ANNEX 2: TEMPLATE FOR PROPOSAL UNDER DERRI

User-Project Proposal:

User-Project Acronym	EVOLVE-MAS
User-Project Title	Electric Vehicle Operated Low Voltage Electricity networks with Multi-Agent Systems
Main-scientific field	Electrical Engineering - Power System Operation
Specific-Discipline	Multi-Agent Systems

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Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	PhD student

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Activity type and legal status* of Organization	Higher Education Institution (1)
Position in Organization	PhD student

* Higher Education Institution (1) – Public research organization (2) – Private not-for-profit research organization (3) – Small or Medium size private enterprise (4) – Large private enterprise (5) – other (specify)

Date of submission	29/01/2011
Re-submission	YES________ NO__X___
Proposed Host TA Facility	TECNALIA-LAB (TA8)
Starting date (proposed)	15/03/2011

Summary of proposed research

The proposed research aims to test experimentally the operation of a Multi-Agent System (MAS) for the control of Electric Vehicle (EV) battery charging and discharging in power distribution networks. The control system will be evaluated in the laboratory facilities of TECNALIA-LAB. The algorithms of the MAS will be designed and developed in order to manage the charge and discharge of the EV batteries according to:

(i) Electricity price signals
(ii) Customer charging preferences
(iii) Distribution network technical constraints.

The EV owner will be represented by an agent that will respond to electricity price signals and the user's preferences. An intermediary agent will be responsible for interacting between a simulated electricity market, the Distribution System Operator (DSO) and individual or aggregated EVs. This intermediary is a form of an Aggregator and its aim is to represent a group of EVs and facilitate their participation in the electricity market.

The MAS which is currently under development at Cardiff University will be adapted to the specific equipment of TECNALIA-LAB. This procedure aims to validate via laboratory testing, that the EV aggregation concept can be used within a liberalised electricity market environment. The operation of the proposed system and the behaviour of the equipment of an individual EV will be evaluated under real conditions. The results and conclusions drawn from the operation of the MAS will be disseminated through appropriate journal and conference publications.

State-of-the-Art

Socio-economic, environmental, technical and political factors are driving a transition of the transportation sector towards low carbon vehicles. The term low carbon vehicles refers to vehicles that release low Carbon Dioxide (CO_2) quantities during their operation, such as Electric Vehicles (EVs). A significant share of European Union's (EU's) 27 member countries' CO_2 emissions (23.1%) is attributed to road transport [1]. EU set targets with respect to the levels of CO_2 emissions from vehicles for the years 2015 and 2020 [2]. These targets together with the actual average of CO_2 emissions (g/km) per vehicle for 2008 and 2009 are presented in Table 1.

Table 1: Average Actual and Target Tailpipe Emissions for New Vehicles in EU_{27} [2]

Year	*Emissions (g/km)*	*Year*	*Emissions (g/km)*
2008	153.5	***2015***	130
2009	145.7	***2020***	95

A document prepared for the European Topic Centre on Air and Climate Change [3] aggregated the projections of various studies regarding the share of new car sales that EVs may have in the future. Table 2 shows the anticipated EV uptake for the following decades

Table 2: Share of EVs in new car sales for 2030 and 2050 in Europe [3]

Year/Scenario	*Pessimistic*	*Moderate*	*Optimistic*
2030	5-10%	5-30%	50%
2050	25%	60%	80%

Several studies that address the impact of EV battery charging on real power distribution networks have been completed [4-8]. These studies show that the high EV associated load that would need to be accommodated by the power system, without any form of control or network equipment upgrading, could further burden the already overloaded distribution networks and modify the voltage profile of distribution feeders. A collaborative study between Cardiff University and TECNALIA illustrated that a dynamic price based control of EV battery charging may reduce the grid demand at a national level (of Great Britain and Spain) by up to 10%, compared to a scenario which lacks any form of control [9].

