DRIVEMODE

Integrated Modular Distributed Drivetrain for Electric & Hybrid Vehicles

Document title: D1.6 Project Status Report 2

D1.6: Project Status Report 2
WP 1, T 1.1

Authors: Mehrnaz Farzam Far (VTT)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N°769989

DRIVEMODE

Technical references

Project Acronym	DRIVEMODE
Project Title	Integrated Modular Distributed Drivetrain for Electric & Hybrid Vehicles
Project Coordinator	Mikko Pihlatie VTT Technical Research Centre of Finland mikko.pihlatie@vtt.fi
Project Duration	November 2017 – October 2020 (36 months)

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Work Package	WP 1 - Coordination
Task	T1.1 - Administrative and financial management
Lead beneficiary	VTT
Contributing beneficiary/ies	All
Due date of deliverable	31 November 2019
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* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

v	Date	Comment	Author	Beneficiary
0.1	15/11/2019	Initial draft	Mehrnaz Farzam Far	VTT
0.2	2/12/2019	Review from WP leaders	WP leaders	All WP leaders
0.3	18/12/2019	TMT revision	Marcello Bardellini	ICONS
1.0	02/02/2020	Final check and submission	Mikko Pihlatie	VTT

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Executive Summary

The purpose of the deliverable is to provide concise evaluation of the project and state the current achievements. It contributes to Task 1.1 Administrative and financial management and objective of financial contribution management and its distribution to consortium.

The status of the project is healthy; all tasks are executed according to the grant agreement (GA). During the first year of the project, deep cooperation through various communication channels were established between partners, which provided fruitful and flexible working environment. Furthermore, the initial requirement specification, iterative concept design and selection phases of the project were defined. In the second year, the detailed design of components, manufacturing processes, testing specification have been completed and the tasks related to integration to the demonstrator vehicle are ongoing.

The project has communicated its results mainly through the website and LinkedIn group. In addition, partners have presented advancements on several conferences, workshops with fellow GV-04 projects (ReFreeDrive and ModulED) and scientific papers.

The usage of financial resources and working hours is reasonable and corresponds to the current state of the project. Slight deviation in timely submission of deliverables did not provide the impact on the project and proactive measures have been taken to eliminate this lag.

Attainment of the objectives and if applicable, explanation of deviations

The deliverable outlines the overall progress of the DRIVEMODE project including the progress of each work package for the second 12 months. It also contains the relevant information on the completed tasks, financial spending and usage of the resources. Achievements of each work package are listed, and possible concerns are evaluated. The document is also complemented with the list of publications that have been presented and are planned. Thus, it can be stated that all relevant objectives for this deliverable were achieved.

The delivery is slightly delayed due to collecting the latest results from partners and discussing them on the general assembly meeting. The general assembly meeting was hold on 19 – 20th of November in Lappeenranta (Finland).

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Abstract

The project status report outlines the overall progress of the DRIVEMODE project including the progress of each work package for the second 12 months, as well as short review on the second-year performance of the project. It contains the relevant information on the completed tasks, financial spending and usage of the resources. Achievements of each work package are listed, and possible concerns are evaluated. The document is also complemented with the list of the planned and presented publications.

The purpose of the document is to provide concise evaluation of the project and state the achievements.

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Project Overview

Progress of Tasks

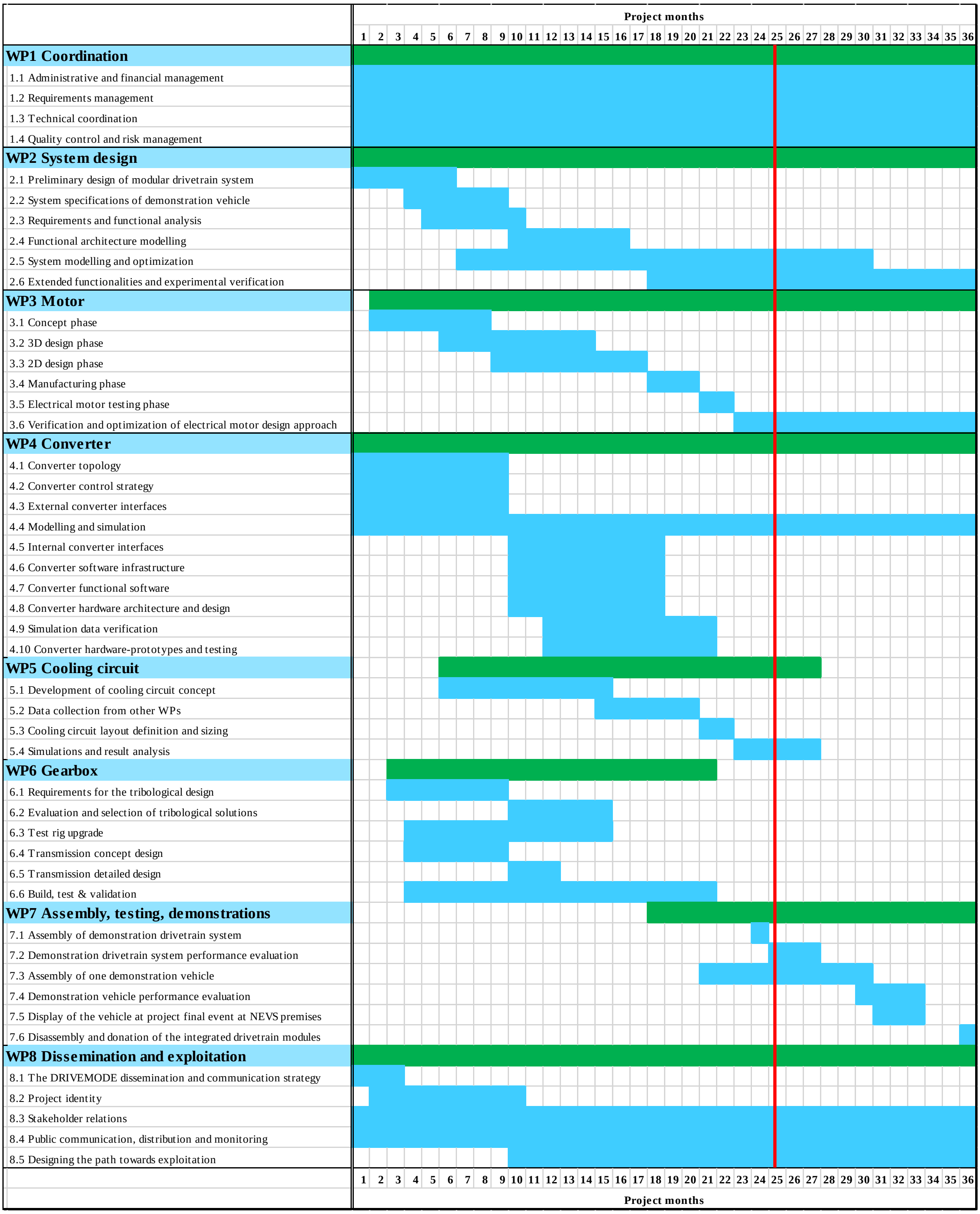

Figure 1 Gant chart of DRIVEMODE project

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Figure 1 shows the overall Gant chart of the project and the month of the project when the third general assembly was hold (red line). The project reached its third milestone on 30th of June 2019 with the submission of D4.3 Converter controller specified and working, D5.1 Documentation of the basic concept of the cooling circuit, and D6.3 Transmission design report. The milestone was delayed because of the deliverable review process to insure the agreement between all partners. This did not have any impact on the project as the information has been communicated earlier. By reaching the third milestone, the project shifted from the detailed and final design of components to manufacturing process.

