Technical Report

Determining the Powertrain Performance of Electrified Vehicles

Documenting work of the EVE IWG on developing an amendment to gtr No. 15 to establish a procedure for determining the powertrain performance of electrified vehicles

Preliminary Working Draft

June 5, 2017

Table of Contents

1. Introduction

Part B of the second EVE mandate includes a subtask to develop an amendment to gtr No. 15 to establish a procedure for determining the powertrain performance of electrified vehicles. This document is a draft technical report outlining the background of EVE work on the power determination subtask.

This first draft version focuses primarily on procedural history of EVE IWG work on this subtask, the options that were considered, the technical rationale and justification for the option that is currently being pursued, and the remaining technical issues that need to be resolved in order to complete a gtr for power determination.

2. EVE Work on Power Determination

NOTE: Much of the text in this section is adapted from "Status report of Part A of the November 2014 mandate for the Electric Vehicles and the Environment Informal Working Group (EVE IWG)," presented at EVE-21.

2.1 WLTP Context

The WLTP test procedure requires information about the vehicle engine power rating to achieve certain purposes related to performing the test procedure. These purposes include:

a) Classification of electrified vehicles into distinct Power-to-Mass ratio classes, based on the powertrain power rating; and

b) Application of the so-called "downscaling method" that enables the test reference cycles to be adapted for low powered vehicles, also based on the powertrain power rating.

Appendix A contains additional background information on classification and downscaling as described in gtr No. 15 (WLTP).

For purposes of rating the motive power of light vehicles, the UNECE currently provides a regulation under the 1958 Agreement that can be used for approval of internal combustion engines (ICE) and pure electric drivetrains for M and N category vehicles. It focuses on the determination of engine power values and in many cases is sufficient to achieve the above purposes.

However, the technical description part of the regulation merely provides for the individual determination of the power of either an ICE or an electric motor. For vehicles with more than one power source, such as an engine and an electric motor that combine to provide a total combined system power, the regulation does not establish a method to determine this total power. The simple addition of individual power results from engine and electric motor is insufficient and can lead to incorrect estimations of the power performance of the vehicle. For example, in many cases (likely the majority), it is the propulsion battery system (also referred to as rechargeable electric energy storage system or REESS) and not the electric motor that limits and therefore determines the power of an electric powertrain. The specific way in which the control system combines the power of an engine and an electric motor (or multiple electric motors) under peak power demand can also affect the validity of simple addition. The situation may become worse in the future because more and more sophisticated hybrid vehicle concepts with distributed power sources are likely to gain market maturity (e.g. electrified vehicles with rim motor concepts, and all-wheel-drive configuration with separate drive motors powering each axle).

2.2 Current Motivation

Currently, a clear demand for an improved power determination procedure comes from the members of the WLTP IWG. The subgroup “Electrified Vehicles” is in need of a total system power specification for the purposes of classification and downscaling.

System power ratings are also useful for other purposes. Among others, it may serve as customer technical information, may be used by regulators (as basis for taxation programs) or by insurance providers (as a classifier for determining premiums).

2.3 Procedural Structure and Goals

Given the above described situation and according to its mandate under the UNECE, the EVE IWG established a subgroup “Determining power of EVs.” The goal was to clarify how an improved technical procedure for the determination of the system power of sophisticated powertrains, such as hybrid electric vehicles with multiple power sources, or pure electric vehicles with more than one electric motor, could be realized in an efficient and simple way.

The scope of the work covered light duty vehicles (passenger cars -M1 and light duty vehicles -N1) and aimed to develop a recommendation or regulation for determination of the performance criterion “system power.” It was agreed that the procedure shall cover all types of HEV (ordinary –NOVC-HEVs and plug-in –OVC HEVs), including the following configurations: Series HEV, Parallel HEV, and Power split HEV. The procedure shall also cover PEVs with one or more than one electric motor for propulsion (e.g. rim motor concepts, or all-wheel drive configurations served by multiple drive motors).