The technical and economic benefits of aggregating Distributed Energy Resources (DERs) and control systems for their management have been addressed in various European projects [10-15]. Some of these projects [10-11] demonstrated the application of MAS technology to control DER in real world implementations and in some of the DERri infrastructures. In project [12] the clustering of multiple micro-grids to form a Virtual Power Plant (VPP) through hierarchical agent based control was studied. The agent-based control paradigm has proved to enable DER participation in electricity markets as well as the capability to provide grid services to System Operators.

A unique characteristic of EVs as DERs is that they can be considered as simple and/or flexible loads/power sources, in terms of power systems. The concept of aggregating EVs was introduced in [16-17]. At present, EV aggregation and management frameworks are studied in various projects including [18-20]. In the project Mobile Energy Resources in Grids of Electricity (MERGE), specifications of a MAS which aims to manage and control the battery charging and discharging of individual EVs and fleets of EVs are provided [21]. This concept included contributions from both DERri applicants.

Previous work done at Cardiff University has indicated that the management of battery charging of aggregated EVs, may provide flexibility to the EV aggregator [22]. In addition, it has been shown that controlling the battery charging of distributed EVs may lead to the accommodation of higher EV uptake levels within distribution network technical constraints in a typical UK distribution network [23]. This network is also used in the MERGE project and is employed by DERri applicants for the development of the proposed MAS.

Building on the MERGE MAS concept, the present project aims to experimentally validate the proposed agent-based system that is currently under development at Cardiff University.

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Detailed Description of proposed project

The agent-based control system for the EV management comprises a hierarchical structure following the concept of the European Union's project MERGE. The types of agents used are: (i) EV Aggregator (EVA) agent, (ii) Micro-Grid Aggregation Unit (MGAU) agent (iii) Cluster of Vehicle Controllers (CVC) agent (iv) Central Autonomous Management Controller (CAMC) agent and (v) the EV agent. The agents are being developed using the Java Agent Development (JADE) framework.

The EVA agent will be responsible for interacting with the external wholesale electricity market, which would be simulated. This agent represents the Aggregator in a geographical area and would be located at the MV substation. Similarly, the MGAU and CVC would be located at the secondary substation at the MV/LV level. The CAMC represents the DSO and is located at the MV/LV substation level. The EV agent is located in the vehicle and represents the EV owner to the Aggregator. The EV owner via a user interface would be able to choose among the four charging modes as depicted in Figure 1.

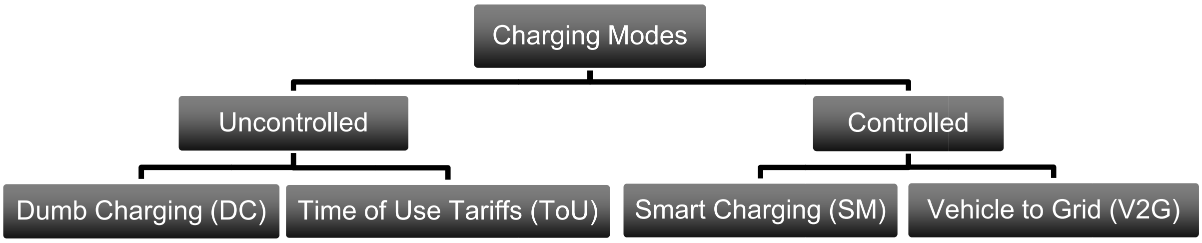

Figure 1: MERGE project EV charging modes

The *EV agent* will control the battery charging and discharging of the EV via the inverter that is coupled to the EV battery. Once the EV is plugged in a charging point, the EV owner chooses the preferred charging mode and the duration of the charging session by means of the user interface. These preferences are transmitted to the MGAU that manages the specific EV under its domain. The MGAU replies with the electricity price schedule (in half-hourly intervals) for the specified preferences. It is anticipated that the power rating of the charging point will be made known to the agent at the time of connection. The EV agent is expected to have the following information for the EV:

- EV battery size and characteristics
- Inverter/charger characteristics
- State of Charge (SoC) estimation

The core procedure of the EV agent is to produce a charging/discharging schedule for the charging session. This is expected to be accomplished by estimating the battery SoC and considering the user preferences and the price signals. The preferred charging schedule is sent to the MGAU together with alternative schedules by means of an economical priority list. The MGAU evaluates the schedules and replies with a set-point for the following time-step (15 or 30 minutes). Deviations from the profile with the highest priority for each EV will be recorded by the MGAU and compensated by the Aggregator. This core procedure is repeated every time-step with updated information regarding the SoC to ensure that the EV owner preferences are satisfied.

