STATUS OF STANDARDIZATION FOR ELECTRIC AND HYBRID VEHICLES AND ITS IMPACT ON DUAL-USE APPLICATIONS

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1 The "dual use" approach

The end of the Cold War caused a considerable change in the global strategic situation. Furthermore, many countries have dramatically cut down their defence budget. In this framework, a new approach to military research, development and acquisition has been devised: whileas many solutions have spun off from military research towards civilian applications (e.g. the Internet or the global positioning system GPS), the military are now more actively looking to the commercial market and are striving to adopt commercial off-the-shelf technology (COTS) where appropriate, particularly when considering "dual-use" technologies, which are defined as "technologies that have both a military utility and sufficient commercial potential to support a viable industry base"[1].
The interaction between military and civilian application fields is the underlying premise of this "dual-use" approach, which is deemed beneficial for all parties involved:

- ☞ The forces can make substantial savings in acquisition and logistical costs through the use of commercial products and the adoption of commercially developed technology rather than designing specific technology for military use.
- ☞ The civilian sector, through incorporating defence considerations into commercial designs, can get a leverage of R&D funding, allowing a more efficient development and deployment of new technologies for all applications.

The electrically driven vehicle is considered a typical application field of "dual-use" technology. Its benefits for military applications are obvious, as stated below; most R&D efforts in electric vehicle technology however have up to now been performed in the civilian sector. Further development to consider electric vehicles for military applications can give a considerable thrust to the development of the technology, compensating the economical drawback that electric vehicles unfortunately continue to suffer on the market compared with ICE vehicles.

The electric combat vehicle represents the best available technology for our armed forces and thus contributes to our overall security. Through the "dual-use" approach, its development can also be a factor towards the deployment of electric vehicle technology in the civilian market and bring benefits to society as a whole. It should therefore be considered a highly commendable activity.

2 The electrically driven military vehicle

The potential of electric propulsion for defence applications has gained considerable interest during the past few years.
Design considerations of military vehicles are based on a number of fundamental requirements: mobility, lethality and survivability. Electrically driven vehicles do present several tactical and technological benefits, the most tangible of which can be summarized as follows[2]:

- ☞ Fuel economy: in a (series) hybrid vehicle configuration, the engine operation can be optimised for efficient constant-power output, resulting in significant savings of fuel (and thus a reduction in required fuel transportation capacity, which is a main advantage for forward-deployed theatre operations), and reduced exhaust emissions and thermal signature.
- ☞ Power availability: the availability of both a generator set and a storage battery can meet the demand of all electric power users in the vehicle. This is very interesting due to the increasing demand of electric power for on-board systems. Power supply can be continuous, to provide hotel load in the order of 30 to 50 kW, or can be pulsed power in the gigawatt range to supply electric weapons such as electric guns or directed energy weapons. Furthermore, the availability of on-board electric supply directly reduces the logistical burden of the fleet by eliminating the towed generators necessary to provide electric power to the field.
- ☞ Silent watch and silent mobility: the energy storage can be sized to meet silent watch requirements for extended periods of time for various missions such as surveillance and reconnaissance. Silent mobility over a limited distance is also achievable where the vehicle can move in or out a hostile territory without being detected.
- ☞ Flexibility: the hybrid electric drives have a modular structure, giving the vehicle designers freedom of design. Components can be arranged and integrated in the vehicle for the optimum utilization of the available space.
- ☞ Enhanced prognostics and diagnostics, through monitoring systems reducing the operation and maintenance costs over the life of the vehicle and thus to help offset the acquisition cost which at the current level of maturity exceeds that of the conventional systems.

These advantages have prompted several nations to consider the “All Electric Combat Vehicle” (AECV); within the NATO, this issue is dealt with by the Applied Vehicle Technology Panel AVT-047, of which the author is a member.

A schematic view of an AECV can be seen in Figure 1.
A long-term scientific study performed by the NATO Research and Technology Organization[3] stated that the introduction of electrical technologies in military vehicles was “unavoidable”, and that in the long term “electric drives will provide better operational performances with potential savings in life cycle costs”.

Electrically driven military vehicles are being developed in several countries; examples include wheeled vehicles such as the US HMMWV (High Mobility Multipurpose Wheeled Vehicle), and the UK HERO (Hybrid Electric Realised Off-Road) based on the Land Rover.

