THE INGRID PROJECT: OPTIMIZED STORAGE FOR COOPERATIVE SERVICES TO POWER DISTRIBUTORS THROUGH ICT-BASED ENERGY MANAGEMENT

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ABSTRACT

This paper gives an overview of an innovative storage service concept and the architecture of its concretization in a field demonstrator actually in progress. Aim of the system is to fulfil operational flexibility requirements and support electricity grid, to accommodate large shares of fluctuating renewable energy sources. The demonstrator will be deployed in Italy (Puglia) to prove the technical and business viability of combining solid-state high-density Hydrogen storage systems with advanced ICT solutions for balancing power supply and demand in the context of a Smart Grid paradigm.

The paper proposes a novel way to deal with the distribution network, by means of an ICT-based Energy Management System, which is being designed and developed for the INGRID FP7 R&D European Project.

INTRODUCTION

In the last years, a high increase of electricity produced by Renewable Energy Sources (RES) has been occurred in all the European countries. In Italy, starting from 18,335 MW in 2000, the installed capacity reached the amount of 41,399 MW in 2011: the EU directives imposed a target of 17% of the national entire energy consumption from renewable sources by 2020. Actually, the partial target of 19.6% was already overcome in 2011, with a total result for the electricity sector alone of 26.6% [1].

In such a scenario, the energy generated from wind and/or solar farms, which are usually positioned in rural areas, cannot be locally absorbed to a full extent due to the countryside dispersed small loads. Local unbalances between the load and the generation may arise with significant net power excess to be injected into the High Voltage (HV) transmission network. In Italy, for example, approximately 800 Medium Voltage (MV) bus-bars present a power counter-flow on more than 1% hours per year (to be compared to 4,000 total sections). With an increasing RES presence, active power counter-flow from MV level could cause higher power losses for long distance transport and, at worst, it may run into constraints on the HV level, leading to possible RES curtailment [2].

The integration of photovoltaic and wind energy poses serious challenges to the network, which might be addressed either through network reinforcement either providing the power network with some flexibility. If adequately combined with real time ICTs supporting monitoring and control, they allow electricity network to be effectively managed in a active way fully realizing the paradigm of a Smart Grid.

STORAGE SYSTEMS ENABLING FLEXIBILITY SERVICES

In the light of the recent trend for service orientation of the future energy systems, turning on DSOs (Distribution System Operator) core business from an asset management oriented to a service-oriented one, flexibility is expected to be offered, consumed and rewarded as a service to effectively operate the grid. At the current stage different ways for providing flexibility exist, ranging from demand-side (i.e. demand response) to supply-side flexibility (back-up capacity, generators flexibility, storage, cross-border compensation).

Storage overall has major advantages over the above sources of flexibility. For example, unlike most backup capacity plants, storage can deal with both troughs and peaks and can mitigate fluctuations close to the respective generation sources. Major drawback for electrochemical storage is technology immaturity and limited efficiency (ranging from the 30-35-45% of the Hydrogen energy storage to 80% of the batteries).

Together with electrochemical storage technology (i.e. direct storage), currently under investigation, indirect storage (or virtual electricity storage) solutions based on conversion of electricity in other energy vectors are gaining a lot of interest. Among them, the electric power to Hydrogen conversion represents a prospective opportunity.

Different flexibility services could be offered by storage systems in a mutual relationship with a DSO: generation profile flattening (capacity firm), black start, demand-supply balance, reserve capacity, ancillary services as voltage and frequency regulation. However the services being offered are strongly depending from the storage system technical characteristics.

Moreover, given the huge complexity of the future grids, system operators are expected to gain benefits from the availability of ancillary services provided by distributed generators [3]. The local balance function, that is the capability of following a required power profile modulating the absorbed/generated power, in the near future could represent a business opportunity for smart customer in areas with large presence of variable RES.

THE INGRID PROJECT

INGRID [4] is a European Project, co-funded by the European Commission within the FP7 Framework Programme for R&D.
The Project's goals can be summarized as follows:

- to design and make available advanced ICT monitoring and control tools aimed at simulating and managing power dispatching in compliance with the power request of the grid, allowing a correct balance between variable energy supply and demand;
- to investigate and validate novel cooperative models for the real time collaboration with the DSO, with the final aim of managing power consumption and supply requests by the provision of support services to the grid;
- to demonstrate the usage of an innovative Hydrogen solid-state storage technology, to be integrated in a closed loop coupled with a set of devices with the objective of achieving a high efficiency regenerative loop (larger than 50-60%) with a reasonable cost;
- to perform limited demonstrative scaled-down test case in Puglia region for assessing the high balancing capabilities of the storage system in presence of high variable electricity demand. The test case includes a small pilot version of a green urban mobility system (recharge of electric vehicles).

THE DEMONSTRATOR

A representation of the INGRID demonstrator is depicted in Fig. 1.
The INGRID prototype is about to be deployed in Troia (Puglia, Italy) where a concrete 39 MWh energy storage will be available soon. The prototype will be connected to a MV primary substation (150 kV/20 kV) and will drain electricity from the electric grid as a modular load from 0 to 1.2 MW.