The EV agent will be adapted to the Electric Vehicle platform available in the laboratory (EV-ON) and will use the SoC estimator module developed in TECNALIA-LAB.

The *Electric Vehicle Aggregator (EVA) agent* is expected to retain the day-ahead schedules of each MGAU. These schedules are predicted by each MGAU and are assumed to have been traded in the forwards market and validated by the DSO and the Transmission System Operator

(TSO). The EVA is expected to initiate a planning period (every 15 or 30 minutes) to monitor, manage and fine tune its contractual position for the following operational period, having the following functionalities:

- Initiate the planning period by sending requests and electricity price schedules to the MGAU agents, in order to receive their preferred demand during the next operational period (15-30 minutes).
- Evaluate the responses from the MGAU/CVC agents and forward the aggregated portfolio to the CAMC agent for technical validation.
  - If the portfolio is validated, the EVA agent informs the MGAU/CVC agents to proceed with the desired set-points.
  - In the case of invalidation, it is expected that the CAMC agent will inform the EVA agent on the location where the problem is foreseen (i.e. line congestion, voltage statutory limits breach). The EVA agent informs the respective MGAU/CVC agents who choose the optimal change of their portfolio (i.e. the cheapest possible scenario). This change is communicated to the EVA and forwarded to the CAMC agent for re-evaluation. This procedure may be repeated until the portfolio is validated by the DSO.
- If at the end of the planning period the total energy required results in a surplus or a deficit, it is traded by the EVA agent with the external electricity market.

In the case of an emergency (i.e. severe congestion of line or voltage statutory limits breach), the CAMC agent will be able to switch off the charging point of the EV connected to the respective node and inform the EVA for this event. The EVA agent will inform the MGAU agent who will initiate its scheduling procedure for the emergency situation.

The *MicroGrid Aggregation Unit (MGAU) agent* will be responsible for the management of dispersed EVs in a residential area. It is expected to distribute electricity price schedules to the EV agents once EVs get connected, having in addition the following functionalities:

- To initiate the planning period for the EVs by sending them requests to update their prioritised list of profiles every 15 or 30 minutes.
- To receive the EV priorities lists and choose the optimal combination of profiles for each microgrid node in terms of cost, with regards to the committed day-ahead profile. The amount of energy required for the next operational period is sent to the EVA agent for evaluation.
- To send the final set-points to each EV agent for the next operational period at the end of the planning period.

In the case of an emergency (i.e. severe congestion of line/area or voltage statutory limits breach), the MGAU agent will choose a charging schedule for the disconnected EV that allows an idle state in the following period. At the start of the following period, the normal operation will resume and validation through the CAMC agent will be required.

The *Cluster of Vehicles Controller* (CVC) *agent* will be located in the facilities where large numbers of EVs are parked, such as offices and supermarkets. The CVC agent will assign charging schedules to the EVs according to contracted energy (day-ahead profiles), customer requirements and technical constraints limitations. In this case the charging decision making procedure relies solely on the CVC agent. The EV owner is only able to choose among dumb or smart charging modes. The rest of the procedure is identical to the MGAU agent. The agent will be adapted to the EV-ON platform available in the laboratory.

The *Central Autonomous Management Controller (CAMC)* agent represents the DSO and it is responsible for validating the EVA portfolio for each distribution network node under its domain.