Tracked vehicles have also been fitted with electric drives, such as the “Wiesel”, a German light airtransportable armoured vehicle, and a hybrid electric version of the popular M113 APC developed in the US.

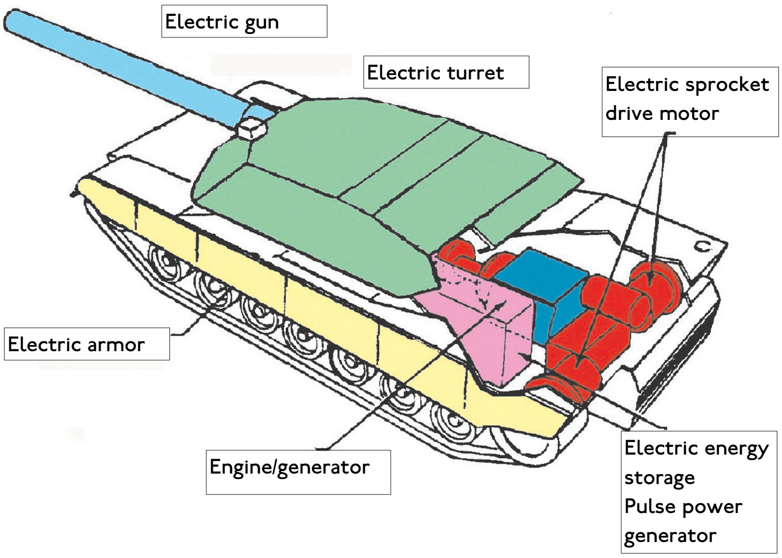

Figure 1 Schematic view of an AECV[4]

3 Standardization and the military

3.1 NATO military standardization

As the world’s largest security and defence alliance, NATO strongly relies on standardization as a means to increase the effectiveness of the military forces of the Alliance. Within NATO, standardization is defined as:

> “the process of developing concepts, doctrines, procedures and designs to achieve and maintain the most effective level of standardization in the fields of operations, administration and materiel.”[5]

NATO standardization is a broad process which may be applied to any NATO activity. NATO standards are generally classified into one of three groups:[6]

- Operational standards, which affect military practice, procedures or formats. Examples are concepts, doctrine, tactics, techniques, training, reports, maps and charts.
- Materiel[7] standards, which affect the characteristics of materiel, including complete systems, subsystems, assemblies, components, spare parts and consumables.
- Administrative standards, primarily concerning terminology, as well as non-military related administration aspects.

Four levels of standardization can be discerned, in ascending order:[8]

- Compatibility: “the capability of two or more items or components of equipment or materiel to exist or function in the same system or environment without mutual interference”.

- Interoperability: “the ability of systems, units or forces to provide services to, and accept services from, other systems, units or forces and to use the services so exchanged to enable them to operate effectively together”.
- Interchangeability: “a condition which exists when two or more items possess such functional and physical characteristics as to be equivalent in performance and durability, and are capable of being exchanged one for the other without alteration of the items themselves, or of adjoining items, except for adjustments, and without selection for fit and performance”.
- Commonality: “the state achieved when groups of individuals, organizations or nations use common doctrines, procedures or equipment”.

Within NATO, standardization matters are treated by the NATO Standardization Organization (NSO), which comprises the NATO Committee for Standardization (NCS), the NATO Standardization Staff Group (NSSG), and the NATO Standardization Agency (NSA).[9]

Standardization documents issued by NATO are mostly under the form of Standardization Agreements (STANAGS). A STANAG is defined as:

> “The record of an agreement among several or all the member nations to adopt like or similar military equipment, ammunition, supplies and stores; and operational, logistic or administrative procedures. National acceptance of a NATO Allied Publication issued by the Military Agency for Standardization may be recorded as a Standardization Agreement.”[10]

STANAGS have no authority in the individual countries, unless implemented by reference or by the publication of an appropriate national document.[11] Nations ratify and implement STANAGS on a voluntary basis.
Another type of NATO standards are Allied Publications (AP), documents which all or some NATO nations agree to use as a common implementing document.

NATO will make maximum use of existing standards: STANAGS will only be developed when the respective requirements are not covered by recognized civilian or already existing military standards; adoption of existing standards needs to be reflected in STANAGS.[12]

Military standards are also issued by individual nations; the following paragraphs will cite the US and the UK as example.

