# 1. PUBLISHABLE SUMMARY

## List of Beneficiaries

| Beneficiary Number | Beneficiary name | Beneficiary short name | Country |
|---|---|---|---|
| 1 (Coordinator) | Centro de Estudios e Investigaciones Técnicas | CEIT | Spain |
| 2 | YORK EMC SERVICES (2007) LIMITED | Y-EMC | UK |
| 3 | IDIADA AUTOMOTIVE TECHNOLOGY SA | IDIADA | Spain |
| 4 | TEKNOLOGIAN TUTKIMUSKESKUS VTT | VTT | Finland |
| 5 | Politecnico di Milano | POLIMI | Italy |
| 6 | MIRA LTD | MIRA | UK |
| 7 | JEMA ENERGY SA | JEMA | Spain |

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## Summary description of project objectives

Nowadays, road transport relies almost exclusively on fossil fuels. In fact, road transport is responsible for one-fifth of the EU's total emissions of carbon dioxide, and these emissions have increased by 26% since 1990. Thus, to achieve the 2020 target of reducing energy consumption and CO2 emissions, Fully Electric Vehicles (FEVs) need to reach a significant market share. Progress towards mass production of FEVs presents vehicle manufacturers with new challenges due to the relative immaturity of the new technologies that are involved. The most notable of these is the electric powertrain, comprising the electric traction machine and its associated power electronics.

One of the main objectives of the HEMIS project is therefore to design an in-vehicle Prognostic Health Monitoring System (PHMS) for the powertrain in order to enhance the safety and maintainability of FEVs. This system will be able to analyze the failsafe state of the powertrain by monitoring selected physical characteristics. It will also estimate its remaining useful life (RUL), and which component will fail first, thus enabling a predictive maintenance policy.

The HEMIS project has a second main objective. The electromagnetic fields emitted by the electric powertrain and their possible effects on the human body, as well as any interference with other systems on the vehicle, have been analyzed. It has then been assessed whether these fields, which may differ from those in a conventional car, can exceed current standards. For that case, HEMIS project proposes to recommend adaptations to the automotive standards so that the electromagnetic field is always below acceptable limits.

The main objectives of the HEMIS project are divided into the sub-objectives specified below:

O.1 Define a generic architecture for the FEV and undertake hazard and RAMS (Reliability, Availability, Maintainability and Safety) analysis.

O.2 Improve the knowledge of failure mechanisms, identifying the most critical ones, and asses which physical magnitudes are the best to monitor the powertrain failsafe state considering the reliability, accuracy, cost and feasibility of integration into FEVs.

O.3 Integrate hybrid information into prognostic algorithms to estimate a RUL value.

O.4 Design, develop and test a prognostic health monitoring system for the powertrain of electric vehicles (PHMS).

O.5 Identify limitations of current legislative requirements regarding electromagnetic fields (EMF) from FEVs and propose Electromagnetic Compatibility (EMC) testing methods to standards bodies.

O.6 Study the relationship between low frequency emissions and the current density induced in the occupants in order to propose reference levels for in-vehicle human exposure to EMF.

## Work performed and main results achieved

The HEMIS project is broken down into eight work packages (WPs) that will lead to the completion of the ultimate goals of the project. All the tasks for the period from 1st June 2013 to 31st May 2014, described in Annex I (Description of Work dated 14/04/2014) have been completed as planned. The following activities were performed during this period:

### WP1: Coordination and management

During the first review meeting some information updates were requested by the EC related with WP1, WP2, WP3, WP5 and WP8. The corresponding deliverables were resubmitted during this period, being these changes detailed in section 2.3. Related with the second period of the project, some technical difficulties in WP4 and WP6 (explained later in this report) lead to a 3-month project extension. All the deliverables and milestones for the period from 1st June 2013 to 31st May 2014, described in Annex I dated 14/04/2014, have been achieved.

### WP2: PHA and RAMS apportionment of the FEV

This work package finished in previous period and was devoted to the definition of a generic FEV architecture and the RAMS analysis and apportionment.

### WP3: Identification of the causes of degradation of the motor and the control, and their consequences

This work package finished in previous period and was devoted to analyse the causes of degradation for the powertrain, as well as their effects and criticality.

### WP4: Monitoring of the physical characteristics of the motor and control and prediction of their RUL

The aims of this work package are to identify which physical characteristics are most appropriate to monitor the performance of the powertrain and to define prognostic algorithms able to estimate the powertrain's remaining useful life. During the first period of the project the most relevant failure modes of the powertrain were identified and some candidate physical characteristics for monitoring these failure modes were preselected.

The objectives for the second period have been achieved:

- The candidate physical characteristics preselected for monitoring have been assessed considering different factors such as the accuracy and reliability of their measurement, the cost of the sensors, the feasibility of their integration in a commercial powertrain, and the detectability, diagnosticability and prognosticability of the component failure based on the variable. The suggestions from the Industrial Advisory Panel were also considered. The selection of monitoring variables is documented in the deliverable D4.1.

- The development of the algorithms for the estimation of the Remaining Useful Life (RUL) of the motor and control systems of the Fully Electrical Vehicle (FEV) has been carried on. The analysis has been focused on those FEV components and degradation mechanisms which had been identified as the most critical ones in the first period: loss of magnetic field, bearings, and stator windings for the motor; and capacitor and IGBT for the control. Finally, the developed MATLAB code was provided to partners in WP6. The algorithms have been documented first in the deliverable D4.2.1 and later in D4.2.2.