The fourth milestone, with title of Components available, is delayed and expected to be achieved by the end of December 2019 (M26) instead of M23. Three pieces of electrical motor prototype (D3.8) and three pieces of transmission prototypes (D6.4) have been manufactured and tested individually. Three converter prototypes (D4.4) have also been manufactures. The testing for one of these converters is completed and testing of the other two is in progress. All the transmission and motor prototypes, along with one of the converters, have been shipped to Danfosss for drivetrain integration and further testing. The other two converters are scheduled to arrive Danfoss by end December 2019.

Finances and usage of resources

The information on the resource usage is collected from the partners every 6 months to have continuous feedback on the financial status. Figure 2 presents the budget spending estimated on the task duration and allocated resources, along with the actual values. It can be noted that there is underuse of resources; the details of which are presented in Figure 3. This is explained by the inaccuracy of the estimates, where the procurement of components cannot be accurately included. The overall trend to decrease the underuse, as shown in Figure 3, demonstrates that situation is healthy and will be improved as the procurement processes are finalized. This is also supported by the plot of working time usage in Figure 4, which demonstrates the working time usage as compared to the expected time. The numbers are slightly bigger than the ones corresponding to the financial budget, as in the initial phase human resources are more intensively used for the design process.

Overall, the financial state of the project is healthy, and differences are mainly due to the limitations of the method used for the estimations.

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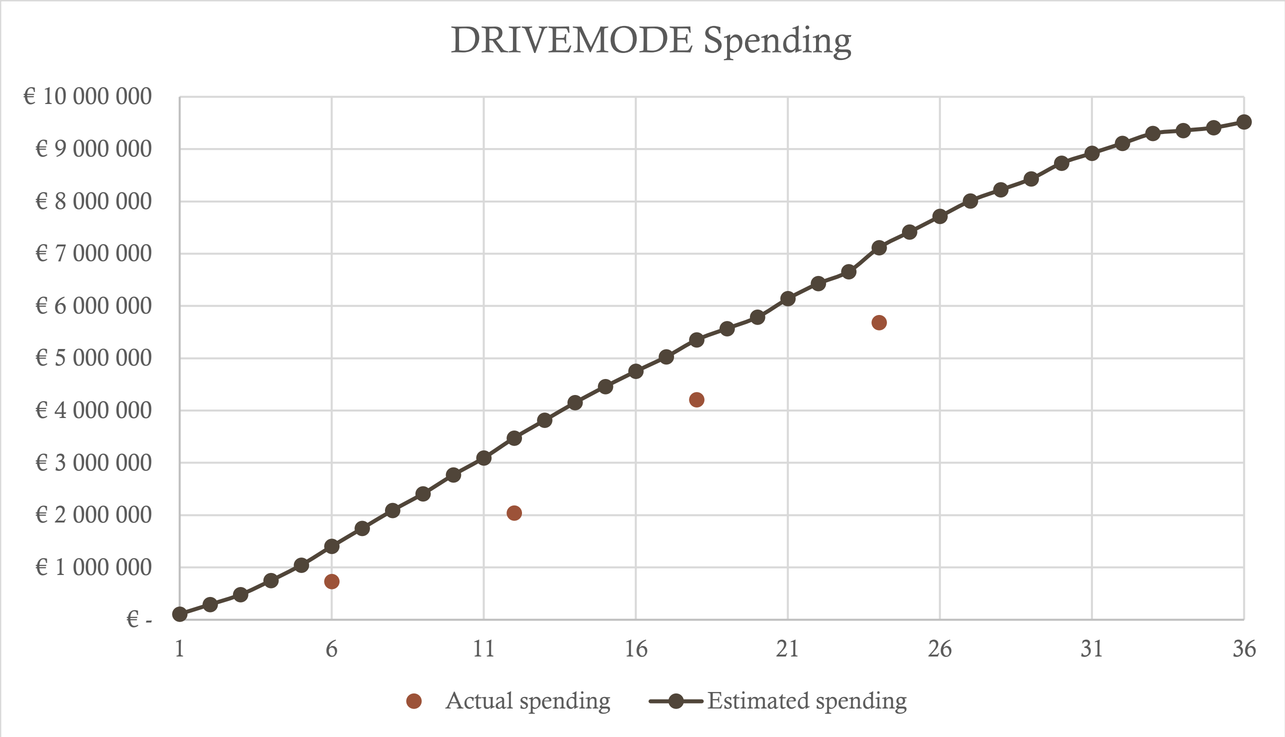