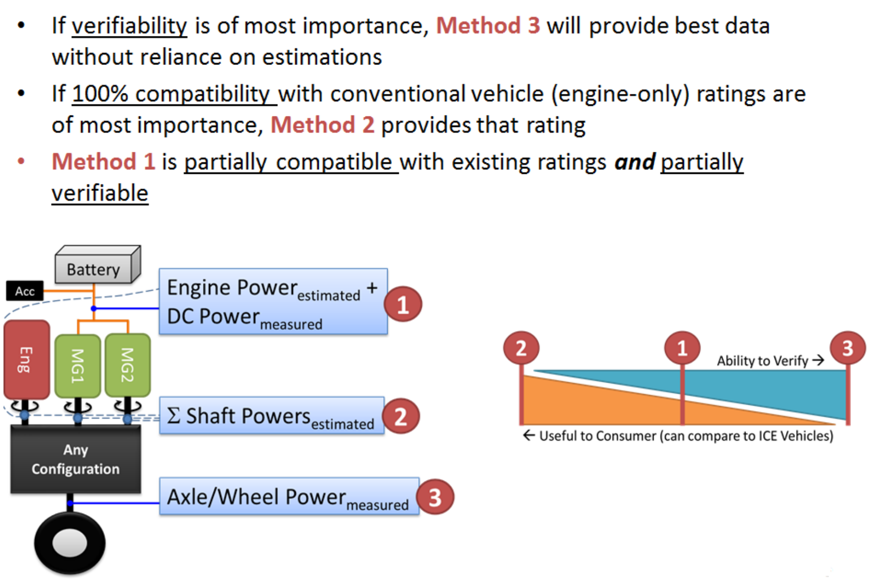
The system power rating, as a measure of vehicle performance, is intended to be comparable to the measure commonly used for conventional vehicles, i.e. the rated power of an ICE. This means that previously identified options to determine the system power by stating the delivered power at the wheels will not be further pursued.

When completed, the regulation shall be integrated into GTR No. 15 (WLTP).

2.4 Activities with Similar Focus

The EVE IWG recognized that activities with similar focus are currently also being pursued by several standardization organizations. The EVE IWG was therefore able to consider several possible paths forward for which considerable research had already occurred. The Society of Automotive Engineers (SAE), the Korea Automobile Testing & Research Institute (KATRI), and the International Organization for Standardization (ISO) had all begun considering how the power of an electric or hybrid vehicle could be best measured. The EVE IWG received presentations from experts with these organizations and discussed the merits and drawbacks of some of the methods proposed by each.

While variation can exist, the EVE IWG agreed with the findings of various other bodies that there are three primary methods in which maximum vehicle power could be reasonably measured. Below is a slide from SAE which illustrates these, and the relative merits of each option. These are referred to as Method 1, Method 2, and Method 3.



These methods can be contrasted in terms of how well the measure can be compared to traditional power determination for ICEs, and in terms of the ability to verify a reported value. Method 2 estimates power at the output shaft of each component, and so is most comparable to ICE power; however, it is difficult to verify without sophisticated instrumentation. Method 3 is highly verifiable through dynamometer testing, but measures only power at the wheels, which is not comparable to ICE output power. Method 1 estimates engine power by an applicable standard, and adds this power to measured DC power from the battery. It is reasonably comparable to ICE power and reasonably verifiable.

The following gives a short overview of relevant worldwide projects dealing with the development of a standard for system power determination, in the U.S. (SAE-standard, ANL), Japan (ISO-standard, JARI) and Korea (KATRI).

2.4.1 SAE J2908 Task Force

The SAE J2908 Task Force led by Argonne National Laboratory (ANL) started a project in November 2014. The project was initially scheduled to be finalized towards end of 2015. Draft documentation related to the test procedure is currently available. Three primary methods of determining HEV system power emerged from the research (Method 1, Method 2, and Method 3 as depicted above). Considering these methods, the so-called “Method 1” found the broadest acceptance during discussions among EVE members, since it showed to be quite similar to or the same as KATRI and ISO methodologies (described below).

