Towards the definition of an input-based Smart Grid regulation through the field assessment of the Italian demonstration projects

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ABSTRACT

Nowadays grid connected Renewable Energy Sources have reached a level that was not even conceivable just few years ago with serious concerns on power systems' stability and security. In 2010, the Italian regulatory Authority for electricity, gas and water system (AEEGSI) started the demonstration phase for smart grids by adopting an input based incentive scheme and a competitive selection process in order to award a limited number of projects. All projects are now in the rollout phase and the first data are going to be collected from the field in a real world environment. This paper describes the project status and defines the fundamentals of a regulation mechanism based on different levels of smartness and on the identification of suitable indicators to assess the performances of smart grids and, consequently, to define penalties and/or rewards for DSOs.

INTRODUCTION

During the last decade the development of DG (Distributed Generation), particularly due to the energy efficiency improvement of fossil fuel generation and to the deployment of new renewable sources, has increasingly stressed the operation of distribution networks, originally conceived to be operated as passive systems for delivering energy to loads. In the next future the need to install energy storages in order to balance the non programmable renewable generation, the growing up of electrical vehicle recharging infrastructures for electromobility, and the increasing of demand response/awareness of customers will create new challenges for the technological innovation of such networks requiring them to become "smarter" by developing innovative operating procedures in this new framework under increasing security and efficiency constraints [1]. This innovation path can be undertaken by developing pilot (or demonstration) projects that apply the knowledge and results obtained by research studies carried out in the last years to some real distribution electricity networks. Recently, following the experience gained during the development of smart metering thanks to ENEL demonstration project [2][3], a number of smart grids pilot projects have been proposed by some Italian Distribution System Operators (DSOs) within the framework of the resolution ARG/elt 39/10 of the Italian Authority for Electricity, Gas and water system (AEEGSI) [4]. This resolution defines which characteristics a distribution grid must have in order to obtain incentives, and provides the rules for preparing and selecting demonstration projects. It is worth noting that the resolution provides mechanisms for the co-founding process too. The assessment and progress monitoring activity of the demonstration projects which is being carried out by the AEEGSI is also a chance for trying to implement an output based regulation mechanism, i.e. based on the effects of a given activity or service, for future incentivizing actions. In recent years Italy has gained a significant experience in output based incentive regulation applied to Quality of Service (QoS) [5][6], but the development of an output based regulation applied to smart grids has proven rather challenging **Errore. L'origine riferimento non è stata trovata.**.

In this paper the demonstration pilot projects promoted by the resolution ARG/elt 39/10 are described with emphasis on the adopted input based selection mechanism. The development of new possible output based co-founding criteria is also discussed.

SELECTION CRITERIA FOR THE DEMONSTRATION PILOT PROJECTS

The selection of the Italian Smart Grids (SG) demonstration pilot projects was carried out, on behalf of AEEGSI, by a board of experts who worked according to the input based regulation philosophy provided by the resolution ARG/elt 39/10. In order to be admitted to the selection process, the project proposals had to fulfil the following minimum requirements:

- to be implemented and tested on a real existing MV network connecting both passive users and active users;
- a reverse active power flow from distribution network to transmission grid for at least 1% of the time in a year in the electricity distribution area covered by the demonstration project;
- real-time monitoring systems able to record all data needed for the correct operation of the network;
- only open and non-proprietary communication protocols for any communication application involving network users in order to minimize customer costs at the network interface.

By referring to the input based regulation philosophy mentioned above, the selection of the projects was based on a comparative assessment according to a key Performance Indicator (PI) based on a combination of quantitative and qualitative indicators. The quantitative indicator is the increase of DG power that can be connected to the grid with few or none network reinforcement without any violation of voltage, current and frequency constraints thanks to the "smart investments" in the network. The qualitative indicator is a technical score attributed by a panel of independent evaluators, coordinated by the board of experts. The technical score is based on four components:

- **A1 – Dimension** considers the number of active users involved, the size of the area involved in the pilot project and the attitude of the project on increasing production from DG;
- **A2 - Degree of innovation** considers the degree of innovation that the pilot project will introduce in the distribution system (ability of aggregating of DG, regulating voltage and managing the production), by making use of communication systems;
- **A3. - Feasibility** considers the timing of the project and the impact on quality of supply;
- **A4. - Replicability** considers the requirement of reproducibility on a large scale, looking at economies of scale and peculiarities of solutions.

According to the resolution ARG/elt 39/10, the selected smart grid demonstration projects granted an extra remuneration of capital cost (2% yearly extra WACC in addition to the ordinary return) for a period of 12 years [4]. The incentive is funded through the network tariff.