Figure 2 DRIVEMODE project overall budget usage

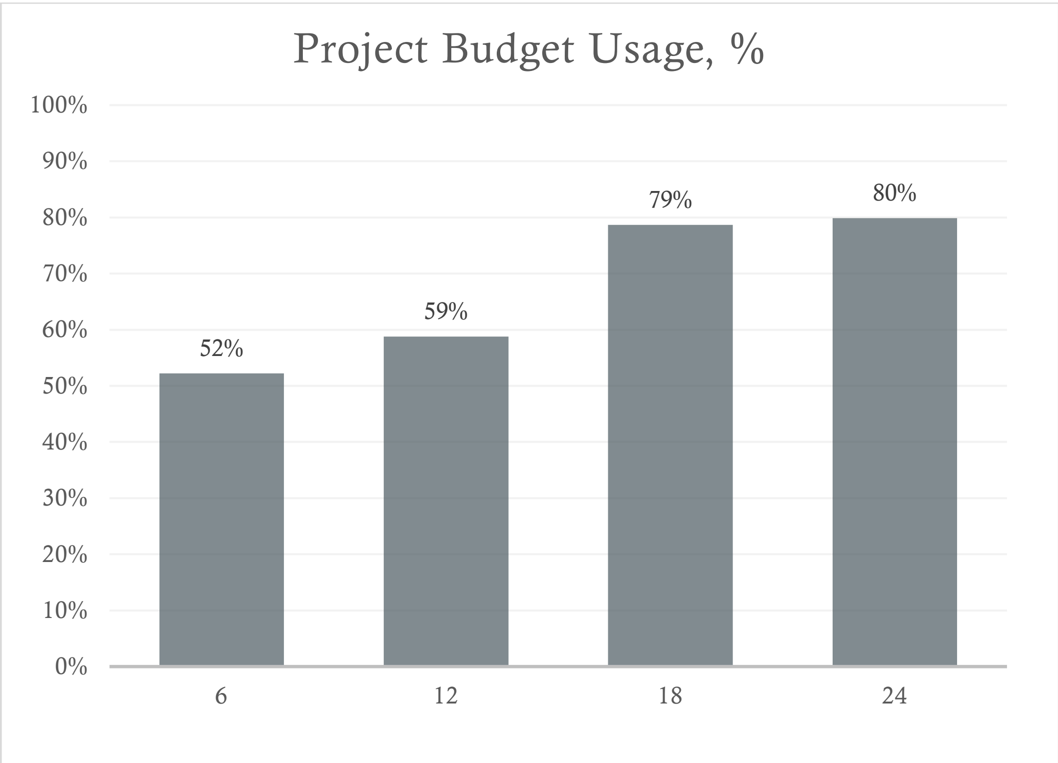

Figure 3 DRIVEMODE budget slippage

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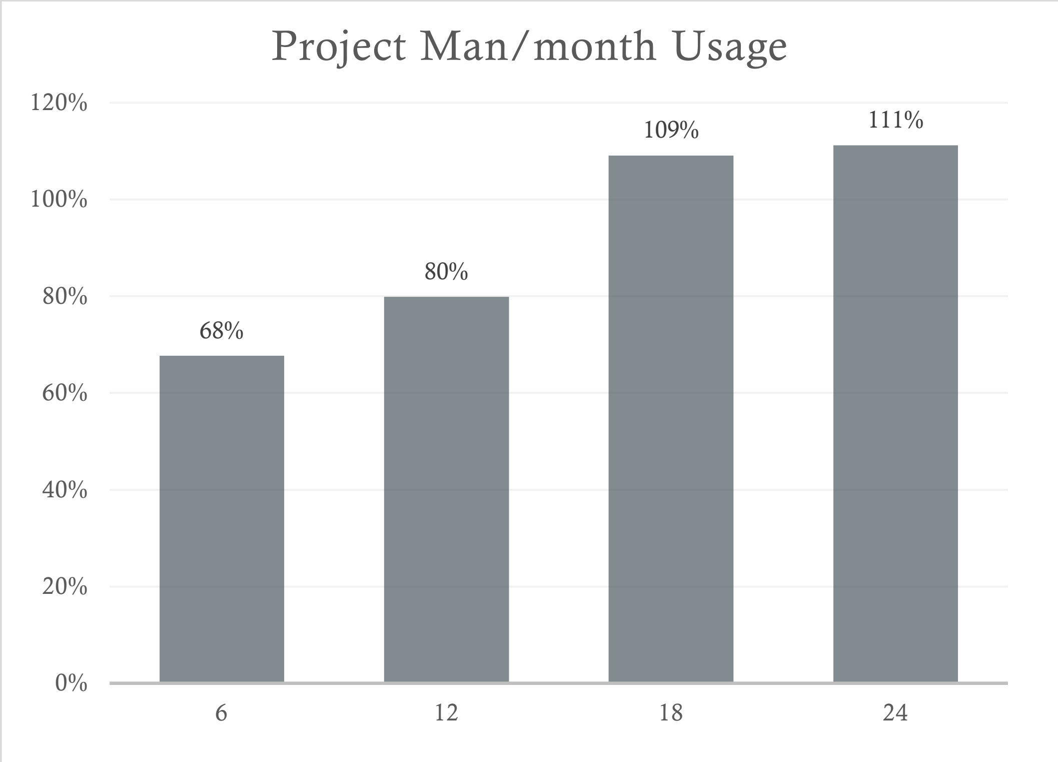

Figure 4 DRIVEMODE usage of man/months slippage

Deliverables

Deliverable review process is a part of T1.4 Quality and risk management, which ensures the agreement between consortium partners and high quality of submitted deliverables. The information on the status of deliverables is continuously collected and evaluated. The deliverable slippage with respect to GA is presented in Figure 5. The overall conclusion is that most of the deliverables are delayed on average for about a month. This was mainly due to the summer holidays and the requirement of having negotiation between partners and reaching the common agreement. The situation is under close supervision and several proactive steps have been adopted to avoid the delays in the future. It can be also noted that so far delays for the deliverables did not have impact on progress of tasks, as it was demonstrated in Progress of Tasks section.

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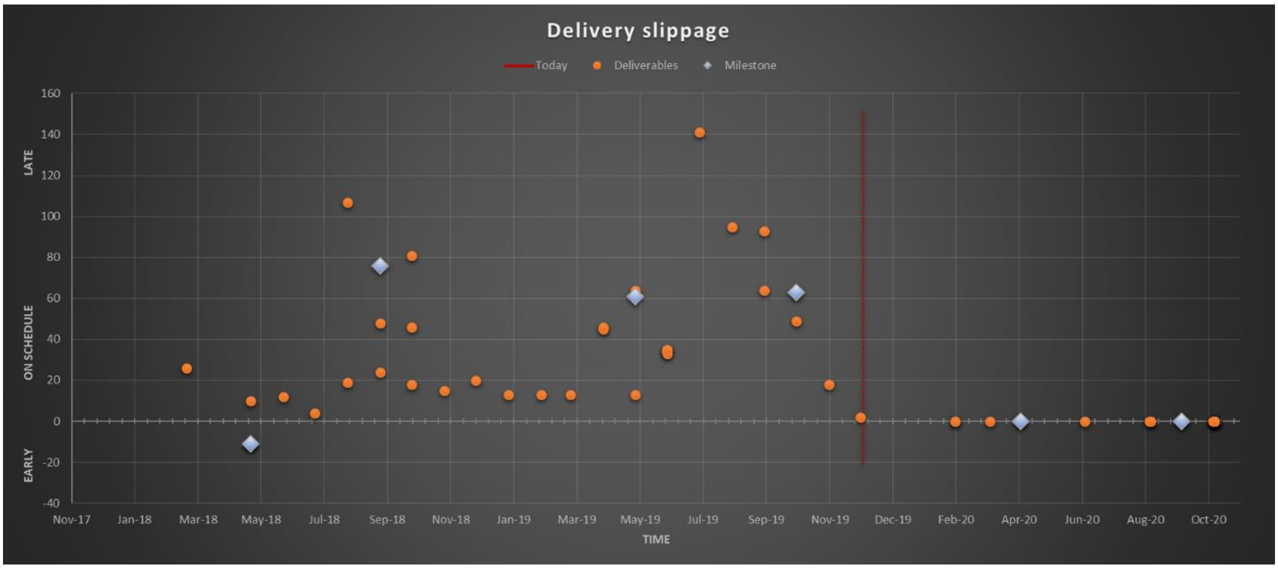

Figure 5 Deliverable slippage with respect to the grant agreement

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WP1 – Coordination

Work Carried Out

Task 1.1 Administrative and financial management (M36, in progress)

- Partners are provided with the common workspace for the information exchange
- The guidelines for the data storage, communication and information exchange are presented
- To keep awareness and motivation between partners the following is adopted
  - Monthly internal newsletter shared for all persons
  - Internal bi-monthly status report presentation of work packages
  - Bi-monthly survey for project participants to provide their feedback anonymously on the project development
- Introduction and induction of new-coming people into the project workflow
- Organization and conduction of project meetings
- Coordination with GV-04 H2020 projects (ModulEd, ReFreeDrive)

Task 1.2 Requirement management (M36, in progress)

- The requirement management system is introduced and launched for the common use
- A dedicated person is working on the requirement collection and evaluation with the help of partners
- The requirement system works as a foundation for the functional analysis in WP2

Task 1.3 Technical coordination (M36, in progress)