3.2 US military standardization

The tendency of the armed forces towards standardization has nowhere been more clearly expressed than in the United States: of the 93000 American standards which are now active, not less than 34000 are issued by the Department of Defense, which is thus by far the largest standards developer in the United States. Only about 8000 of these standards define strictly military commodities and practices, the remainder defining subjects which are also used in the commercial sector.[13] The military also played a pioneer role in the definition of procedural and quality management standards: the well-known ISO 9000quality standard for example can be traced back to the US military standard MIL-Q-9858 of 1959.[14]
The US DOD approach on military standardization went through a major reform however since 1994, when Secretary of Defense William Perry issued a memorandum[15] directing that performance-based specifications and standards or nationally recognized non-

governmental standards (such as IEC or ISO standards) be used in future acquisitions, referring to military specifications and standards only as a last resort when no acceptable non-government standards are available (e.g. for weapon systems and the like).

3.3 UK military standardization

A similar policy is pursued for the military standardization in the UK. The UK MOD pursues to make the maximum use of standards in all its design and procurement activities whereby civil standards are preferred, because they reduce barriers to international trade and increase competitiveness. Military standards should only be used when there are no suitable civil standards available.
The hierarchy for the selection of standards for UK MOD procurement is as follows:[16]

1. European standards (CEN - CENELEC - ETSI), due to the obligations of the MOD for public procurement contracts
2. International standards (ISO - IEC - ITU)
3. British national standards (BS)
4. NATO standardization agreements (STANAG)
5. UK MOD defence standards (DEF STAN)
6. UK MOD departmental standards and specifications (e.g. Naval Engineering Standards)
7. Other nation's military standards
8. Recognized industry standards

UK Defence Standards (DEF STAN) are produced only when no suitable civil standard is available and when they have a clear advantage, which may be operational (e.g. NATO compatibility and interoperability) or logistic. The two main types of DEF STAN are Performance Standards and Procedural Standards.[17]

Other international military standards are the Quadripartite Standardization Agreements (QSTAG) produced by the ABCA countries (America, Britain, Canada, Australia).

4 Standards for electric and hybrid military vehicles

As seen in the paragraph above, the general tendency in military standardization is to adopt civilian standards where available and appropriate. Particularly in a (at least for the military) new field such as electrically driven vehicles, it is likely that the civilian standards, which have been discussed elsewhere in this work, are to be adopted.
Military standards are however in existence covering a number of aspects which concern the vehicle, the main areas being voltage, battery and vehicle standards.

4.1 Military standardization for voltage

One of the main tasks of the electric power plant (APU + battery) on board the military vehicle will be to provide electric power to subsystems, which are now supplied from towed generator sets. Voltage levels for such subsystems are specified in NATO STANAG 4133[18]:

- ☞ d.c. system: 2 DC 28 V
- ☞ Single phase a.c. systems:
    - ☛ 1/N/PE AC 50 Hz or 60 Hz 230 V
    - ☛ 1/N/PE AC 60 Hz 115 V
- ☞ Three phase a.c. systems:
    - ☛ 3/N/PE AC 50 Hz or 60 Hz 400/230 V
    - ☛ 3/N/PE AC 60 Hz 200/115 V
    - ☛ 3/N/PE AC 400 Hz 208/120 V
    - ☛ 3/N/PE AC 400 Hz 416/240 V

These voltage levels will also have to be supplied by the electrically driven vehicles; one should note that, with the exception of the medium-frequency 400 Hz supplies which are most typical for aeronautic applications, the voltages specified in this military standard are comparable with the voltages in common use by electric utilities in most parts of the world, specified in IEC 60038.[19]
There will thus no major problem in adapting these voltages.

4.2 Military standardization for batteries

The armed forces are large users of batteries, ranging in size from small button cells to large submarine batteries of up to 10000 Ah. The US military for example has about 3800 types of battery in use; and this is one of the domains where standardization efforts have allowed to improve design and performance and to lower cost.[20] The use of military or commercial standardized batteries has been mandated by a US Department of the Army memorandum from 2002.[21]

A considerable number of standards for military batteries have been published; most of these however refer to battery types designed for specific applications such as aircraft batteries or submarine batteries.