Moreover the prototype will inject electricity to a LV feeder, if needed, in order to provide ancillary services ranging from 0 till 90 kW [5].

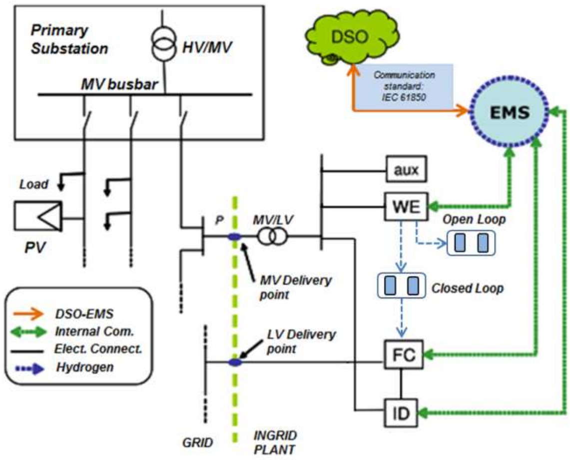

Fig. 1. Simplified INGRID plant representation

The choice of the primary substation was carefully carried out among different solutions: the selected one was the substation where the highest power reverse flow occurs. The curves in Fig. 2 represent the power requested by the distribution network to the transmission and transport network, managed by Terna, the unique Transport System Operator (TSO) in Italy. Fig. 2 shows the reduction of the electricity coming from the traditional generator during the years 2010, 2011 and 2012. Where the power flow curves reach negative value, a power reverse flow occurs [6].

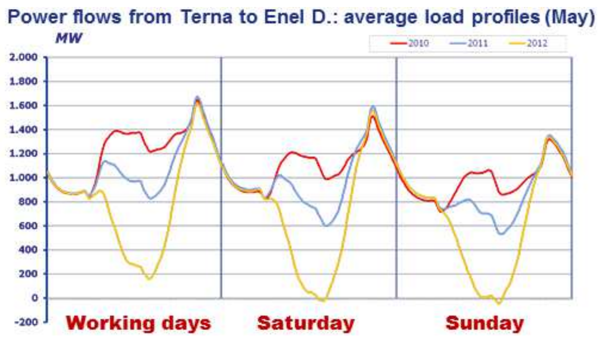

Fig. 2. Electricity exchange profile from Terna to Enel Distribuzione in Puglia region.

The INGRID system is composed by: a Water Electrolyser (WE), a Fuel Cell (FC), an Electric Vehicle Recharge Station (EVRS), a Hydrogen Storage System (HSS) and, in a larger concept, an internal RES based plant. Moreover, the connection to both the low voltage and the medium voltage electric grid and the possibility to reverse the Hydrogen gas into either the methane pipeline or Hydrogen market are considered.

The Hydrogen produced by the WE is safely adsorbed by the HSS modular sub-units. The particular characteristic of the HSS is the metal hydride technology usage, which has the following features [7] [8]:

- it adsorbs and desorbs Hydrogen at a constant pressure;
- the high-temperature metal hydride and the low-temperature metal hydride have similar dissociation pressures (self-regulating);
- the Hydrogen solid storage has the capability to store more Hydrogen per mass unit than gas and liquid storage forms;
- valves and pumps to extract the Hydrogen from the reactor vessel and to return the Hydrogen back to the reactor vessel may be avoided.

As aforementioned, the produced Hydrogen may be sent to the open loop consisting in either a Hydrogen market or methane distribution network as considered in [9]. Moreover, the Hydrogen may be used to re-obtain electricity by means of the FC (*closed loop)*. The FC generator can either supply a urban mobility system or provide ancillary services to the grid in order to solve issues related to the voltage profile or to load overflow [10].

The urban mobility system may receive electricity from the FC generator or through the grid connection, the whole depends by the Energy Management System (EMS) [11] decision based on both the economic benefits and DSO requests. The Electric Vehicle Recharge Station (EVRS) is considered without an energy storage system since the buffer function is already performed by the HSS.

THE ENERGY MANAGEMENT SYSTEM

The EMS, which manages the entire INGRID system, will exchange significant data with both external and internal subsystems, such as the Distribution Management System (DMS) and the Hydrogen Production and Distribution System (H_2P&DS), respectively. The INGRID concept may be represented in a logical way as reported in Fig. 3.

The EMS has the objective to gather the appropriate data and, on the basis of the strategy defined by the plant administrator - let's assume economically driven - it provides the optimal plant configuration, in terms of set-points and electric connections for the internal devices. The EMS optimizer tries to balance several needs: following the DSO requests, satisfying the Hydrogen merchants and EV (Electric Vehicle) recharging requests and the economic benefit. The EMS main activity is composed by two stages: planning and operational scheduling.