- To proceed with initial multidisciplinary and multiobjective design procedure, the Design Group has been established
- Meetings were carried on weekly basis with the aim to steer the development according to the project aims
- Several workshops on finding common grounds and tailoring the technical solution have been conducted during face to face project meetings
- To apply iterative and adaptive design procedure the process based on visual management has been adopted
- Several integration groups between work packages are established for certain areas
  - Software integration
  - Data acquisition and instrumentation
  - Drivetrain integration
  - Computer aided design (CAD) models maintenance and integration has been carried out till end of 2018
- Currently status evaluation meetings for technical issues are conducted every two weeks

Task 1.4 Quality and risk management (M36, in progress)

- The procedure for the internal review of deliverables is established
- Review and clarification of the overall schedule has been completed
- Testing plan has been prepared and evaluated
- Risk assessment is repeatedly conducted, and risk mitigation strategies are prepared

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WP2 – System Design

Work Carried Out

Task 2.1: Preliminary design of modular drivetrain system (M6, completed)

- Preliminary design of modular drive system is completed, and a report is submitted to EU.
- A peer reviewed conference paper titled "Multiple electrical machines applied for high drive train efficiency" based on the pre-study conducted for the project was presented at International Conference on Electrical Systems for Aircraft, Railway, Ship Propulsion and Road Vehicles (ESARS) and International Transportation Electrification Conference (ITEC), Nov 2018.

Task 2.2: System specifications of demonstration vehicle (M9, completed)

- The documentation of this task presents the specification of the demonstration vehicle. The specifications outlined here are at System Level (i.e. at Vehicle Level) and at Subsystem Level (i.e. Battery, Electrical machine, Cooling system and Gearbox).
- The subsystems performance specifications and specifications on interfaces between them are largely based the existing demonstration vehicle, i.e. NEVS 9-3 EV.
- In the end of the document, the last two sections present the Packaging Models shared amongst the consortium members and the driveline layout for the prototype vehicle respectively.
- D2.2 System specification of prototype was submitted and approved by M14. The deliverable was delayed by 3 months to ensure agreement within WPs on the specifications and the subsystem level requirements. This delay affected neither the project schedule nor the project outcomes.

Task 2.3: Requirements and functional analysis (M11, completed)

- The task was dedicated to analyzing the system specification, function requirements, and the project goal statement, to identify set of design criteria crucial for screening and selection of the various concept selection, therefore, making comprehensive decision in the design project.
- A report has been delivered, summarizing the research to identify functional and performance criteria to provide guidance in decision-making and for evaluation and selection of the best concept. There are two reports, one summarizes the methodology used and an application example, and the other comprise of the matrix table of the methodology for evaluating the concepts.
- The deliverable introduces the instrumentation to evaluate different concepts, defines criteria and provides their comprehensive analysis. Thus, it can be stated that all relevant objectives for the deliverable were achieved. In addition, the deliverable presents a set of tools for task 1.3 Technical coordination.

Task 2.4: Functional architecture modelling (M16, completed)

- Comprise modelling of the system architecture to research for optimal module, integration, scalability, distribution, and cost-effectiveness of the design and prototype.

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- The final report has been reviewed, approved and submitted.
- D2.4 Functional Architecture of prototype was submitted and approved by M21. The task comprises studying design data and researching documents from the relevant WPs and defining the system architecture based on the demonstration prototype concept for the precise definition of the interfaces in the overall system. The deliverable, which was planned for February 2019, was postponed to May 2020 to be able to collect all needed information and bring more clarity in the functional architecture modeling.

Task 2.5: System modelling and optimization (M30, in progress)

- The aim of the task is to build drivetrain models and conduct research on optimal modular designs. The activities in this task include:
  - (Ongoing) Building component simulation models, which are accurate enough, to evaluate the performance like efficiency and estimation of costs and size/weight of individual components. Initially, a MATLAB-based system simulation model was developed to evaluate current and voltages. Nevertheless, due to some technical challenges such as requirements of adapting the MATLAB script for various vehicle architecture and adapting loss estimation of power electronics using data sheet values, a FEM parameterized electric drive model has been developed; which includes electric motor, inverter, control in PLECS and Simcape. Simscape based model will be considered for further system modeling.
  - (Ongoing) Collecting design data and models from other WPs. A preliminary model of electric machine using flux linkage maps has been developed for system simulation, which can be used to estimate electric machine phase current, voltages, power factor etc. in steady state with reference torque and speed generated from a standard drive cycle.
  - (To be started) Conducting simulations on different drive cycles. The variables of the study include power, voltage, speed, type of motor, type of gearbox, batteries, and other key parameters. The goal is to reach system optimization toward high efficiency and low costs. The MATLAB script designed for system modeling will be implemented for adoption.
  - (Ongoing) Providing support for the design and manufacturing of the demonstration vehicle with theoretical studies and addressing the safety issues concerning new technologies, high speed and high voltage. These two activities are considered as part of design group meetings and other technical discussions during project meetings.
- D2.5 Report on system modelling and optimization is due M30.

Task 2.6: Extended functionalities and experimental verification (M36, in progress)

- The feasibility to include functionalities of steering assistance, braking, and regeneration is being investigated and verified with laboratory realization. The activities include:
  - (Ongoing) Building a simplified static vehicle model with functionalities of steering, braking and regeneration and a drive control model including drivetrain and load. Vehicle auto-body dynamic model, tire-road dynamics model, PMSM traction model with simple gearbox model are stablished. Integration of these models is in progress.
  - (Ongoing) developing control strategies for steering by differentiation of wheel speeds, and control strategies for traction forces distribution, braking and

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regeneration optimization. Several surveys are finished for exploring extended functionalities, including:

    - Survey on the state of the art of traction forces distribution strategy for *powertrain efficiency optimization*.
    - Survey on the state of the art of driving force distribution and control for *vehicle motion stabilization*.
    - Survey on the state of the art of *braking force distributions strategy* of four-wheel drive electric vehicle.
    - Survey on the state of the art of *wheel slip control* and *speeds differentiation control*, integrated with electronic stability control.

  - Designing and prototyping a downsized drive with controller, converter, and motor (20 kW peak power), conducting measurements and comparisons with simulations. 60kW hairpin wilding PMSM traction system, including controller, inverter and water-cooling system is designed and prototyped. High power load experiments are being prepared. Load /generator section will be setup soon.

- Possibility of using real time simulation for experimental verification has been investigated:
  - Load/generator motor section will be setup soon.
  - Back-to-back system will be realized to realize full power rate load experiments.
  - Load permanent magnet machine will be operated as torque control mode, with advanced motor control algorithm to realize high performance load emulator.
  - The traction-load motor bench will be linked to the distributed driven powertrain hardware-in-the-loop system for future functions test and verification.

Achievements and possible areas of concern

Achievements

- D2.2 System specification of prototype
- D2.4 Functional Architecture of prototype
- D2.6 Report on extended functionalities of drivetrain control.

