cold start and temperature in battery performance. Even with extreme values for temperature in battery and with battery temperature changing during cycle, none of the options tried (resistance and capacitance constant, temperature dependent or temperature and SOC depend) seemed to sort any effect in consumption. For every run the influences of temperature in battery performance were then neglected, so one should expect for cold start UDDS a value slightly higher for consumption. The temperature influence can also explain the better range obtained for Aggressive US06 where the battery temperature is expected to rise with the acceleration pedal load. The increase in temperature of the battery will decrease its

Table 5 - Results comparison for NISSAN Leaf range between data from INL [7] and AVL Cruise model results.

Range	**Range INL[7] [km]**	**Range Calculated [km]**	**Diff [%]**
City	178.5	174	2.5%
Highway	149.2	150.9	(1.1)%
US06	109.8	120.2	(9.5)%

efficiency, increasing the consumption and then decrease its range.

With air-conditioning system on, the comparison between results calculated with AVL Cruise plus KULI and data from INL [7] are represent in table 6.

The value for UDDS consumption at Cold Start can be explained with the starting cabin temperature and ambient temperature. Comparing with the value without A/C, the consumption is greater due mainly to two factors: first the A/C is on and working at maximum power while trying to remove vehicle heat and bring the temperature down from 35 ºC to 22 ºC and the second one, which was not considered by AVL Cruise as discussed previously, the starting temperature of the battery was at 35 ºC which is above its operating temperature and tend to increase during due to acceleration load. Thus, only the air-conditioning system influences the increase in consumption in the model used and the greater ambient temperature has no effect in this simulation. Accounting for temperature impact on battery performance one should get higher results with the model used.

Table 6 - Consumption comparison between data from INL [7] and results from AVL Cruise with KULI interface.

Driving Schedules	***Consumption [7] [kWh/100km]***	***Consumption AVL Cruise [kWh/100km]***	***Diff (%)***
UDDS (Cold Start)	18.23	17.94	(1.6)%
UDDS (Hot Start)	17.05	17.71	3.9 %
HWFET	16.90	17.45	3.3 %
US06	22.35	23.75	6.3 %
SC03	17.97	18.47	2.8%

At last, table 7 shows a comparison between range results calculated for EPA driving schedules with and without A/C.

From table 7, it's clear that the main impact of the air-conditioning system is in the urban cycle, UDDS. Although the range without A/C is calculated at ambient temperature of 22.2 ºC and the range for air-conditioning system was calculated for moderately extreme conditions with 35 ºC with solar radiation, the results presented suggest that the air-conditioning system can impact from 12% to 25% in extreme conditions.

Table 7 - Comparison between range values for simulations with and without A/C for EPA driving schedules simulated.

Driving Schedule	***Range without A/C [km]***	***Range with A/C [km]***	***Difference [%]***
UDDS	174	130.2	25.2
HWFET	150.9	132.6	12.4
US06	120.2	97.4	19
SC03	-	125.2	-

4.4 Other Simulation

4.4.1 New European Driving Cycle (NEDC)

Without air-conditioning system

For NEDC, the calculation was done using SOC target to 0 %, this means that NEDC was continuously run until there was no more battery charge for another cycle. The total range is the total energy consumed doing all repetition cycles dividing by the distance travelled plus an extrapolation for the percentage of SOC left. The final value of SOC is 6.33 % after 13 complete NEDC runs. Consumption in average was 15.19 kWh/100km.

With air-conditioning system

The simulation method quasi stationary 2 (necessary for KULI interface) does not allow a simulation with SOC target which was done previously on the simulation of NEDC without air-conditioning system. The consumption calculated was 19.86 kWh/100km. To calculate the total range, an extrapolation was made using the final SOC of 90.9 .% for a single cycle. Using the distance of 11.013 km for a single NEDC one gets a value for range of approximately 121 km (which is not true and with this simulation one got less consumption values when SOC tend to 0, though is an approximation by excess).

4.4.2 World harmonized Light vehicle Test Cycle (WLTC)

Without air-conditioning system

The velocity profile from AVL Cruise of WLTC is represented in fig. 5. For this single cycle run the consumption was 16.39 kWh/100km. For calculation of vehicle range, one performed a calculation task in AVL Cruise using a SOC target of 0 % starting at 100 %, determined the travelled distance and extrapolated for the percentage of SOC left. The calculation stops when the SOC is not able to run a complete WLTC. The battery results for a single WLTC run are represented in fig. 6.

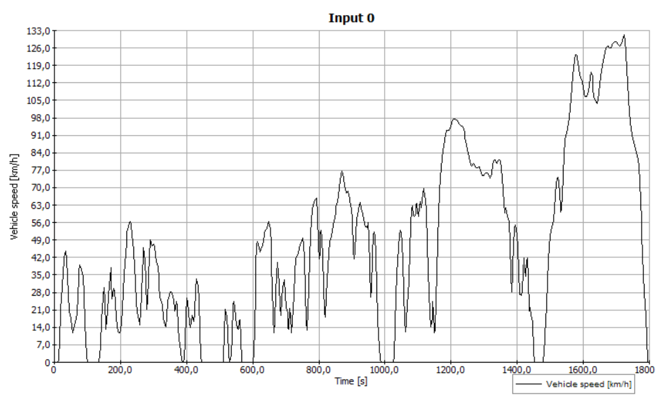

Figure 5 - Velocity profile of a World harmonized Light vehicle Test Cycle (WLTC).