The nominal rating method ("Method 1") is based on determination of individual power at the component level (internal combustion engine, and battery power) and can therefore be considered as similar to current engine power ratings. ANL has investigated different test types (e.g. running a test vehicle at several fixed speeds vs. running a test vehicle with a speed sweep or ramp) in order to determine the maximum system power a vehicle can deliver.

Under Method 1, the definition of the hybrid system power follows a simple addition of the rated engine power and the electric power of the battery (Hybrid system power = Engine power + Electric power). The engine power is the rated power by SAE J1349. Electric power is a measured electric assist on the dynamometer.

By contrast, so-called "Method 3" is based upon hub dyno or chassis dyno measurements and provides accurate determination of axle or wheel power. It is a sophisticated test, leading to highly verifiable results, e.g. for engineers to communicate power levels. However, because it measures power at the wheels rather than at the component level, the EVE IWG considers it not to be directly comparable to current measures of ICE power. Similarly, Method 2 was not selected in part because it would be difficult to verify due to the need for complex and invasive instrumentation.

2.4.2 Korea Automobile Testing & Research Institute (KATRI)

KATRI started its research project in July 2013 with the aim of developing a national standard for the determination of a representative power for (N)OVC-HEVs and EVs with in-wheel motors. It is intended for use in the national vehicle classification. It was finalized in June 2015 and the result will be harmonized with the research result on determining power of EVs in EVE IWG. Nominal rating and system power tests were studied using a powertrain dyno or a chassis dyno with added instrumentation.

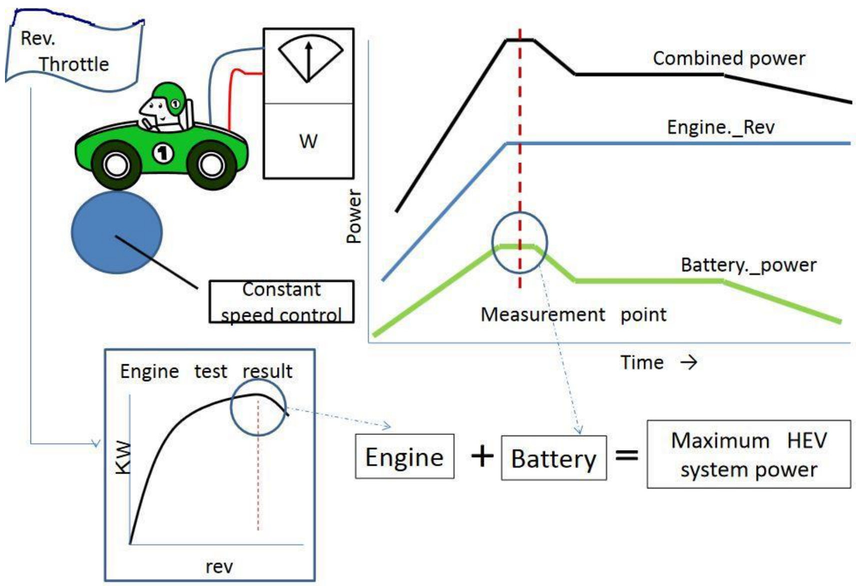
The definition of the hybrid system power follows the same approach as the SAE procedure, namely that it involves a simple addition of the rated engine power and the electric power of the battery (Hybrid system power = Engine power + Electric power). The engine power is the rated power according UN-R85. The electric power is the measured power of the electric on board power source of the vehicle determined during chassis dyno testing.

Aside from this procedure and similar to the SAE methodology, a somewhat more sophisticated system power test provides not only accurate measurement of wheel or axle power but also useful information of system torque.

