Making energy management in the railway system smarter

The MERLIN project ‘Sustainable and Intelligent Management of Energy for Smarter Railway Systems in Europe: an Integrated Optimisation Approach’ is co-funded by the EU 7th Framework Programme and involves 18 partners including European railway systems integrators and equipment suppliers, railway operators and infrastructure managers, research centres, consultancies companies and professional associations. MERLIN’s main aim is to investigate and demonstrate the viability of an integrated management system to achieve a more sustainable and optimised energy usage in European electric mainline railway systems.

In order to reach the project objectives, an architecture of a Railway Energy Management System (REM-S) has been developed and a new business model for the system has been elaborated. The Railway Energy Management System implemented in MERLIN is an integrated solution aiming at achieving a more sustainable and optimised energy usage in European electric mainline railway systems. This can be obtained through a system monitoring the energy consumptions of the different subsystems of the railway network and their components and suggesting a ‘smart’ solution for the optimisation of use of energy in the different parts of the system.

Because of the distributed nature of the railway system, the system size, complexity and uncertainties, as well as the dynamic and moving nature of the loads, the energy management system is proposed to construct based on dividing the railway system into different local areas (zones). At least one intelligent substation must be present in each zone, acting as interface for the zone entities. Hence, it must be able to communicate to the other local entities, to the intelligent substations of neighbouring zones, and to the Control Centre, and through it to electricity market.

Figure 1 (page 5) depicts the general concept of the Railway Energy Management System architecture developed in MERLIN.

The architecture of the system, developed according to the Smart Grid Architecture Model (SGAM), i.e. a reference model of smart grid architectures for different sectors of application issued by the CEN – CENELEC – ETSI Smart Grid Coordination Group, consists in the optimisation of the energy flow through the railway system at different levels.

The first level is on a daily basis – Day Ahead Optimisation (DAO) – to calculate the optimum behaviour of the network for the next 1-2 days time horizon, trying to fix the energy need for the whole network with the market prices; this is performed by the Control Centre.
Then a Minute Ahead Optimisation (MAO) is locally performed for a minutes defined timeslot, to update the energy needs of each zone, matching with detailed predictions from each actor (energy source, storage system,...) and the energy bought at the DAO Operation. Following the DAO profile, MAO covers the interaction with all zone agents to fulfil power restrictions and suggestions, to accommodate surpluses and needs of the adjacent zones, and accordingly to suggest actions to zone agents, i.e. SSTs (substations), RSSTs (reversible substations), DERs (Distributed Energy Resources), ESSs (Energy Storage Systems) and the trains passing through the zone in the next timeslot.

Finally a Real Time Operation (RTO) actuates the calculated optimal timeslot profiles for the zone calculated by the MAO, taking into account the real time status and behaviour of all the components of the zone. The RTO suggests the best implementation mode, generating indications to be fulfilled by the different actors and/or components.

In this architecture DAO runs a Global Energy Management System (EMS) for the whole railway network yielding energy, power or cost optimisation with a top-bottom approach based on train timetables and power estimation profiles, railway distribution network characteristics, DERs estimated generation and External Consumers power estimated demand. In minutes ahead time slices, Local Energy Management System executed in each zone optimises power profiles locally with the target of following Global EMS plan. The Local EMS is done by coordinating resources to address fast, unanticipated occurrences, such as use of regenerated energy from trains, surplus energy stored in ESS or request of more energy for a train which is delayed. This level of optimisation is the link between centralised EMS and the Real-Time Operation in all zone agents.

As depicted in Figure 1, the REM-S, i.e. the integrated operational solution aiming at optimising the energy management of the railway systems, includes:

- On the wayside part:
  - the Energy Dispatcher, responsible for energy control: Central Energy Dispatcher for Day Ahead Optimisation at network level, Local Energy Dispatchers for Minutes Ahead Optimisation locally and for Real-Time Operation for implementation
  - the Energy Buyer Decision Maker (EBDM), interfacing with the electricity market, is responsible for electricity purchase decision and short-term energy trading.
  - On-board part:
    - the Dynamic Onboard Energy Manager (DOEM), reacting dynamically to the indications received from ground; it interfaces to the driver through the DAS.

After the definition of the REM-S architecture, the definition of the new business model applicable to the system has been carried out, in order to evaluate the system usability and applications.

Starting from the analysis of business models already used in the electricity market on one side, and from the conventional business model in the railway domain on the other side, the business models applicable to the MERLIN REM-S have been identified and the role of the actors involved has been defined.

Business activities between different companies are basically value flows among the business partners. The business model can be demonstrated by mapping the framework of these value chains. The value chains interconnect all business participants, and the medium to transfer the values from the firma to the customer, is namely the product, which can be commodity, service, information, etc. In a practical business case, the activities usually emerge in sequence, and due to this nature, the value flows come with some natural orientation.

As far as the MERLIN project is concerned, the interaction between the electricity market and the railway industry (infrastructure manager and railway operator) has been taken into consideration. Among MERLIN project actors, railway operators and infrastructure managers are both end-users in the view of the electricity market, as they consume electricity in most cases.

Figure 2 represents the value flows among the different actors involved in the project and shows how the MERLIN system is connected to the different actors of the railway and electricity domain.