There are also a number of generic battery specifications issued by the military. The British DEF STAN 61-9[22] for example states qualification approval procedures, and also describes a number of tests to be performed. Supplements to this standard define dimensional requirements and test procedures for specific types of batteries that are standardized for military use, e.g. a 6 V, 170 Ah type.[23]

New applications such as electric vehicles, where new types of batteries are implemented, will have to refer to civilian standards like those published by IEC.

4.3 Military standardization for vehicles

A number of nations have published general documents for the requirements of military vehicles. The British DEF STAN 23-6[24] for example gives guidance to the common technical requirements of military vehicles. This document makes extensive reference to other standards which are applicable, covering both NATO STANAGS, ISO standards, BS standards, DEF STANS and other documents.

This type of documents will of course also be applicable when the vehicles are fitted with electric drives.

5 Hybrid vehicle performance standards: recommendations

5.1 Introduction

For hybrid vehicles in particular, performance testing must be adapted to the characteristics of the drive train. The following paragraph gives an overview of some issues which are to be taken into account.

Research performed [25] on existing ISO, CEN and SAE standards has shown that the definition of a universal performance standard for a hybrid electric vehicle (HEV) is not a straightforward issue.
A first point is the possible availability of different operation modes in the same vehicle. To get an overall assessment, it is essential that all available modes (for as far as they are compatible with test cycles) are measured, cf. the approach taken by SAE J1711[26].
For "pure-electric" (with the auxiliary power unit (APU) switched off) ore "pure thermal" (with the electric drive train not intervening in traction) modes, if any, relevant measuring procedures for respectively electric and ICE vehicles should be used, with however the same speed cycles to be used where applicable to allow comparison among all modes.

For the hybrid driving modes however, the main issue is the consideration of the state of charge (soc) of the on-board rechargeable energy storage system (RESS) during the test. The evolution of the soc is strongly dependent on the configuration of the HEV and its control strategy.
One can make the distinction between several possible cases:
- ☞ whether or not the HEV is externally chargeable;
- ☞ whether or not the APU is designed to deliver a constant output power;
- ☞ what is the typical application profile for the vehicle. The increased demand for auxiliary power supply which may occur in military vehicles has also to be taken in account here;

5.2 Externally chargeable hybrid

The externally chargeable HEV presents the following application profiles:
- ☞ Battery-electric vehicle with "range extender" APU; for such vehicle, electric operation will be the principal mode, with hybrid mode used occasionally when the need arises to cover a longer distance.
- ☞ Hybrid vehicle with zero-emission capability; for such vehicle, hybrid operation will be the principal mode, with electric mode used for example in city centers.

Test procedures for these types of HEV should take into account both electric and hybrid operation modes:

- ☞ For electric operation, without APU use: measurement of the range and energy consumption can be performed according to the procedures for battery-electric vehicles (ISO 8714[27]). The RESS should be fully charged at the beginning of the test, and recharged from the grid after the full range has been covered.

☞ Hybrid operation. The test to be performed here can be based to the FCT-HEV test from SAE J1711[28], with the initial SOC at 100 % and with the RESS recharged from the grid at the end of the test. This is a practical hypothesis since it may be reasonably expected that the user of an externally chargeable HEV will charge the vehicle from the grid overnight, using energy which is cheaper and more environmentally friendly than when recharging from the APU.

5.3 Non-externally charged hybrid

For non-externally chargeable HEV, the most critical point in the testing procedure is the SOC balance over the test. Due to the variety of drive train structures and control strategies envisageable, it is difficult to put forward one standard procedure which would fit for all.

The main issues to be considered here is the evolution of the RESS SOC during the test. It is thus necessary to measure the energy flows going in and out of the RESS. For the latter, the correction techniques presented in SAE J1711 and SAE J2711[29] can be envisaged; the most accurate choice being to limit the acceptable energy change to ± 1 %, taking into account the following issues:

☞ When the SOC change after performing the prescribed test cycle is consistently too high, this may be due to the "time constant" of the energy balance strategy embedded in the drive train control system. It could be envisaged to extend the test cycle with additional basic cycles until the desired level is achieved.

☞ The choice of the initial SOC level may also influence the outcome of the test. For this type of vehicle, it is most likely less than 100 % (cf. the PCT-HEV test in SAE J1711). The influence of the initial soc is also dependent of the drive train strategy; and unless one wants to extend the number of tests (and hence their expense) considerably, it seems acceptable to start the test with a SOC level stated by the manufacturer, which could be between certain limits however (e.g. between 40 % and 80 %).