This is expected to be carried out by means of an online power flow algorithm that is already implemented in JAVA^{TM} at Cardiff University. In addition, this agent will monitor the electrical nodes of the laboratory test network and will have the ability to disconnect EVs in the case of emergency (i.e. congestion or voltage statutory limits breach). The disconnection will follow a priority list which will be updated to avoid disconnection of the same EV during probable subsequent events. During emergency situations, the CAMC agent will inform the EVA agent which will proceed with the emergency condition procedure. It is anticipated that the DSO will have to compensate the EVA and the EV owner for this disconnection.

Objectives

The proposed project will have the following objectives:

- To design, develop and implement algorithms in order to manage the EV battery charging and discharging according to customer preferences, electricity price signals and distribution network technical constraints.
- To adapt the developed MAS to the laboratory equipment and test the interaction of the MAS with the EV agent which will be located at the Electric Vehicle platform (EV-ON).
- To test the operation of the multi-agent system under laboratory conditions: Through the variation of the laboratory generator and load parameters, different system emergency situations (reaching technical constraints violations) and loading conditions will be simulated in the laboratory.
- The system response to the emergency situations will be analysed. Different response time to the emergency situations will be subject of the experiments:
  - i) Problem foreseen by the CAMC agent (i.e. response time required in hourly horizon)
  - ii) Unforeseen emergency situation (i.e. response time required in seconds horizon)

The following are required from the infrastructure to achieve these objectives:

- User training on safety procedures would be expected. Health and safety assessment will be performed before the beginning of the experimental work.
- Computers to host the agents.
- A hybrid inverter/charger for the simulation of EVs with V2G capabilities.
- Monitor capability of the battery's State of Charge and control of the inverter's active power input/output, in order to be integrated in the multi-agent system.
- Evaluation of network operation will be required from the measurement equipment in order to monitor different nodes of the network.
- Variable controllable loads and generators with controllable outputs in order to simulate different system load conditions.
- Software and communication infrastructure between the computers and the laboratory hardware (i.e. charger/inverter, SoC estimator, multimeters, controllable loads, generators)
- Assistance in (i) the development of the simulated electrical network, (ii) the transfer of measurements to the agents and the (iii) set-points from the agents to the laboratory equipment would be expected.

The proposed system will be tested in both normal and emergency operations. Possible unforeseen issues would be documented and analysed. Practical difficulties that are usually faced in the laboratory will be tackled by careful planning in collaboration with TECNALIA's staff, as required.

Expected Outcome and Value

The expected outcome is the demonstration of the operation of the Multi Agent System able to manage the charge and discharge of EVs according to customer preferences and network technical constraints. With this control system it is expected to demonstrate the synergy that can arise between EVs and system operators in future networks with a high EV uptake. The purpose of the control system is to demonstrate the capability of the EVs to be treated as dispersed energy storage systems rather than just dumb loads, able to participate in a liberalised electricity market and defer extensive distribution network equipment upgrades.

The performance of this system will be measured and documented in detail. The results and the conclusions drawn will be compiled in a report with the help and supervision of TECNALIA-LAB's staff, as required, and also disseminated in relevant publications.

Originality and Innovation of proposed research – Broader Impact

The novelty of the proposed project lies on the management of EVs as Distributed Energy Resources. The proposed control is intended to enable the management of EV battery charging, in order to achieve their smooth integration in electricity distribution networks. The application of intelligent management systems and in particular, agent-based technology will be evaluated under laboratory conditions. The reliability of the system will be tested under different electricity network conditions.

The MAS approach of the present project aims to provide the EVs with the capability to participate in electricity markets and in the provision of ancillary services, such as coordinated voltage control. In such way, economical benefits, both for utilities and EV owners, may be achieved.

The multi agent system technology has been used in several projects in order to manage Distributed Energy Resources (mainly distributed generators). The control system aims to tackle the uncertainties of these "new" DERs imposed by human behavior, such as satisfying the customer preferences with regards to the electricity required to charge their EVs, including temporal uncertainties of EV grid utilisation.

Several studies have concluded through simulations that the EV uptake will impact distribution networks. The proposed project aims to demonstrate the feasibility of a management and control framework in a laboratory environment.