In the business model proposed for the MERLIN system and represented in Figure 2, the following actors are present:

- The Electricity Market Operator, representing any company in charge of all the operations required for the electricity market operation (receiving the purchasing/selling bids, matching process, billing). Here the Electricity Market
Operator is introduced by the liberalised electricity market, which is in charge of operating the organised electricity markets.

- **The Grid Owner**, having the role of Transmission System Operator (TSO) and Distribution System Operator (DSO); the first one is an entity entrusted with transporting energy in the form of electrical power on a national or regional level, using fixed infrastructure; DSO is responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity.

- **The Energy Supplier**, referring to a party that supplies the customers or the market with electricity, and receives profits from the energy trading activities.

- **The operational Railway Energy Management System (REM-S)**, i.e. the integrated operational solution aiming to optimise the energy management of the railway systems, collaborating with internal and external partners, and carrying out the optimisation measures. These measures are either implemented by EBDM or delivered to the infrastructure manager and railway operator, and then they accordingly apply the optimisation approaches.

REM-S includes:

- **Energy Buyer Decision Maker (EBDM)**; it helps determining the best way of combining the available contracts with the participation in the spot markets to optimise the price of the energy. The EBDM module uses as an input a list of constraints supplied by an external *Electricity Procurement Planner* (EPP) (bidding strategy, long-term constraints for the bidding etc.). The *Electrical Market Forecast Provider* sends to the EBDM information regarding market prices previsions, behaviour of future sessions of the electricity market etc.

- **Energy Dispatcher**, responsible for the overall global energy dispatching at network level (Global Optimisation) and local energy dispatching (Local Optimisation) in REM-S.

The Electricity Procurement Planner and the Electrical Market Forecast Provider are external entities; the Energy Buyer Decision Maker can be independent or an external entity, as well as an internal entity or department of other actors, like an infrastructure manager and railway operator.

In the view of railway industry, the satisfaction of the customer demand is always the top priority. Introducing the MERLIN architecture, the values transferring with the customers have not been obviously changed. First of all, the railway operator supplies the customers with reliable delivery service, which means punctual arrival, safe operation and reliable transport plan. The customers purchase the transport service after providing the data about their intended deliver plans; whilst the operator publishes their regular operation plans and provides customised trip offers.

The new mapping model introduced in MERLIN is more complex than in the ‘conventional’ situation, owing to the introduced new role, the REM-S. A new value, efficiency optimisation, has been added to the overall mapping. In the MERLIN project, this optimal efficiency is realised by the new MERLIN architecture. It represents the sum of the functions carried out by the REM-S. As it is responsible for the efficiency optimisation, the efficiency value is initiated from it and flowing to the relevant partners, the railway operator and infrastructure manager. In the meanwhile, the braking energy enables the railway operator to feedback energy to the electricity market, which leads to some bidirectional value flows. This efficient energy optimisation helps...
The approach proposed from MERLIN is therefore bringing additional values in the railway domain, allowing an optimisation of energy, power and costs related the different actors involved in the whole system.

Reference
1. www.merlin-rail.eu

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The railway operator and the infrastructure manager need the information about electricity consumption from metering devices, in order to settle the energy bill, as well as the overall track arrangement plan, so as to confirm transport plans. Accordingly, the infrastructure manager also needs the periodical train schedules to accommodate all customers’ demands, and needs the approximate electricity consumption to purchase adequate electricity. In the MERLIN model, the feedback electricity from braking energy leads to some new information exchange and a new value flow from the railway operator to the infrastructure manager.

The energy supplier has the direct contact with the railway industry through providing electricity to the infrastructure manager. The energy supplier is conventionally mainly connected only with one actor from railway industry. The MERLIN model has introduced some new flows related to the energy supplier. The electricity can also flow from the infrastructure manager back to the energy supplier, as the regenerated energy flows from trains through railway infrastructure to the supplier or to the electricity market. The information exchange between REM-S and energy supplier contributes to the optimal planning of energy purchase. Moreover, the values exchange between the energy supplier and the railway operator is existent; nevertheless the electricity always flows through the infrastructure manager, namely the infrastructure manager is always involved. Besides, the other values, e.g. the information flow and cash flow between the railway operator and the energy supplier, can be both linked through the Electricity Market Operator and direct connection.

The canvas model of MERLIN has also been drafted, in order to comprehensively depict the business activities. Figure 3 (page 6) represents the canvas model for the railway operator. In comparison to the conventional model, a new customer segment has been introduced: the electricity market. The electricity market comes into being due to the liberalisation process of the energy industry. The reason why it is a customer for the railway operator lies in the braking energy feedback from the trains to the electricity market and due to the fact that the railway operator, according to the market liberalisation, is allowed to select the energy supplier. The central control/distributed control behaves as the channel to reach the customer.

Figure 4 (page 6) shows the canvas model for the infrastructure manager. The customer segments remain similar with those in the conventional model. Namely, the railway operator is the main customer. With central control, the business activities of infrastructure may also be distributed by the central control, which contributes to the global efficiency optimisation. Therefore, the Energy Buyer Decision Maker, which sends out the control price commands, becomes a key partner for the infrastructure manager. In addition, the smart grid technology enables the infrastructure manager to efficiently and economically operate the storage equipment, especially by trading electricity at the peak of consumption profiles. This facility also introduces a new part of revenue for the infrastructure manager.