5.4 APU bench testing

Heavy-duty vehicles like buses and trucks represent a large application field of hybrid drive technology. Testing procedures for consumption and emission of hybrid heavy-duty vehicles are not so straightforward however: whileas for light-duty vehicles they can be derived using existing test cycles for conventional vehicles, this does not apply for heavy-duty vehicles, where the standard test methods for conventional vehicles are based on static bench tests of the engine (e.g. the European Stationary Cycle 13-mode test, illustrated in Figure 2, introduced by directive 96/96/EC[30], which replaced the 13-mode cycle from regulation ECE-49), which can not be meaningfully applied to hybrid vehicles, since in these vehicles the instantaneous behaviour of the engine is decoupled from the instantaneous road load, and the standard set of measuring points and their weighting may not apply.[31]

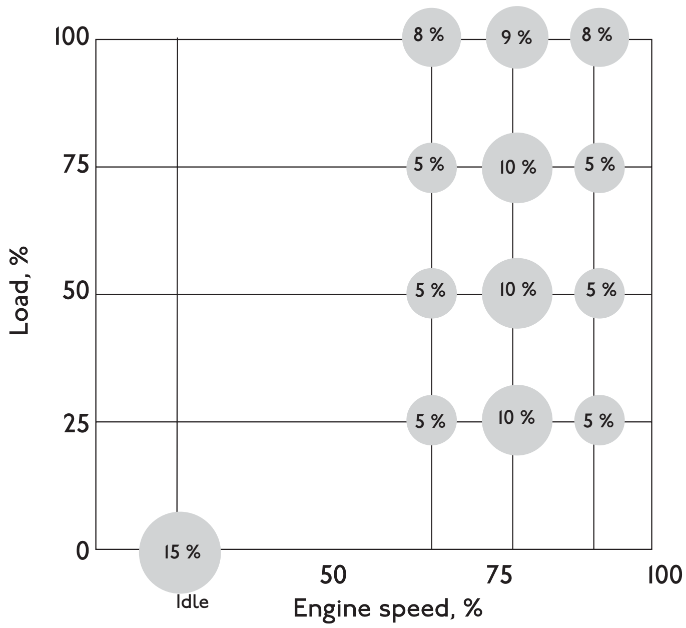

Figure 2: European Stationary Cycle 13-mode test

According to the drive train strategy, the following cases can be distinguished, taking into account the output power and set point of the APU[32]:

☞ APU delivering a constant power
This is typically the case for series hybrid city buses; this configuration allows the APU to be operated at is optimal point, minimizing energy consumption.. Since the APU output power (and hence its consumption and emissions) is constant, it can be easily characterized on an engine test bench. A vehicle test however is recommendable to show the concordance between APU behaviour on and off the vehicle. Furthermore, the behaviour of the APU with a fully charged RESS (and thus a reduction of the APU output power) should be investigated.

☞ APU having a limit number of operating points
Also this case can be easily described by a bench test focusing on the pre-set operating points.

☞ APU delivering a dynamic power
This is a more complicated case; a reliable test in this case would necessitate the knowledge of the typical operation of the APU. This necessitates performing a cycle test corresponding to an actual road cycle in order to know the dynamic operation range in order to define relevant points for bench testing the APU. A quite simple procedure for this could be to start with the operating points of the 13-mode (or a similar) test, adapting the weighting of the individual operating points according to their relevance in the use cycle of the considered APU.

It is clear that the tests to be performed will have to be customized for each vehicle in order to be representative taking into account the underlying drive train strategy. This customizing however requires a thorough knowledge of the control strategy and the underlying parameters, knowledge which vehicle manufacturers usually consider as

proprietary and anxiously guard. A legal obligation, such as the conformity to type approval regulations, will be necessary to have such information disclosed.
One could state that the use of customized engine tests would disallow a valid comparison between engines. However, taking into account that the use of the engine will be specific for each HEV and that the generic engine test (designed for ICE vehicle) is ill-suited for testing HEV engines, it is clear that the engine should be tested in a mode of operation which mimics its actual use in the vehicle.

5.5 Fuel and electricity consumption

It is not evident to calculate electricity consumption back to fuel consumption, due to the variety in the electricity production mix. It thus seems more advisable not to try to combine fuel and electricity consumption in one overall consumption figure, except in singular cases where the origin of the electricity used is fully known (e.g. renewable energy sources).
Furthermore, the juxtaposition of an electricity consumption figure (kWh/km) with a fuel consumption figure (l/100 km) is more interesting for the vehicle user, who acquires these energies from different sources and is thus enable to assess the economic impact (i.e. consumption cost) of the vehicle.