2.4.3 International Organization for Standardization (ISO)

New Work Item Proposal (NWIP) N3477 proposed by the Japan Automobile Research Institute (JARI) was approved in June 2015. It started as a formal project of ISO/TC22/SC37/WG02. This ISO methodology also includes the definition of the hybrid system power as the arithmetic sum of engine power and battery power, as shown in previous cases

(Hybrid system power = Engine power + Battery power). It is necessary to measure the battery output under the HEV system control. The engine power is the rated power determined by ISO 1585. The battery output should be measured when the hybrid system as a whole delivers maximum power on a chassis dyno. The exact point of maximum system power is determined by carrying out a series of test runs while driving the vehicle at different but constant speeds to find the maximum brake power of the chassis dyno that the vehicle is able to run against. The evaluation results in a power-versus-speed curve that shows a point of maximum power at a certain speed as shown in the following image.



3. Proposed Work and Technical Justification

3.1 Work Plan

At EVE 21, a draft workplan was presented for proceeding with a GTR on power determination, laid out as follows:

I. Consideration of the concepts:

Reference Method – Chassis Dyno

Candidate Method – Component Testing and calculation

II. Consideration of Remaining Technical Considerations

Load Collectives and Maximum Power

Reference Method => Chassis Dyno Testing with completed vehicle

Candidate Method => Component Testing and calculation to determine SP

Customer Information and other information with added value

III. Determination of work plan with task list and allocation of workload

IV. Proof of concepts: Studies with different types of HEVs including series HEV, REX and PEVs (with one or more electric motors)

V. Testing, refinement / improvement and validation of the method(s)

VI. Drafting of the regulation

VII. Proposal for a draft amendment to GTR No. 15

VIII. Approval at GRPE, voting at WP.29 AC.3

3.2 Progress on Work Plan

At EVE-22, the EVE members agreed that the ISO method presented the best option as a basis for development of a test procedure by the EVE IWG. This method is very similar to the SAE's "Method 1" mentioned previously. It shows good verifiability, and as a measure of vehicle performance it is comparable to ICE rated power, which makes comparisons between ICE ratings from conventional vehicles and maximum HEV system power ratings relatively straightforward. However, validation of the ability of the method to effectively serve the purposes of WLTP as envisioned will be necessary.

It was also discussed whether the ISO method should either be incorporated by reference (as of a certain date), or should it be incorporated as text. At the time of this writing, the current draft of the ISO method has not been provided to EVE and so cannot be referred to or reviewed for this version of the draft technical report. The ISO method is expected to be published in the November 2017 time frame.

The ISO method includes two variations (referred to informally as the German method and the Japan method). There was some debate as to whether the GTR should select a single method, or provide a choice between the two variations. It was generally decided that having two methods would be acceptable (as long as the results are the same given the correct inputs), because it provides the opportunity to choose the method that best fits the data or equipment that are available, or the powertrain architecture being tested.

While the methods are believed at this time to deliver equivalent results, this remains to be investigated in more detail. It could be said that both methods include some uncertainty in that both methods call for certain information to be estimated or assumed. The German method relies on an estimated gear efficiency, while the Japan method requires an assumed electrical component efficiency.

It was also recognized that the state of charge (SOC) of the REESS could affect measured power. After technical discussions with experts from the WLTP –IWG Subgroup EV, the members of the EVE IWG agreed on the concept to determine the maximum HEV system power with REESS fully charged.

Another step to be taken is the validation of ISO test results, after review of the selected method(s). Several contracting parties volunteered to assist with such testing, including ECCC (Canada), Joint Research Centre (JRC), EPA, and possibly NTSEL.

At EVE 22, the co-chair from Japan requested that EVE leadership take on the task of drafting the GTR, with initial priority placed on the reference method over the candidate method.

Accordingly, a drafting group has been formed to begin writing the technical report that would support the gtr (i.e., this document), and the introductory content of the gtr itself. The drafting group begins its work with this document, which is made available for discussion at EVE 23.

It was also suggested that at some point in the near future, a parallel effort should also be undertaken to further develop the candidate method by means of testing at laboratories of the contracting parties, but at this time this is considered a secondary goal.