CURRENT DEVELOPMENT OF THE DEMONSTRATION PILOT PROJECTS

Enel Distribuzione has the most comprehensive project, whose aim is to combine the generation from distributed energy resources with a reliable and safe management of the system under real operating conditions. The project offers a new approach to the distributed generation management, which monitors the active involvement of both distributors and customers, recognized as prosumers of energy. Monitoring occurs through a broadband connection, based on a Wi-Max communication protocol as well as a fibre optics communication infrastructure. The project includes the installation of nearly 8,000 'Smart Info' devices for customers connected to the low voltage grid. These devices will supply information regarding changes in the price of energy based on time slots, promoting efficient use and increasing active customer participation in the management of the system. The project also includes the installation of a charging station for a fleet of five electric vehicles, integrated with a photovoltaic plant and a multi-functional storage system. The project adopts an innovative model for the protection, automation and management of power generation according to the principles of smart grids.

The project carried out by ACEA, a medium/large size utility located in Rome**,** has the ambition of realizing a real smart grid prototype, which could be replicable on the entire network of the utility. For that reason, the network involved in the pilot project is a significant part of the real MV network, which includes 2 primary sub-stations, 68 secondary cabins, 70 km overall length of MV lines, 28 MVA of distributed generation and more than 1000 LV end users. The project focusses on advanced automation of MV network (i.e. advanced fault line automatic localization, management of distributed generation plants, a novel monitoring system of transient faults for localizing the trigger point), acquisition of electrical and environmental variables of the MV and LV grids using TETRA/GPRS network enabling the new management techniques to be applied such as optimization of feeder voltage profiles, power flow management, minimization of energy losses and diagnosis of primary substation components (power transformers and circuit breakers).

The project proposed by DEVAL, a small utility located in the Alpine region, is aimed at restructuring an existing MV network by employing innovative technologies enabling the active network operation with particular attention to standardization and unification requirements as well as costs minimization. The main features are advanced network automation, Var/Volt control under normal operating conditions, active power limitation/regulation under emergency conditions, real-time monitoring of both load and distributed generation, real-time control/dispatching of local resources. The proposed architecture is a sort of "extended substation" organized into three functional levels (Primary Substation level, Secondary Distribution and User Substation level, Active User level). The communication system respects the centralized hierarchical control of the "extended substation" concept and employs a heterogeneous infrastructure (wireless, HSDPA, 3G, fibre optics, communicating each other through the IEC 61850 protocol) in order to better cope with the specific territorial constrains.

A2A, a large size utility of Northern Italy, is carrying out two companion projects, trying to apply the same concepts to different network contexts. The main features of the projects are: advanced network automation, tripping of DGs remote controlled by the DSO in case of network faults, logical selectivity between DSO and end users (active and passive) protection systems, Var/Volt control of DGs under normal operating conditions, active power limitation/regulation under emergency conditions, DG monitoring and real time data provision to TSO, and optimal management of DGs based on production forecast and real-time control. These projects aim at fully exploiting the regulation potentialities of Distributed Generation through a local dispatch, suitably coordinated with the TSO, which may also enhance the network hosting capacity.

The last projects are led by two small utilities located in Central Italy. The ASSEM San Severino Marche project represents a further application of the "extended substation" concept, i.e. electric system organized into logical levels, centralized hierarchical real-time control of remote distributed generation and use of different transmission vectors, whereas the ASM Terni smart grid project is more focused on services and the participation of active users to network management; more specifically the realization of the fundamental infrastructure to implement proper services for increasing energy efficiency, use of renewables and e-mobility is the most important aspect of the project.

The final stage of the projects will be devoted to the real-life experimentation. The assessment of the results will be performed with metrics capable of quantifying the level of smartness reached and the overall achieved performances (in terms of quality of service, hosting capacity, loss minimization, etc.).

INPUT vs OUTPUT BASED REGULATION

The on-going assessment activity of the demonstration projects will represent a good opportunity to study and tune an output based regulation mechanism. In fact a good regulation should be based on outputs, i.e. on the effects of a given activity or service, rather than on inputs, which means impose some predefined choices to the regulated company. Indeed, performance measurement requires clear and fair indicators strictly related to the pursued objectives and cleansed of external effects outside the control of network operators. For this purpose, levels of smart grid according to the increasing "smartness" of their characteristics are proposed in the following:

- **smart grid basic level**: the SGO can use an ICT system for the ultra rapid DG disconnection during line disturbances. The SGO exchanges data with TSO for power systems control and security;
- **smart grid advanced level**: in addition to the features of the preceding level, SGO adopts Volt/VAR regulation systems;
- **smart grid full operation level**: in addition to the features of the preceding levels, SGO adopts Volt/VAR centralised/decentralised regulation systems that enable all final customers to access the system services market, possibly by exploiting also storage facilities.