With air-conditioning system

During a single simulation of the cycle with air-conditioning system, the total consumption was 4.692 kWh with a travelled distance of 23.26 km which

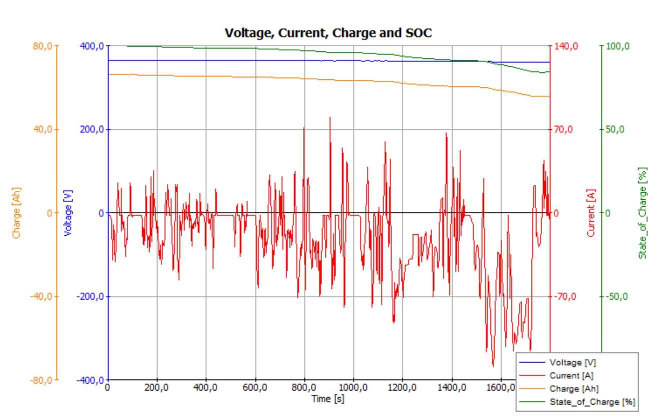

Figure 6 -High voltage battery results for a single WLTC.

represents a mean consumption value of 20.17 kWh/100 km. For the same reasons explained in 4.4.1 with A/C, it was extrapolated the range value using a single cycle simulation. For the initial SOC of 100 % and the final SOC of 80.4 %, the total range calculated was 118.7 km.

A final comparison between vehicle range with and without air-conditioning system for all driving schedules simulated is presented in table 8. There is a decrease in vehicle range for all driving schedules (as expected) and those increases are higher in driving schedules that try to replicate urban conditions such as UDDS, part of NEDC and part of WLTC. UDDS is the driving schedule with the biggest impact of air-conditioning system which can decrease the range in 25 %. In a global way, air-conditioning system can decrease the range of the electric vehicle in 12 to 25 %.

Table 8 - Results for range for all driving schedules simulated.

Driving Schedule	***Range without A/C [km]***	***Range with A/C [km]***	***Difference [%]***
NEDC	152	121	20.4
UDDS	174	130.2	25.2
HWFET	150.9	132.6	12.4
US06	120.2	97.4	19
SC03	-	125.2	-
WLTC	142	118.7	16.4

Conclusion

In this work it was study the influence of air-conditioning in electric vehicles consumption and range for New European Driving Cycle (NEDC), Environmental Protection Agency of United States (EPA) Driving Schedules and for the new World harmonized Light vehicle driving Schedule (WLTP).

The definition of the model was initially done with AVL Cruise software which is a very good tool to modulate the vehicle and results were obtained in terms of consumption and range. Starting with the definition of the vehicle based in Nissan Leaf 2013 and tried to replicate the results obtained experimentally in NEDC by Nissan itself and the results obtained by INL and ANL in track and dynamometer results. The first results obtained in terms of coasting test, acceleration maximum speed and some cycle runs were used to calibrate the model and one got close results.

For NEDC the consumption simulated in AVL Cruise is 0.19 kWh /100 km greater than the value announced by Nissan. In terms of maximum speed, acceleration and peak power from the battery the results are close to the measured by INL. In EPA driving schedules the results for consumption were also close with 5.4% increase for UDDS, 2.3 % increase for HWFET and a decrease of 4 % for US06. For range one got a decrease of 2.5 % in UDDS and increases of 1.1% in HWFET and 9.5 % in US06.

In order to simulate air-conditioning system, one had to find other software because it is not possible with AVL Cruise alone. KULI developed by MAGNA was the software chosen due to its already implemented interface in AVL Cruise. KULI is a very complex and complete software which allows to change many parameters from geometry of the components to almost every design parameter. With the model developed, the consumption results obtained with air-conditioning system were slightly higher, in the same line as before, than the results published (3.9 % for UDDS, 3.3 % for HWFET, 6.3 % for US06 and 2.8 % for SC03).

At last, comparing results obtained during the simulation with and without A/C for all driving schedules and although the range without A/C is calculated at ambient temperature of 22.2 ºC and the range for air-conditioning system was calculated for moderately extreme conditions with 35 ºC with solar radiation, the results presented suggest that the air-conditioning system can impact from 12 % to 25 % in extreme conditions.

Future Work

With the new normative arriving and the need to pass WLTP test to homologate light vehicles in European Union an intense effort need to be made by manufacturers in their vehicles. The development of electric vehicles need to respect normatives and it should account all types of driving conditions and styles across all member states.

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