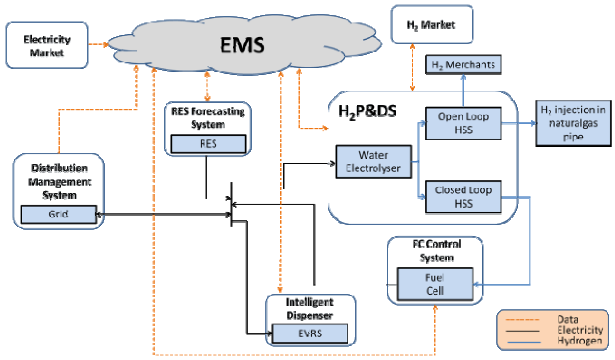

Fig. 3. Energy Management System scheme block [6]

At the beginning the EMS schedules the plant configuration along the whole *time horizon*. In real time for each *time slot* in which the horizon is subdivided, if a deviation from the scheduled activity occurs a re-scheduling job is performed [6].
The logic structure of the monitoring and control strategy is based on the master-slave control concept, where the EMS is the *master* and the remaining subsystems are the slaves.

In the followings, the list of subsystems (*slaves*) is reported:

- DMS (Distribution Management System);
- RES Forecasting system;
- H_2P&DS (H_2 Production & Dispatching System);
- Intelligent Dispenser (ID);
- Fuel Cell Control System (FCCS);
- Electricity Market.

The H_2P&DS is in charge of managing the WE set-points and HSS adsorption and desorption flow rate. Furthermore, the H_2P&DS manages the Hydrogen request related to the open loop. On the basis of those requests, it translates the Hydrogen demand and related delivery data as a set of constraints for the EMS. Then, the EMS can schedule and directly set the WE functional mode in real time.

The ID is in charge of managing the electric vehicle charges, taking into account the EV recharge bookings, EV recharge forecasts and the electricity price for EV owners. The Electricity Market communication is needed to know the electricity price.

The DSO's DMS provides the EMS with the desirable energy absorption/injection. This piece of information is enhanced with the incentive tied to the DSO requests. The DSO-EMS data transfer is realized by means of the IEC 61850 communication standard. The FCCS is in charge of receiving the functional mode set-points decided by the EMS.

SERVICE PROVISIONING AND POTENTIAL BUSINESS MODELS

INGRID has been investigating novel storage flexibility services tailored to support DSO requirements enabled by a cooperative framework. In order to enable novel cooperation models with the DSO with the aim of supporting its requirement for ensuring security and stability of the power distribution network.

It is worth underlining that in the literature usually a distinction between 'power' and 'energy' services is adopted. In the first case the device is able to exchange large power quantity in a short time (up to tens of seconds) while in the second application it is able to steadily exchange the rated power for longer times (hours typically). Pumped hydro, together with Compressed Air Storage Systems (CAES), is suitable for large size storage, while electrochemical technologies are gaining increasing interest for both power and energy applications with sizes depending on the specific equipment (energy/power ratio). The INGRID concept relies mainly on the 'energy' framework, thanks to its decoupling action between the power network and the Hydrogen system.

The proposed system can offer services to the DSO exploiting its flexibility in capturing the electricity produced by RES based plants, and then producing Hydrogen or providing electricity for EVs. The absorption/supply of electricity, following economic-based computations, also depends on the DSO requests. In particular a first set of services at both MV/LV have been already identified matching with technical requirements of the tailored applications:

Medium Voltage services
These services are provided through longer term solid Hydrogen storage and later Hydrogen value chain usages (Open Loop), to support electricity supply-side management services as a 'smart load':
- congestion relief (e.g curtailment mitigation /avoidance),
- capacity firming (i.e. balance of rapid RES fluctuations).

Low Voltage services
These services are provided through near-real time (within the range of minutes to few hours) by means of the high efficiency Hydrogen energy storage (Closed Loop) with later power re-electrification through fuel cell to support LV power grid energy management:

- residential/commercial peak shaving
- energy time-shifting,
- demand-supply balance,
- voltage regulation,
- collaborative support to the Electric Mobility Management of the power distributor (i.e. power generated via fuel cell could provide whereas necessary the power for electric vehicles recharging, when the DSO/retailer is not able locally to deal with it).

Different services could be deployed by the storage operator, depending from the storage ownership model. In that respect there are different feasible options which are under current investigation:

- INGRID owned and operated by a RES generator;
- INGRID owned and operated by a third party Independent Service Provider (Merchant model);
- INGRID owned and operated by an end user (e.g., commercial center);
- INGRID owned and operated by a DSO (which currently conflicts with the regulatory framework).

Despite all the relevant studies demonstrate a negative profit for the storage systems supporting DSOs in the current framework, INGRID has been investigating on combining different storage services in a vertical or/horizontal way. In particular INGRID services will be rewarded at the same time for the services offered at MV and LV networks, generating parallel revenue streams.

Despite Hydrogen energy storage is clearly underperforming with respect to other storage technologies, however overall system efficiency should trade off losses in energy conversions against curtailment reduction.

CONCLUSIONS AND FUTURE PLANS

The INGRID prototype will be one of the several components installed in a Smart Grid and it will be able to operate with the DMS and to communicate by means of the ICT infrastructure of the Smart Grid. The future challenge will be the evaluation of the grid impact of INGRID system and investigate about the best optimisation approaches of the energy balance problems. In future works all the concepts and issues discussed in the paper will be furthermore explained and particularised, while the progresses inside the project are achieved.

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