3.3 Technical Considerations / Topics for Validation and Study

3.3.1 General Validation

It is intended that the selected method should allow all HEV configurations (series, parallel, power split) to be reasonably assessed. As has been shown by an ANL study, SAE “Method 1” can result in an over estimation of system power in certain series hybrid systems. EVE members agreed that further research work would be necessary and seems appropriate to fully assess and incorporate appropriate aspects of the ISO method. It was noted that care should be taken to ensure that the procedure covers the purpose adequately and does not give rise to unusual situations. For example, for a REX PHEV where the ICE power is less than the electric machine power, it might be possible to “cherry pick” among the two variations of the ISO method to deliver a result that would assign a longer all-electric range than under the other variation.

3.3.2 Consideration of CS and CD Modes

There was some discussion of whether power values should be determined separately for CD and CS modes of a OVC-HEV to avoid “cherry-picking”. For example, the BMW i3 has a greater combined power in CD mode, while the Volt has a greater power in CS mode. This could potentially lead to selection of the lower power value (CD vs CS) for downscaling, in order to deliver a longer range by establishing a less demanding cycle than the other value would dictate.

3.3.3 Establishment of Input and Output data

EVE IWG members agreed that all necessary input data needed for a robust power determination procedure must be specified. The same holds true for the list of output data resulting from use of the procedure. Examples of each category are given below. The list is currently not finalized and represents a next task of the technical work program.

Examples of input data include: road load values (parameters of the road load polynomial F1, F2, F3), vehicle weight, engine power map, etc.

Examples of output data include: system power, vehicle speed, engine / motor speed, REESS-data (voltage, current, power), etc.

3.3.4 Load Collectives and Maximum Power

This concerns definition of an appropriate load pattern (fixed speed, speed ramp, etc.) to find the point at which the vehicle delivers maximum system power.

ISO provides a series of fixed vehicle speeds to test and identify maximum system power. However, a detailed method of dividing and specifying vehicle speed intervals has not been set. In some cases, the manufacturer's recommendation seems to be needed. For the unambiguous determination of maximum system power, a maximum power curve is needed that is based on a filtered raw data curve applying a 1s moving average filter.

SAE J2908 TF uses a full power sweep or a segment sweep to find the vehicle speed at which the maximum system power is delivered. For the unambiguous determination of maximum system power, a 1s to 5s window filter is considered to overcome transient spikes or signal noise.

There was also some uncertainty about the length of the time window for the filter. Under the ISO proposal, two power duration options exist. Japan proposes a peak power result from a 2-second window moving average. Germany proposes a peak result from a 2-second window at the end of a 10-second maximum power period (that is, a 2-second average from t=8 to 10 seconds).

3.3.5 Reference Method

The gtr is ultimately expected to outline two methods: the Reference Method and the Candidate Method. The reference method refers to chassis dyno testing with a completed vehicle. The candidate method refers to a method by which component testing and calculation can be used to determine system power in lieu of dyno testing.

Validating the reference method should involve close cooperation between the expert groups from the respective standardization organizations SAE, ISO and the KATRI, as they are the leading experts concerning the determination of the system power by means of chassis or hub dyno methods. These organizations and/or national labs will likely provide the necessary test capabilities. Test burden collectives must be defined in detail in order to get meaningful maximum system power ratings. Additionally, since this item is closely related to demands coming from the WLTP (GTR No.15), it is indispensable and expected that experts from WLTP Subgroup EV will support the work.

3.3.6 Candidate Method

The desire to develop a candidate method reflects manufacturer interest to have a certified procedure that is based on a combination of component testing (partly after UN-R85, partly pursuant battery specification practice) and calculation. This could reduce the financial burden of testing and improve process flexibility during type approval. The candidate method, however, must be carefully validated against the SAE / ISO /KATRI standards before it could be endorsed as an alternative method.

3.3.7 Use as Customer Information for Fair Comparison

Members expressed interest in seeing that the power rating delivered by the procedure is useful for fair comparison between battery-like HEVs and PEVs (as well as between electrified vehicles and conventional vehicles).