Proposed Host Transnational Access (TA) Infrastructure/Installation – Justification

The proposed project requires an installation where different load conditions can be simulated within a distribution network. The existence of EV battery and inverter equipment, and appropriate communication infrastructure between EV-charging point embedded processors and platforms that will host the agent-based system is deemed essential. The proposed host TA infrastructure is TECNALIA-LAB (TA8), for the following reasons:

- A system (EV-ON platform) for algorithms development and simulation of Electric Vehicles connected to the electricity network is existent and functional under the supervision of TECNALIA's experts.
- The EV-ON platform is equipped with a controllable bi-directional inverter/charger, which will provide the possibility to emulate EVs with V2G capabilities.
- A real micro-grid with the capability to be modulated, with TECNALIA-LAB equipment, according to experiment requirements is existent.
- Different system load conditions can be simulated by using the laboratory equipment such as the controllable diesel generators and the AVTRON load banks.
- The SoC estimation module developed in TECNALIA-LAB will be utilized for monitoring the EV battery's State of Charge.

- TECNALIA-LAB's staff has expertise in development of algorithms for the management of EVs, as presented in the publication "Platform for development of V2G Algorithms for Participating in Electricity Markets" E. Zabala et al. presented in the 2nd European Conference Smart Grid & E-Mobility 2010.
- TECNALIA-LAB's staff has extensive experience in aspects of design, development and operation of multi agent systems and smartgrids; has participated in major European research projects such as Microgrids, More Microgrids and EU-DEEP, and at present participates in ADDRESS and Cityelec projects.
- The lead user has collaborated with TECNALIA-LAB and as a result a journal paper has been submitted for publication.

For the above mentioned reasons, it is assumed that the infrastructure provided by TECNALIA-LAB (TA8) provides excellent conditions for the development of the proposed project.

No additional costs are expected, as all the required equipment is assumed to be in the laboratory facilities. The Multi Agent System software platform used is open source, therefore no extra costs are foreseen to incur.

Synergy with ongoing research

The EV multi agent system control tested in the TA infrastructure, together with the experimental results will be part of both candidates PhD thesis. The possibility to validate the control system through experimental results would increase the value of the control system, not being limited to a software environment.

Both users are participating in the European project Mobile Energy Resources in Grids of Electricity (MERGE), where part of the control system has been developed. Through the experimental validation of the system a synergy between both projects (MERGE and DERri) would arise. This project will provide the opportunity to validate MERGE findings through the utilization of DERri TA infrastructures.

Dissemination – Exploitation of results

The results of the tests performed in the infrastructure would be disseminated in appropriate peer-reviewed journals and/or conferences by means of at least one research paper. Some possibilities would be:

- IEEE Transactions on Smart Grid
- IEEE Transactions on Power Systems
- Universities Power Engineering Conference (UPEC)

Time schedule

Week No. (from 15/03/2011)	***1***	***2***	***3***	***4***	***5***	***6***	***7***	***8***	***9***	***10***
Introduction to the laboratories, identification of requirements, develop safety procedures										
Adaptation of agents to equipment:										
-- Development of test electrical network										
-- Development of interaction between agents and hardware of EV-ON platform										
-- Introduction of equipment parameters in agents										
Setting up other equipment (e.g. power meters)										
Testing period										
Analysis of results										

Description of the proposing team

Panagiotis Papadopoulos and Iñaki Grau Unda are pursuing their PhD in the Centre for Integrated Renewable Energy Generation and Supply (CIREGS) of Cardiff University.

Cardiff University is one of Britain's major centres of higher education. CIREGS was established in 2007. Recognising the changes that are anticipating in the future electricity supply system, CIREGS is developing research capacity in integrated renewable energy generation and supply, including "Smart Grids" of the future and contributing towards meeting the UK medium-term renewable energy targets. The research team of CIREGS, led by Prof. Nick Jenkins, has a track record of undertaking a number of EU and other funded projects.