WP3 – Motor

Work Carried Out

Task 3.1: Concept phase (M8, completed)

- Literature survey and evaluation of possible solutions
- Two concepts of electrical machines according to specifications from WP2
    - Induction machine
    - Permanent magnet machine
- FEM modelling of both machines
- Evaluation and comparison of the concepts

Task 3.2: 3D design phase (M14, completed)

- Detailed definition of interfaces to Inverter, Transmission and Vehicle cooling circuit
- Optimizing the permanent magnet synchronous machine (PMSM) electromagnetic and mechanical design
- Detailed definition of lamination design and air gap dimension
- Detailed design of E-Motor 3D CAD housing and shafts

Task 3.3 2D design phase (M17, completed)

- 3D CAD modelling and preparation of drawings
- Prototype of round wire winding has been done
- 3D FEM simulations for thermal behavior using computational fluid dynamics
- Cooling optimization
- 3D calculations of optimal skewing to reduce the cogging torque
- Modal analysis and evaluations of resonant frequencies
- Bearing currents estimation and design of mitigation measures

Task 3.4 Manufacturing phase (M20, completed)

- Three PMSMs were manufactured according to the defined specification.
- D 3.8 Three pieces of electrical motor prototype samples was submitted

Task 3.5 Electrical motor testing phase (M22, completed)

- Overview of the planned tests and their status:

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Test name	Status	Test pass
Functional Performance Testing		
Continuous load operating range	PARTIALY	tbd
Short time overload operating range	NOT DONE	-
Efficiency map (Characteristic motor maps)	PARTIALY	tbd
Functional Electrical Testing		
Withstand voltage	DONE	pass
Insulation resistance	DONE	pass
Winding resistance	DONE	pass
Functional check of position sensor	DONE	pass
Functional check of thermal sensors	DONE	pass
Connection check of thermal sensors	DONE	pass
Open circuit voltage	DONE	tbd
Open circuit loss	DONE	tbd
Short circuit current	DONE	pass
Short circuit torque	DONE	pass
Functional Mechanical Testing		
Visual inspection	DONE	pass
Dimensional check	DONE	pass
Cooling duct tightness	DONE	pass
Cogging torque	DONE	pass
Vibration test - imbalance	DONE	pass

- Since the DRIVEMODE inverter was not ready at the moment of testing, the machine is tested using standard DANFOSS Inverter EC-C1200.
- Resolver prepared for the E-motor was not supported by the delivered inverter, so all the load tests were done in ‘Sensorless’ mode which leads to difficulties in optimal torque control. The efficiency measurement is done partially, but the results are not quite reliable. Detailed efficiency measurement will be done when the torque control is optimized.
- The continues load test is done for the following operating points:
    - @1000 rpm /50 Nm
    - @5000 rpm /50 Nm
    - @15000 rpm /21 Nm

  For these operating points, the steady state temperatures of the most critical winding spots are within thermal class of the motor. Due to the torque and speed limit of inverter, the operating points with higher speed-torque values were not possible to be measured. Other operating points will be tested after the inverter control is optimized.

  The now low tests (done in several different conditions) show deviations in back EMF, the reason is still not clear. Possible causes are deviation in magnet properties or imperfections in manufacturing of the active part.
- The short circuit tests are done, showing similar deviations from the simulation results also open voltage measurement, which could indicate a deviation in magnet material properties or dimensions of the active part.

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- Mechanical design deviates from e-axel on drive end

Task 3.6 Verification and optimization of electrical motor design approach (M36, in progress)

- Simulation and test results comparison
    - Analysis of first measurement shows following:
        - windings
            - no errors in winding found during high voltage test
        - no load behavior
            - tested up to maximal speed 20.000 rpm and no mechanical problems are detected
            - induced voltage (back EMF) is ca. 15% smaller than simulated values. The reason is still under investigation.
        - continuous load behavior
            - were possible up to 15.000 rpm, with limited torque
            - in range 1000-5000 rpm machine was loaded with nominal torque where no thermal boundaries are reached
              Measured efficiency is 2-4% smaller than simulated values. Reason for the deviation could due to non-optimal control of the used inverter and smaller values of back EMF.
- D3.10 Report on optimization of electrical motor is due on M36.

Achievements and possible areas of concern

Achievements

- The following deliverables were submitted and approved:
    - D3.3 3D-CAD model
    - D3.4 Technical specification manual of electrical motor
    - D3.5 Parameters of electrical motor for converter controls
    - D3.6 2D drawings of the assembly and the interfaces electrical motor
    - D3.7 Test specification for stand-alone testing of electrical motor
- D 3.8 Three pieces of electrical motor prototype samples is submitted

Possible Areas of Concern

- Current area of concerns:
    - Big vibration in the gearbox, not solving this issue can destroy components → BorgWarner is working on a solution to this matter
    - Assembly problems regarding to the resolver → all participants are informed, and the Bench-Test is optimized for this matter

Having the correct inverter for the measurement → Danfoss is working on the solution

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WP4 - Converter

Work Carried Out

Task 4.1: Converter topology (M9, completed)

- Research of power electronics topologies and selection of best suitable one together with WP3 partners for selected motor topology.

Task 4.2: Converter control strategy (M9, completed)

- Control strategy for the drive application in consideration of performance and cost. Also taking into account the modularity concept and possibilities for central and individual control of several system units with chosen motor and gearbox.

Task 4.3: External converter interfaces (M9, completed)

- Addressing the mechanical and electrical interface to the motor, gearbox and battery as well as HW/SW interfaces to the vehicle system and other modular components.
- Cost analysis of the manufacturing and service strategy.

Task 4.4: Modelling and simulation (M36, ongoing)

- Completed:
    - Comparison of 4 to 3 chip solutions, 4 chip solution more expensive
    - Thermal simulation of complete power path from dc to AC (reduced hotspot although additional losses considered)
- Ongoing:
    - Concept of more complex 2-ways coupled simulation of thermal interaction between the chips and the flex-layers
- Future work:
    - Model fitting to measurements

Task 4.5 Internal converter interfaces (M18, completed)

- Addressing the mechanical interface to the control board and its cooling requirements.
- Addressing the electrical interfaces between the control board and driver section, and electrical interfaces between the control board and the driver section, external signals and internal sensors.

Task 4.6 Converter software infrastructure (M18, completed)

- SW architecture to support modular concept and chosen motor and gear box control functionality.
- Functional safety ISO26262.

Task 4.7 Converter functional software (M18, ongoing)

- Completed:
    - Software infrastructure w/ HW drivers and services
    - Danfoss Editron "stock" Motor Control algorithm integration
- Ongoing:

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    - Motor Control and driverboard SW integration
    - NEVS fieldbus system integration
    - Traction application
    - Protections
- Future work:
    - Thermal Model integration
    - Shunt and Shuffle control

Task 4.8 Converter hardware architecture and design (M18, completed)

- Detailed electrical and thermal characterization of the developed converter.
- Optimized thermal performance of the converter, especially for extreme operating conditions.
- Other focus area of the task:
    - Electronics architecture to support required power, control and system functions;
    - Suitability for the automotive environment and cost in focus;
    - Architecture suitable to meet functional safety ISO26262 requirements.

Task 4.9 Simulation data verification (M21, in progress)

- Completed:
    - Improvement of existing lab test equipment to obtain a higher degree of automation for fast validation of complex thermal models
- Ongoing:
    - Thermal measurements of converter hardware
    - Automated calculation of semiconductor cross coupling factors for thermal models
- Future work:
    - Comparison of simulations and measured results
- Delay:
    - Cause: The thermal measurements of converter hardware are delayed due to new ideas for calibration, which required additional tools and limited available time slots at the test setup.
    - Risk: Minor risk of affects to other tasks, because the known deviations between simulation and measurement are lower than the defined safety margin for the inverter output power proven by simulations. Actual plan to complete the task is December 2019.