It is worth noting that at any of the above smart grid levels, the presence of a reliable ICT infrastructure enables also the implementation of advanced grid automation systems for Fault Location Isolation and Service Restoration (FLISR), which significantly improve the continuity of supply of active distribution networks. Advanced FLISR systems positively impact the Quality of Service (QoS) for all customers and, since Italy has an advanced QoS regulation, the smart grid effect on QoS will be part of that specific regulation and will not be considered in this paper. For an output-based regulation, the main variables involved should be identified. In order to simplify the problem the set of such variables should be limited in number and easily measurable. Moreover, variables should synthesise as better as possible the system behaviour and highlight the increase of benefits for final customers. In this work, the set of variables identified as the most representative of the "smartness" level of a distribution system is [8]-[11]:

- the capacity to connect new DER with a small CAPEX rate,
- the QoS for producers and consumers,
- the DER energy production,
- the voltage profile, and
- the integration with TSO control systems.

DER connection costs

One of the reasons why in recent years the stakeholders of the distribution system moved towards SG is the fact that SG technologies allow the integration of novel DER with less or none capital expenditures if compared to the more traditional approach in distribution business. This is often referred to as the increasing of *hosting capacity* achieved with, for instance, voltage regulation and the implementation of local markets for ancillary services. Even though the increase of *hosting capacity* is a clear follow up of SG implementation, it should be recognised that its usage for output based regulation is neither easy nor straightforward. Indeed, distribution systems, particularly in Italy, have recently been drastically revamped to allow the interconnection of RES. As a consequence, there are portions of the network that can now easily accept more RES and DER with really few investments; however, these networks cannot be considered SG in the sense used in this work. Indeed, if the rate of investments was used as one of the leading indicators for the SG output based regulation, there could be a clear risk to reward as SG a network previously revamped according to the traditional "*fit&forget*" policy simply because it can accept more generation than before the upgrading. In order to avoid (or limit) such risk, the amount of CAPEX in the MV/LV distribution network during the prefixed time horizon of regulation framework (e.g., three years) has to be taken into account.

QoS for producers and consumers

The performance of increasingly complex power distribution systems is often described by reliability indices for the overall systems as well as performance indices or other metrics for particular technologies and resources [7]. The indexes that are more useful for smart grid regulation are the following:.

SAIFI, *System Average Interruption Frequency Index*

SAIDI, *System Average Interruption Duration Index*

CAIDI, *Customer Average Interruption Duration Index*

CAIFI, *Customer Average Interruption Frequency Index*

CEMIn, *Customers Experiencing Multiple.*

The SG can positively impact all these indices depending on the smartness level introduced. The interruptions suffered by DER for network problems are seldom considered in reliability calculations, and the improvement achievable with SG with different level of complexity is often jeopardized by indexes that do not explicitly consider DER. Indeed, the availability of communication signals with small latency (100-200 ms) improves reliability indexes referred to DER. In the *Basic level SG,* CAIFI and $CEMI_n$ improvements for DER are expected. If FLISR is implemented, then the novel protection system will allow identifying within 100-200 ms a faulted area and reconfiguring the network so that only generators and customers in the faulted portion will be disconnected. This results, for instance, in a SAIFI reduction. This improvement is perceived by DER only if FLISR allows the prompt disconnection of only the generators involved in the fault. In the *Advanced level SG***,** the SG is supposed to have both advanced FLISR and Volt/VAR in place. The communication system is used for voltage regulation, namely achieved with the optimal control of the reactive power produced by DER (particularly at MV level). Since the vast majority of DER is interfaced with power electronic converters, the provision/absorption of reactive power can be easily achieved without the curtailment of active power. The second SG tier again positively impacts both CAIFI and $CEMI_n$ for DER since there is less or none need to disconnect generator due to sustained overvoltage. Finally, with *Full operation level SG,* it is again supposed to use FLISR and volt/VAR regulation. In this case DER and aggregated active demand, eventually with distribution storage devices, can participate to a local market for ancillary services and there are systems in place that allow the optimal exploitation of all resources. Again, in this case the optimal management of DER can reduce CAIFI and $CEMI_n$ for DER but, since power congestions a positive impact has to be expected also for the SAIFI.