During this second period some difficulties arose because the degradation process and/or the evolution of the candidate variables during degradation were not sufficiently documented in literature so as to select the monitoring variables and build the corresponding algorithms. Thus, data sets had to be produced through simulations and laboratory tests. This led to a temporary delay in WP4, which was corrected during the period, and the further implication of partners in WP6.

**WP5: Analysis and measurement of EMC characteristics and health impact of EMF**

Along the second period, EMC emissions from PM motors were measured and further testing of switched reluctance motors was done and documented in the deliverable D5.2. The results obtained show that high magnetic field can be measured close to the electric powertrain and falls off rapidly with distance. The fields take the form of low frequency radiated emissions and are generally narrow band in nature and depend greatly on the cable layout. Also, testing procedures and suitable test equipment for filling the gaps detected during the first period in existing automotive standards have been proposed and documented in the public deliverable D5.4. It also includes a contribution suggesting possible test requirements for wireless charging of traction batteries.

Additionally, an approach for modelling the impact of low frequency magnetic field exposure on the human body has been proposed, implemented and documented in the deliverable D5.3. Due to the limitations of existing modelling tools, the approach applied is based on representing the longitudinal currents flowing on the steel skeleton of a typical FEV. The internal electric field and current density induced have been computed for frequencies up to 3 kHz in a number of representative traction current exposure scenarios. The results allowed assessing the validity of existing field reference levels, which have been developed for a standing human under uniform field exposure, instead of seated occupant exposed to non-uniform field distributions. The conclusion is that the magnetic flux density reference levels defined in the ICNIRP 1998 exposure guidelines provide a safety margin in terms of the exposure limits of both ICNIRP 1998 and the more recent ICNIRP 2010 guidelines (for low frequency effects). However, the magnetic flux density reference levels specified in ICNIRP 2010 and the EU occupational exposure directive 2013/35/EU does not provide adequate protection with respect to the exposure limits. A summary of these results, together with the exposure measurements reported in D5.2, has also been collated into the public deliverable D5.5.

**WP6: Identification of hazard limits and design and implementation of on-board monitoring systems**

This work package is devoted to the design, development and testing of the monitoring systems for the powertrain subsystems. During this period, a distributed structure has been proposed and discussed with the Industrial Advisory Board. In this architecture, a central electronic board executes the algorithms defined in WP4, and some slave boards (specific for control, motor or EMC) collect the data needed by the former. All modules are connected by a CAN network.

The processors for both the central board and slave boards have been selected, and the protocol among them has been defined. The work during this period has been focused on the development and programming of the slave boards for the motor and the control, the tuning of the algorithms' parameters based on the information provided by the slaves in working conditions, and the validation of the algorithms results. Additionally, the antenna for EMF measurements has been developed and some measurements have been taken in the partners' premises in order to analyze its output and define its future integration in the PHMS.

Finally, a catalogue of potential mitigation techniques has been developed (e.g. traction conductor configuration, shielding etc.), based on a literature review and previous research within WP5. These techniques have been documented in a public document.

During this period, partners in WP6 have collaborated in the degradation data collecting for WP4. Also, the development of the slave boards in parallel with the algorithms definition asked for some re-definitions of slave boards and thus to a delay in WP6. As a consequence, a 3-months project extension was requested and agreed.

**WP7: Verification of the on-board monitoring systems for the fail safe transition**

This work package is devoted to integrate the prototype of the on-board monitoring system. Latter, it will be verified by means of a test setup. During this period a first scheme of the test-setup has been proposed and the test cases outlined in the WP2 have been further developed.

**WP8: Dissemination and exploitation**

This work package focuses on the dissemination of the R&D results of the project. The dissemination was implemented through the following activities: web page, contributing to courses and conferences, meetings with stakeholders and workshops with the industrial advisory panel.

## Expected final results

The **first outcome** of the project is a prototype of an in-vehicle prognostic health monitoring system for the powertrain, comprising the electric traction machine and its associated power electronics. This system will provide information on the failsafe state of the electric powertrain and will enable to apply a condition based maintenance policy on its subsystems.

The **second outcome** of the project is the proposal of design guidelines with mitigation techniques regarding electromagnetic compatibility and the impact of electromagnetic fields on human health; as well as low frequency emissions testing methods. This information has been submitted and handled to standardization bodies and manufacturers of FEVs during the second period.

## Potential impact and use

HEMIS will contribute to increase the reliability of FEVs by analysing the failure modes of new building blocks, such as traction electrical motors and the associated power electronics. Moreover, the safety of FEVs will be significantly improved by means of the PHMS, able to detect the failsafe state of the FEV's electric powertrain. This could be used both to trigger safety automatic actions and/or to warn the driver about the failsafe state of the vehicle.

Besides, the RAMS analysis developed in HEMIS will improve the FEV design. In this sense, FEVs' manufacturers have been provided with information about the major contributors to the degradation of the powertrain, as well as with design guidelines on EMC issues. This way, HEMIS will strengthen Europe's position in existing markets, such as automotive industry, on-board monitoring systems and predictive maintenance.

Moreover, the PHMS will predict the remaining useful life of the subsystems analysed, thus aiding to the decision on when maintenance actions should be performed. Hence, maintenance costs will be reduced, while additional services are provided to FEV users.

## Project logo and website

http://www.hemis-eu.org/