Task 4.10 Converter hardware-prototypes and testing (M21, in progress)

- Completed:
    - Final converter with lightweight and robust housing incl. optimized cooling system (Semikron)
    - Basic function and performance testing (Semikron)
    - Basic software end to end PWM output testing, where driverboard control software was by-passed manually (Danfoss)
- Ongoing:
    - Performance testing of full SOA area (Semikron)
    - Inverter functional testing on desktop setup (Danfoss)

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- Future work
  - Performance testing with final control software (Semikron)
  - Inverter functional testing on the test setup (Danfoss)
  - Component functional testing, such as driving the electrical motor produced in WP3, of the converter depends on finalizing the integration of the two discrete software parts from Danfoss and Semikron. This has an implication to the starting of drivetrain functional testing as the converter is one of the three main drivetrain components and may have an implication on NEVS demonstration vehicle system testing as well.

Achievements and possible areas of concern

Achievements

- Semikron achievement:
  - Thermal analysis of the inverter
  - Manufacturing of three inverter
- Danfoss achievements:
  - Software integration
  - Testing control boards
  - Interface of traction application
  - Building the test setup
- Submitted and approved deliverables:
  - D4.1 Target specification of external converter interfaces
  - D4.2 Report 1 with simulation results
  - D4.3 Converter controller specified and working
- D4.5 Report 2 with simulation and measurement results is submitted.

Possible Areas of Concern

- Previous area of concerns and update on them:
  - High rotational speed of the motor (>20 000RPMs) requires high switching frequency and fast control loop. With the pre-existing control implementation, the fastest control loop time level runs at 62.5 µs cycle period, requirements for decreasing the fastest control loop cycle period may arise.

    Update: This concern is still valid. Functional testing of the converter will tell us more where we stand.

  - Also related to the high rotational speed. May impose higher performance requirements to the actual output frequency of the inverter. If this realizes the DSP modulator implementation may have to be moved to the FPGA or equivalent technical solution.

    Update: As a technical solution alternative, moving parts of the MCU duties to the FPGA is not viable anymore. The FPGA was removed from control PCB

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layout once it was realized that the PCB "real-estate" was not big enough to house the FPGA i.e. removed due to (mechanical) control board space requirements.

- Increase of personnel and hours put in are expected to be increasing as the project timeline is shifting from design phase to implementation phase. Possibilities of increasing resourcing is being evaluated.

  Update: This concern is still valid. Danfoss engineering and testing resources are in heavy utilization thus difficulties in assigning resources to any bigger development effort(s) that were unforeseen.

- Current area of concerns:
  - Motor control software integration → this is the primary focus area and Danfoss is working in close collaboration with Semikron to solve this issue.
  - Engineering resourcing might become of an issue → as counter measure this can be outsourced, if applicable
  - The two above mentioned challenges may affect the drivetrain testing and the system integration at NEVS → all effort is to avoid any delay

Deviations from GA

D4.4 Delivery of three converter prototypes for drivetrain integration to WP7, due on M22, has been delayed. One fully assembled converter is delivered to Danfoss. The delay for delivery the other two parts is due to the ongoing Motor Control software integration and testing. HW and peripheral interfaces have been tested, however, measurements flowing is still in progress. Core functionalities must be finished to drive the LF and RF drivetrains. This delay may affect the starting of WP7 testing activities at NEVS.

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WP5 – Cooling Circuit

Work Carried Out

Task 5.1: Development of cooling circuit concept (M15, completed)

- Data gathering from NEVS on the existing cooling circuit from the baseline vehicle; understanding of constraints;
- Evaluation of need/possibility of improvements and modifications for the cooling circuit of the demo vehicle;
- Data gathering from SEMIKRON and AVL for a rough estimation of the pressure drops and thermal loads of the components of the IDM;
- Proposal of different solutions for the cooling circuit.

Task 5.2: Data collection from other WPs (M20, completed)

- Characterizing the first part of the cooling circuit simulation, used to collect the data needed to define in a proper way the components to be implemented.
- Data collection on thermal loads and specific operating conditions from WP 2, 3, and 4.

Task 5.3: Cooling circuit layout definition and sizing (M22, completed)

- Defining the proper design configuration of the cooling circuit.
- Final choice for the coolant pump. This choice is based on different factors such as the data from IDM components (such as thermal loads and pressure drops), modularity, economic feasibility, and reliability.

Task 5.4: Simulations and Result Analysis (M27, in progress)

- Simulation of the cooling circuit under an entire driving cycle, design and tuning of a control strategy for the cooling circuit management and result analysis.

Achievements and possible areas of concern

Achievements

- D5.1 Documentation of the basic concept of the cooling circuit was submitted and approved.
- The following deliverables are submitted for approval:
  - D5.2 Thorough data collection from other partners and WPs and further analysis to build up a database
  - D5.3 System modelling for the evaluation of the final design
- D5.4 Results analysis and final report and/or scientific publications will be submitted soon.

Possible Areas of Concern

- The radiator map has been modelled by using limited data from few experimental points, which may lead to the design of a control strategy with low accuracy and reliability. For

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this reason, the control strategy will be tuned on the only data available and the control strategy already used in the donor vehicle will be implemented for sake of robustness. This will lead to the design of a reliable but rather simple control strategy, instead of a novel control strategy aimed at increasing the efficiency of the powertrain.

Deviations from GA

- No technical deviations.
- There has been a deviation in the use of resources between actual and planned use of resources in Annex 1, especially related to person-months per work package, owe to the activities carried out in the first year of the project, which have required a higher effort than the estimated. Another person has been added to the WP with an increase of the actual use of resources. Nonetheless, total final personnel costs will remain unchanged.

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WP 6 – Gearbox

Work Carried Out

Task 6.1: Requirements for the tribological design (M9, completed)

- Translation of requirements from vehicle level to gearbox system.
- Evaluation and definition of limits and possible solutions from the gearbox point of view.

Task 6.2: Evaluation and selection of tribological solutions (M15, completed)

- Selection of gear finishes and coatings for evaluation through testing under rolling-and-sliding contact.
- The tests with a twin-disc tribometer consisting of transversally ground steel discs and the selected gear transmission oil were carried out under experimental conditions that represented the lubrication and contact pressure conditions under average and extreme conditions in the prospective gear contacts.
- The experiments showed the benefit of applying polished gear flank surfaces and furthermore of using DLC-coatings on the surfaces.
- Preparations for tribological tests, with the aim of pre-evaluating surface roughness values and DLC-coatings for the transmission gearwheels, were done.
- Samples were made from the chosen gear steel grade, and with representative hardening and surface finishing.

Task 6.3: Test rig upgrade (M9, completed)

- New rig motor was purchased with capability of running at speeds up to 20 000 rpm.
- New rig motor is installed together with motor control unit.

Task 6.4: Transmission concept design (M15, completed)

- A concept selection phase has been carried out in the following steps:
  - Multiple concepts for the transmission were generated.
  - Factors of selection were identified.
  - Factors assigned weights of importance were defined.
  - The concepts were given a ranking of the factors, resulting in a final selection of a transmission design to develop.
- Efficiency maps for different gear ratios provided. The total system energy consumption was not analyzed for a driving cycle.
- The chosen gear ratio was selected on the basis of calculated efficiency maps with the fact that too high RPM will have a negative effect on the chosen lubrication system, which is not driven by an external pump.