6 Conclusions

It is clear that there remains a considerable work to be done on the field of defining relevant performance standards for hybrid vehicles. Due to the various hybrid structures possible and the plethora of drive train strategies which can be implemented, the definition of suitable test procedures for hybrid vehicles and their drive trains is not a straightforward issues and merits further consideration.
For the particular case of military vehicles, special constraints such as the use of auxiliary power for supplying on-board systems, as well as specific mobility requirements will also have to be taken into account.

7 References

[1] US DOD Dual Use Science and Technology Program
[2] NATO AVT-047
[3] Baudoin Y, Life cycle cost of all-electric combat vehicles, NATO RTO, Doc. RTO-TR-13, 1999
[4] Lee, H.G. et al., Developmental Concept of Hybrid Electric Propulsion Systems for Future Combat Vehicles, EVS-19, Busan, 2002
[5] NATO Logistics Handbook, 1997, ¶1705
[6] NATO Logistics Handbook, 1997, ¶1711
[7] Materiel (not "material"): a general NATO term covering equipment stores, supplies and spares
[8] UK MOD, INT DEF STAN 00-00 (Part 1)/3, ¶12.3.2
[9] NATO Handbook, 2001, p 318
[10] NATO AAP-6, nato Glossary of Terms and Definitions
[11] UK MOD, INT DEF STAN 00-00 (Part 1)/3, ¶15.1.1
[12] NATO Logistics Handbook, 1997, ¶1708
[13] S. M. Spivak, F.C. Brenner, Standardization Essentials, 2001, p139
[14] Ibid, p 102
[15] The Secretary of Defense, William J.Perry, "Specifications & Standards - A New Way of Doing Business", 1994-06-29
[16] UK MOD, INT DEF STAN 00-00 (Part 1)/3, 1999-06-04, ¶26
[17] UK MOD, INT DEF STAN 00-00 (Part 1)/3, 1999-06-04, ¶28
[18] STANAG 4133:1992, "Method of specifying electrical power supplies : standard types of electrical power"
[19] IEC 60038:1983+A1:1994+A2:1997, Table 1. For the three-phase 60 Hz network however, the most recent version of the IEC standard specifies a voltage of 120/208 V and not 115/200 V
[20] Defense Standardisation Program Case Study, Aircraft Batteries and Components, Defense Standardisation Program Office
[21] Development, Acquisition and Fielding of Weapon and Information Systems with Batteries, Department of the Army memorandum, 2000-01-04
[22] DEF STAN 61-9(Part 1)/4:1993: Generic specification for batteries, rechargeable, secondary - Part 1: General requirements
[23] DEF STAN 61-9 (part1)/3 Supp. 2 Issue 2: 1973: Specification for battery, secondary - portable lead-acid type 6 V 170 Ah (fully dry charged) - NATO stock no. 6140-99-910-1545
[24] DEF STAN 23-6:2000, Guide to the common technical requirements for military logistic vehicles and towed equipment
[25] P. Van den Bossche, "The electric vehicle, raising the standards". PhD thesis, VUB, 2003, ¶6
[26] SAE J1711:1999 "Recommended practice for measuring the exhaust emissions and fuel economy of hybrid electric vehicles"
[27] ISO 8714:2002, "Electric road vehicles – Reference energy consumption and range – Test procedures for cars and light commercial vehicles"
[28] SAE J1711:1999, ¶4.3.2
[29] SAE J2711:2002, "Recommended practice for measuring fuel economy and emissions of hybrid-electric and conventional heavy-duty vehicles"
[30] Directive 96/69/EC of the European Parliament and of the Council of 1996-10-08 amending directive 70/220/EEC on the approximation of the laws of the member states relating to measures to be taken against air pollution by emissions from motor vehicles;
[31] Cf. R. Smokers, "Hybrid vehicles in relation to legislation, regulations and policy", EVS-19, Busan, 2002
[32] Cf. J. Van Mierlo, Simulation software for comparison and design of electric, hybrid-electric and internal combustion vehicles with regard to energy, emissions and performance, PhD thesis, VUB, 2000, ¶3.4