RES/DER energy production

RES/DER energy production depends on many different factors as the availability of the primary source, the reliability/availability of the power plant as a whole, and, finally, on the QoS of the system. The QoS affects the capability to generate energy in two ways. Indeed, there are cases where the generator is connected to a portion of the system that suffered for a fault. In this particular situation the producers suffer for poor QoS as well as the other consumers fed by the same portion of the system. All actions that improve general QoS are positive for the producers too. Furthermore, generators in network without SG are disconnected also for faults in the feeder independently from the reciprocal position of faults and the generator itself. Indeed, the DG loss of mains protection should command the generator disconnection when perturbations on voltage and frequency are detected in order to avoid unintentional islanding. For this reason, it clearly emerges that the level of QoS for a producer is usually worse than the one perceived by the ordinary consumers, and this fact often causes to producers significant economic damages, particularly because the process of disconnection detection and reconnection can take significant time. Indeed, the DG/RES average size normally does not justify the presence of personnel for operating the plant and the remote control is not sophisticated enough, and for this reasons hours and sometimes days are necessary for DG/DER service restoration.

The SG can relieve these issues and, again, a measure of the improvements can be used for the performance-based regulation. It is clear that a simple measurement of the not-produced energy by DER/RES cannot be used because there is the risk to charge the DSO DER power plant malfunctions or efficiency decays. For these reasons, the use of the number of interruptions per customer/producer is better suited to SG regulation. The measure of the energy not produced can be used as a performance indicator with the most advanced SG implementations, which are based on a full control of DER and DG that might require the curtailment of active production. In this case, the smaller is the energy curtailment the cheaper is the system operation and, as a consequence, the higher is the SG performance. The energy not delivered due to SG control actions is a clear index for assessing the effectiveness and optimality of the Energy Management System used by the SG.

Voltage profile

Voltage regulation is nowadays a major issue in the day-by-day operation of distribution systems. RES and DER often cause overvoltage, particularly in the point of common coupling with the network. With SG the voltage quality and voltage profile can be improved with the optimal operation of at least DER for reactive support and, in more advanced applications, with the inclusion of active demand and distribution storage devices as well as the control of active power. For voltage regulation purposes, the communication infrastructure does not require very small latencies since the time granularity for this regulation is at least 10-20 seconds or greater. The number of participants represents the challenge here, particularly if LV customers and prosumers will be involved. The communication noise and the reliability/availability of the communication system might be a serious concern. The deployment of Advanced Metering Infrastructures (AMI) can make it possible the acquisition of voltage measurement in the nodes where generators are connected. The measurements can be grouped by gravity of overvoltage, if any, and by the relevant duration. A simple indicator can be the weighted average of the overvoltage in the range 1-5% weighed with the correspondent duration time.

Integration with TSO control systems

The amount of RES and DG connected to the distribution systems reached such a level that it can be no longer treated as a negative load. Primary substations will have to offer the same control capabilities offered to TSO. For this reason, each 20 seconds the expected production at the primary substation level aggregated by photovoltaic, wind, CHP, and other DG should be provided to TSO including LV generation. This means a tremendous effort for DSO since MV and LV producers normally are not equipped with measurement devices capable to transmit data with such high frequency. Furthermore, there is also a serious challenge for the communication system that has to take into consideration a high number of participants. The solution of installing millions of power measurement devices for the huge economic effort that is not affordable by DSO in the present situation of financial crisis. Then, there is a general consensus on the fact that state estimators will have to be used to integrate the data gathered from some strategic points in the network. The quality of these estimators is fundamental for the proper operation of smart grids, but it is fundamental for the operation of Power Systems. The quality of estimates provided by DSO to TSO can be another performance parameter of the SG. The uncertainty of estimates can be measured easily by comparing estimates with what really happened in the system. The performance indicator might be the reduction of the uncertainties achieved year by year with the integration of measurement devices, the adoption of advanced state estimators and the improvement in data analytics.

CONCLUSIONS

The Italian smart grid pilot projects are going to be completed very soon. The paper has described the most important features of these projects. The data to gather from the field in order to prepare the regulation for smart grid are also identified in the paper. The regulation should promote the innovation in the distribution system so that future networks will have systems in place to handle the novel paradigm of power generation. In order to avoid the risk that smart grid incentives do not give the expected benefit, the regulation should be based on the identification of few and simple indicators and on a metric that allows a fair assessment of the performances. The paper proposes five indicators, easy to calculate, that can be used to reward the DSOs that invest money in smart grids.

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