Task 6.5: Transmission detailed design (M12, completed)

- The design of the selected transmission concept was completed.
- Computer aided engineering to simulate and analyze the transmission design was performed.
- Computer aided engineering tool to optimize and analyze the lubrication system was used.

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- o Analysis of concept housing model with computer aided engineering tool was carried out.
- o A CAD model of the complete hardware, within the scope of the supply of work package 6, was made.
- o Complete drawings for production intent of the transmission were completed and presented.

Task 6.6: Build, test & validation (M21, completed)

- o Build transmissions. Testing and validation of function, lubrication, NVH, efficiency and accelerated durability. To be performed in the updated 20.000 rpm test rig. Documentation. The measurement results will be related back to the simulated performance. One transmission unit will be shipped for complete system testing with the converter and electrical machine. In addition, one unit (or two units, depending on drivetrain setup) will be shipped for installation in the target vehicle and tested there.
- o Producing and building transmissions are carried out.
- o Test of function is carried out in rig (run-in of system). NVH tests were started but had to be aborted due to high vibrations at 18 000 RPM. Efficiency tests with different gear sets will be carried out during week 50, 2019. Due to limited availability to test rig and test personnel, vibration cause analysis and durability tests had to be cancelled.
- o Three prototype transmission units were assembled at BorgWarner and shipped to Danfoss in Finland for system testing. The transmissions included normal grinded gears. Two right hand units and one left hand unit were shipped. Included in the shipment were temperature sensors and oil.

Achievements and possible areas of concern

Achievements

- o D6.1 Tribology design requirements report.
- o D6.2 Tribology solution evaluation report.
- o D6.3 Transmission design report.
- o D6.5 Transmission prototype delivery.

Deviations from GA

- o Large vibrations have been identified in the transmission test rig. The cause is at current time unclear but believed to be induced by mechanical rig setup. However, this issue is not affecting the time plan for prototype delivery to Danfoss, D6.5.

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WP7 - Assembly, testing, demonstrations

Work Carried Out

Task 7.1: Assembly of demonstration drivetrain system (M24, in progress)

- All the components, i.e. Inverter, eMotor, Gearbox and sub-frame with mounts, brackets and cooling module (radiator assembly), delivered on site at Danfoss facility in Lappeenranta Finland.
- Mechanical assembly almost complete.
- Instrumentation of all the sensors and actuators done.

Task 7.2: Demonstration drivetrain system performance evaluation (M27, not started)

- Not yet started

Task 7.3: Assembly of one demonstration vehicle (M30, in progress)

- The following activities have been completed:
    - 800V rechargeable energy storage source (RESS) is ready and mounted on the test bench.
    - Mechanical integration
    - Electrical integration (LV & HV architecture)
    - Thermal integration
- The software integration is still in progress.
    - VCU and Inverter SW integration in progress CAN protocol and CAN frames reviewed and agreed.

Task 7.4: Demonstration vehicle performance evaluation (M33, not started)

- Not yet started.

Task 7.5: Display of the vehicle at project final event at NEVS premises (M33, not started)

- Not yet started.

Task 7.6: Disassembly and donation of the integrated drivetrain modules (M36, not started)

- Not yet started.

Achievements and possible areas of concern

Possible Areas of Concern

- Previous area of concern and update to them
    - **800V Charging Station:** Currently at NEVS, all the charging infrastructure is for 400V system. To test the charging functionality of 800V battery system, an 800V charging station is essential. This issue has been flagged and NEVS is looking into possible solutions.

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UPDATE: This issue has been solved by adapting new HV architecture i.e. by using an 800-400 DCDC bi-directional converter. Furthermore, the carryover On-board charger can be utilized for AC charging (slow charging) of the 800V battery pack. The charging functionality is under test with promising early results.

- **HV Architecture:** Various components in the existing NEVS 9-3 EV operate at 400V (like DCDC 400-12V converter, On-board charger and AC compressor/heater). There are ongoing activities to find the possible solution for this issue. However, NEVS engineers view this as a concern mainly due to unavailability of off-the-shelf components rated at 800V. Furthermore, this issue will not affect the main objective of the demonstration vehicle but will only reduce the ride experience of the demonstration vehicle.

  UPDATE: As mentioned earlier, the use of new 800-400 DCDC bi-directional converter has allowed for both 800V and 400V DC bus. By employing this strategy, we have effectively eliminated the need of replacing the carry over components that use 400V.

- **SW Integration:** Some incompatibility issues with CAN Protocol (especially Identifier bits), with the inverter-VCU SW interface. SW integration team is further evaluating the issue and looking for possible solution.

  UPDATE: CAN protocol has been agreed between NEVS and Danfoss. CAN frames between the VCU and Inverter have also been reviewed and agreed.

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WP8 - Dissemination and exploitation

Work Carried Out

Task 8.1: DRIVEMODE dissemination and communication strategy (M3, completed)

- DRIVEMODE D&C plan contains the main strategic and operative guidelines that shall govern the overall dissemination and communication strategy.
- D8.1, submitted on M3
- D8.8, submitted on M18

Task 8.2: Project identity (M10, completed)

- The DRIVEMODE logo
- The official Brandbook
- DRIVEMODE website (http://drivemode-h2020.eu), released on time in M4 (as reported in D8.2)
- Social media strategy:
  - Twitter: the hashtag #DRIVEMODEH2020 has been launched since the beginning. A series of social media GIFs have been produced to promote project workshops.
  - A common LinkedIn Corporate Page (called Electric Drivetrain Innovation Cluster), jointly managed by the dissemination leaders of the GV-04 projects (ModulED, ReFreeDrive, and DRIVEMODE)
- The official project flyer has been produced and printed (D8.4, submitted on M10).
- The DRIVEMODE short animation video completed (as described in D8.3).
- The partners' internal repository for documents' exchange (released in conjunction with the launch of the project website).

Task 8.3: Stakeholder relations (M36, in progress)

- Dissemination Tools:
  - Info packs will be produced according to the needs and results/innovation related to the project. The first Info Pack has been produced on M16 about the *Integrated Drive Train Module*
  - Technical Handbook (M34), including key info about the main features of DRIVEMODE solutions & technology
  - One digital storytelling tool, to be released towards the end of the project
  - Video interviews (3), press & news releases: to be carried out towards the end of the project.
  - Yearly e-Newsletters
- Networking, Clustering, Events:
  - 2 Workshops, 1 Webinar (M34), 1 Final Event (M36)
  - World Magnetic Conference during Colitech 2018 (September 2018, Pordenone, Italy)
  - Workshop on high efficiency and low-cost drivetrains for electric vehicles (March 2019, Brussels)

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- World Magnetic Conference during Colitech 2019 (September 2019, Pordenone, Italy
- 1st Conference on Sustainable Mobility (CSM2019, October 2019, Catania, Italy)
- Clustering Activities with GV-04 projects (ModulED, ReFreeDrive): TRA 2020 Helsinki (27-30 April 2020) joint stand at EC booth. DRIVEMODE participating also with video producer and journalist

Taks 8.4: Public communication, distribution and monitoring (M36, in progress)

- Journalistic articles will be written by professional journalists to inform and to stimulate the readers' interest on DRIVEMODE and its activities. They will be distributed to a wider audience via online information multipliers, thematic platforms and magazines. Up to now, 2 journalistic articles have been produced.