Proposing Team's Publications

I. Grau, P. Papadopoulos, S. Skarvelis-Kazakos, L. M. Cipcigan and N. Jenkins, "Virtual Power Plants with Electric Vehicles", 2nd European Conference SmartGrids & E-Mobility, Brussels, October 2010.

Papadopoulos, P., Skarvelis-Kazakos S., Grau, I., Cipcigan, L. M., and Jenkins, N., "Predicting Electric Vehicle Impacts on Residential Distribution Networks with Distributed Generation", IEEE Vehicle Power and Propulsion Conference, Lille 2010.

Papadopoulos, P., Skarvelis-Kazakos S., Grau, I., Awad, B., Cipcigan, L. M., and Jenkins, N., "Electric Vehicle Impact on Distribution Networks, a Probabilistic Approach", 45th Universities Power Engineering Conference, Cardiff UK, 2010.

P. Papadopoulos, A.E. Umenei, I. Grau, R. Williams, L. Cipcigan and Y. Melikhov, "Effectiveness of a New Inductive Fault Current Limiter Model in MV networks", UPEC, Cardiff, 2010.

Papadopoulos P, Cipcigan L, Jenkins N, Grau Unda I, "Distribution Networks with Electric Vehicles", Universities Power Engineering Conference, Glasgow UK, 2009.

Grau Unda I, Cipcigan L, Jenkins N, Papadopoulos P, "Microgrid intentional islanding for network emergencies", 44th Universities Power Engineering Conference, Glasgow UK, 2009.

Grau Unda I, Papadopoulos P, Skarvelis-Kazakos S, Cipcigan LM, Jenkins N, "Electric vehicles to support intentional islanding", North American Power Symposium, Mississippi State University, USA, October 4 - 6, 2009.

Papadopoulos P, Cipcigan L, "Wind Turbine's Condition Monitoring: an Ontology Model", 1st International Conference on SUPERGEN, UK-China Network, Network of Clean Energy Research, April 2009, Nanjing China, 2009.

Moreira, C. L., Rua, D., Karfopoulos, E., Zountouridou, E., Soares, F., Bourithi, I., Grau, I., Peças Lopes J. A., Cipcigan L.M., Seca, L., Moschakis M., Rocha Almeida P. M., Moutis P., Papadopoulos P., Rei R. J., Bessa R. J., Skarvelis-Kazakos S. "Extend Concepts Of MG by Identifying Several EV Smart Control Approaches to be Embedded in The Smartgrid Concept to Manage EV Individually or in Clusters", Mobile Energy Resources in Grids Of Electricity, Deliverable D1.2, September 2010.

Skarvelis-Kazakos S., Papadopoulos, P., Grau, I., Gerber, A., Cipcigan, L. M., Jenkins, N., and Carradore L., "Carbon Optimized Virtual Power Plant with Electric Vehicles", 45th Universities Power Engineering Conference, Cardiff, 2010.

Carradore L, Turri R, Cipcigan L, Papadopoulos P, "Electric Vehicles as flexible energy storage systems in power distribution networks", International Conference on Ecologic Vehicles and Renewable Energies, Monaco, 2010.

Role of each member in the project

Both users will be responsible for:

- the identification of laboratory requirements and the development of safety procedures with the staff of TECNALIA-LAB, as required,
- the development and validation of the test electrical network,
- the setting-up of appropriate monitoring and measurement equipment,
- the test report preparation and writing.

The proposed MAS will be tested collaboratively by both users. The responsibilities of each user with regards to the development and implementation of the tests to be performed in TECNALIA-LAB are:

Panagiotis Papadopoulos will be responsible for:

- the adaptation and operation of the EV agent in the EV-ON platform of TECNALIA-LAB,
- the communication between the MGAU agent and the EV agent,
- the adaptation and operation of the CAMC agent.

Iñaki Grau Unda will be responsible for:

- the simulation of the EVA agent,
- the adaptation and operation of the CVC agent in the EV-ON platform of TECNALIA-LAB,
- the communication between the MGAU and CVC agents with the EVA agent.