For examples, in some cases, a PEV and a REX may have the same electric powertrain, but each vehicle (PEV and REX) might give different results if tested by a different test method chosen to get maximum power. This may lead to confusion and misunderstandings for customers for purchasing vehicles. For instance, if a PEV has its maximum power determined by UN-R85 and the REX – considered a series HEV – were tested by the system power method applying the power of REESS, the results might appear different.

3.3.8 Peak Power or Power Curve

There was some debate as to whether the procedure should identify a single peak power rating, or a range of powers (perhaps a power curve). While a single peak power should satisfy the needs of WLTP, in some cases a power curve may be more useful.

3.3.9 Repeatability

There continues to be uncertainty as to whether a single test is adequate to determine a peak power rating, or if several tests are required for a more robust result. This is likely to be one of the topics of the testing program.

Also, neither the ISO nor the SAE J2908 procedures provide guidance for accounting for vehicle power derating after repeated maximum power runs.

3.3.10 Warm Up State for PHEVs (ISO procedure)

For the ISO proposal, maximum battery power is anticipated to occur at maximum SOC. However, it may be difficult to achieve maximum SOC under test conditions. For PHEVs in CD mode, it remains unclear how to achieve a thermally warm state while simultaneously the vehicle remains at maximum SOC state. That is, a PHEV cannot normally be both warmed up and fully charged; some discharge must occur during warmup. Similarly, for HEVs, achieving full SOC probably must be done by performing artificial regeneration via the dynamometer. These issues will need to be studied and accounted for.

Appendix A: Classification and Downscaling under WLTP

A.1 Vehicle classification in WLTP

The WLTP vehicle classification is based on the ratio between **rated power** and **curb mass** (pmr). Based on an analysis of the dynamics of in-use data, the following classification was agreed during an early period of WLTP development:

Class 1: pmr ≤ 22 kW/tonne

Class 2: 22 kW/t < pmr ≤ 34 kW/tonne

Class 3: pmr > 34 kW/tonne

For (N)OVC-HEV a system power value is needed, which would be equivalent to the rated power for an ICE. For PEV it was already decided to use the peak power of the electric machine for the pmr determination (=> e.g. UN-R85). Nevertheless, this decision was made as a preliminary "worst case solution," and further discussion of this has been included in the work of the EVE System Power task force, to consider whether there is a more appropriate solution.

According to WLTP, currently, electrified vehicles (OVC-HEV, NOVC-HEV, and PEV) are to be tested as Class 3 vehicles. As described in Annex 8, "All OVC-HEVs, NOVC-HEVs, PEVs and NOVC-FCHVs shall be classified as Class 3 vehicles. The applicable test cycle for the Type 1 test procedure shall be determined according to paragraph 1.4.2. of this annex based on the corresponding reference test cycle as described in paragraph 1.4.1. of this annex."

A.2 Downscaling in WLTP

In drivability studies some vehicles near the border line of the classifications were unable to follow the prescribed speed trace. For the particular cycle sections where the drivability problems occur, a so-called downscaling procedure takes effect. The speed trace is lowered by a factor based on the ratio between the maximum required power of the cycle phases where the downscaling has to be applied and the rated power of the vehicle.

Paragraph 8 of Annex 1 describes downscaling in detail. The cycle to be driven shall depend on the test vehicle's rated power to mass in running order ratio, W/kg, and its maximum velocity, v_max, km/h. [...] Drivability problems may occur for vehicles with power to mass ratios close to the borderlines between Class 1 and Class 2, Class 2 and Class 3 vehicles, or very low powered vehicles in Class 1. [...] Since these problems are related mainly to cycle phases with a combination of high vehicle speed and high accelerations rather than to the maximum speed of the cycle, the downscaling procedure shall be applied to improve drivability.

NOTE: Also in this case for (N)OVC-HEV, a system power value is needed, which would correlate equally well with the maximum cycle power and the rated power for an ICE. This equivalent system power is, however, not necessarily the same for vehicle classification, because the acceleration behavior at low speeds is more important for vehicle classification.