Task 8.5: Designing the path towards exploitation (M36, in progress)

- Completed:
  - Identification of ER and IPR:
    - Organized and run interview calls for individual exploitable results with all partners
    - Preliminary IPR Discussions in each call & in Nuremberg workshop
    - Preliminary consolidation of ERs collected & first draft of library (before Nuremberg workshop)
    - Second draft of library with revisions/suggestions from ICONS
  - Market analysis report:
    - Desk analysis of legal issues, impacts on DRIVEMODE and foreseen mitigation/other actions
    - Agreement on topics & approach with NEVS
    - Desk research and collection of inputs
    - Draw up of market analysis structure
    - Coordination with NEVS for final deliverable
    - Collection of exploitation inputs via questionnaires from participants at Coiltech Fair (Pordenone) and CSM (Catania)
  - Business model:
    - Leveraged Library of ER for initial discussion on individual business models
    - Set up of business model & governance frameworks depending on final exploitation pathways of the powertrain (4 options identified)
    - Two workshops to discuss DRIVEMODE business model (Nuremberg & Lappeenranta)
  - Exploitation plan:
    - Leverage inputs from all other STs to start planning/designing DRIVEMODE strategy at individual and project level
- Ongoing:
  - Identification of ER and IPR:
    - Second round of interviews/calls with partners to solve doubts and fill missing information
    - Continuous discussions and updates to individual libraries and IPR strategy via emails

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        - Dive on joint exploitable results and related IPR including the powertrain
        - Final Consolidation and delivery of Library at month 30 (VTT & ICONS)
        - Continuous update of legal issues, impacts on DRIVEMODE and foreseen mitigation/other actions
    - Market analysis:
        - Market analysis draw up (Drivers & barriers, analysis of competition, stakeholders, value chain, target market & demand)
        - Involvement of partners and end-users (to feed supply and demand side perspectives)
        - Delivery of market analysis report at month 35 (NEVS & ICONS)
    - Business model:
        - Business model and plan interviews following interviews on library of ER to industry partners to drill down into business model issues
    - Exploitation plan:
        - Gathering of inputs from all other STs
        - Gap analysis (to identify gaps in the exploitation roadmap) and further activities
        - Finalization of exploitation plan and delivery at month 36 (ICONS)

Achievements and possible areas of concern

Achievements

- The following deliverable were submitted and approved:
    - D8.1 Dissemination & Communication plan – M3
    - D8.2 Project website – M4
    - D8.3 Project animation video – M10
    - D8.4 DRIVEMODE flyer – M10
    - D8.8 Report on dissemination and public communication activities – M18
- DRIVEMODE project was presented in the following conferences:
    - Coiltech, 25-26 September 2019, Pordenone, Italy
    - CSM2019, 14-15 October 2019, Catania, Italy, joint dissemination with GV04 projects

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Publication Plan

Table 1 List of publications

Date	Authors	Title	Conference/Journal Details
2018.11.09	Nimananda Sharma, Yujing Liu	Multiple electrical machines applied for high drive train efficiency	2018 – IEEE ESARS-ITEC
2019.09.23	Mehrnaz Farzam Far, Michael Burghardt, Roland Bittner	Advanced powertrains for electric vehicles: Workshop on the latest EU Research in traction technology for electric vehicles	Coiltech 2020, Pordenone
October 2019	Tribioli L., Chiappini D., Miljavec D., Vukotić M.	Performance evaluation of an electric vehicle with multiple electric machines for increased overall drive train efficiency	Conference on Sustainable Mobility, CSM2019
2019.12.10	Flink et al.	High Speed Electric Drivetrain	CTI, Berlin, 2019
2019.12.04	Mikko Pihlatie	DRIVEMODE, Integrated modular distributed drivetrain for electric & hybrid vehicles	H2020RTR19 Conference, Brussels

Table 2 List of planned publications

Date	Authors	Title	Conference/Journal Details	Lead WP
27 – 30 April 2020	Mehrnaz Farzam Far, Mikko Pihlatie, …	Cluster demonstration: Next generation electric drivetrains for fully electric vehicles, focusing on high efficiency and low cost	TRA2020, Helsinki	WP1, …
17 – 19 June 2020	Nimananda Sharma and Yujing Liu	Design and Analysis of Auxiliary Inductor in Electric Machine Emulator for Traction Application	2020- IEEE ISIE	WP2
23 – 26 Aug 2020	Nimananda Sharma and Yujing Liu	Design and verification of an Electric Machine Emulator control for Traction Application	2020 – ICEM	WP2

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May 2020	Xiaoliang Huang, Nimananda Sharma, Yujing Liu	Validation of wheel slip control and traction optimization for distributed electric vehicles with Hardware-In-the-Loop system	TBD	WP2
27 – 30 April 2020	Mario Vukotić, Jutta Kinder, Katrin Wand, Michael Burghartd, Janne SamiKeranen, Damijan Miljavec	Hair-pin Winding in High-Speed Permanent-Magnet Machine		WP3
24 – 26 March, 2020	Nathalie Becker, Sandro Bulovic, Roland Bittner, Reinhard Herzer	Thermal simulation for power density optimization of SiC-MOSFET drive train inverters	CIPS 2020, Berlin (Abstract submitted and accepted)	WP4
5 – 7 May 2020	Roland Bittner, Sandro Bulovic, Matthias Kujath, Nathalie Becker, Sven Buetow, Nicola Burani	110 kW, 2.6 l SiC-inverter for DRIVEMODE - a highly integrated automotive drivetrain	PCIM 2020, Nueremberg (Abstract submitted)	WP4
17 – 21 May 2020	Sven Buetow, Roland Bittner, Sandro Bulovic, Reinhard Herzer, Johannes Klier, Nathalie Becker	Optimization of Automotive SiC-Sixpack Converter System with New Gate Connection for SiC devices and New Integrated Discharge Unit for Functional Safety	ISPSD 2020, Vienna (Abstract submitted)	WP4
TBD	Tribioli L., Chiappini D., …	Novel control strategy for the cooling circuit of a high efficiency electric vehicle	TBD	WP5

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Conclusions

The status of the project is healthy, all tasks are executed according to the GA. Deep cooperation through various communication channels has been established between partners providing fruitful and flexible working environment. The project has gone through initial requirement specification, iterative concept design, selection phases, detailed design of components, manufacturing processes, and component testing. The tasks related to IDM integration and further testing specification are ongoing.

The project has communicated its results mainly through the website and LinkedIn group. In addition, partners have presented advancements on several conferences, workshops with GV-04 sisters projects and scientific papers.

The usage of financial resources and working hours is reasonable and corresponds to the current state of the project. Slight deviation in timely submission of deliverables did not provide the impact on the project and proactive measures have been taken to eliminate this lag.

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Appendices

List of abbreviations

GA	grant agreement
WP	work package
FEM	finite element modelling
CAD	computer aided design
PMSM	permanent magnet synchronous machine

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