

Small hydro and distributed generation – problems and perspectives – the play is worth the candle?

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1 Introduction

In recent years, Distributed Generation (DG) is one of the recurrent keywords in the electric energy field. Many high level studies foresee an essential role in the 21st century for DG, expecting significant energy and money savings for billions € and kWh, and the consequent environmental and societal benefits. The expected benefits claimed associated to the expansion of DG, in particular, are related to the large increase of small renewable production plants, that can be operated only in case today electric grid installations and operation practices are changed.

Small hydropower, due to its feature of intrinsically distributed and site-specific electric energy source, can play - even though little acknowledged if compared to other Renewable Energy Sources - a major role in the implementation of DG systems.

With reference to the Italian situation, for example, it must be said that, despite of the more and more increasing hindrances to the implementation of new plants, in the period 1999-2009 the number of small hydro plants (up to 10 MW installed capacity) increased by more than 270 and the installed capacity from 1787 to 2190 MW, out of a total RES installed capacity (excluding large hydro) in 2009 of 11.454 MW that is 23% of the total. The energy produced by small hydro in 2009, the last year which the official statistics are available for, was 10.383 MWh out of a total RES production (excluding large hydro) of 30.576 MWh, that is one third; the comparison between installed capacity and energy produced underline once more the well peculiarity of small hydro in terms of reliability, predictability and continuity of supply so that it makes it the ideal energy source for DG.

However, among small hydro people the perception of the opportunities and the challenges connected to DG is still poor, mainly because of scarce knowledge of the power system issues related to this subject.

That's why the paper deals with the three main orders of problems related to the implementation of DG systems driven by small hydro:

- the legislation side, by reviewing the actual normative framework from technical rules, administrative procedures and legal interfaces, to measures for grid stabilization, referred to control and regulation of voltage and frequency in transmission and distribution grid, with the aim to outline the main adjustments required to implement a new generation of DG, in which the small hydro power plants could play a primary and significant role;
- the generation side, by investigating the main problems and constraints to hydropower generation coming from being a producer inside a smart grid, both from the operation and the adjustment of the existing equipment point of view; additional network (ancillary) services that could be provided by hydro power plants will be investigated depending on the equipment installed and on the control procedure that would be necessary to adopt. The impact of such new framework will be detailed adopting a technical - economic approach.
- the grid (especially distribution, but also transmission) side, by enucleating the main and indispensable technical issues related to the implementation of DG, in terms of current technical barriers to the DG penetration given by the distribution network limits today present, possible technical solutions and related costs. In particular, in this environment, the contribution potentially provided by hydropower generation specifically designed to this goal will be highlighted and its value will be compared to other RES power plants.

2 Regulatory framework

2.1 Transmission Grid

According to the unbundling, that is generally acknowledged throughout the world following the electricity market principles, electric systems are typically divided in three main sections: generation, transmission and distribution. Such subdivision is also implemented in the European Union legislation framework even from the administrative point of view: i.e., the same company cannot be at the same time a producer, a distributor and a transmission operator.

In Italy, Terna is the Transmission System Operator (TSO) and is responsible for operating and maintaining the transmission grid (EHV and HV, i.e., 380 kV - 220 kV - 150 kV), keeping security and balance of the system.

As the Italian legislation [a] prohibits TSO from owning generating equipments, Terna must purchase power balancing services and reserve capacity from commercial power producers. These services are part of a more general set of services, called Ancillary Services (AS).

2.2 Distribution Grid

The final delivery of the electric energy to small/medium customers is performed by the distribution segment at medium voltage (MV, typically in the range 15 kV-24 kV) and low voltage (LV, 400 V) levels. The distribution grid is managed by local distribution companies, in short DSOs (Distribution System Operators).

In the past, the distribution grid was planned and designed to delivery electricity to end users in a one-way direction, following the broadcasting model: from few centralized big power plants to millions of users.

2.3 Ancillary Services

Electricity is not a storable commodity. Hence it is necessary to produce the requested quantity and distribute it through the system, in such a way as to ensure that electricity supply and demand are always balanced, thus guaranteeing the quality of the service.

Some Ancillary Services (AS) are particularly interesting for the goal of the present paper:

- *frequency control*: necessary to balance in real time any unbalance caused by the unexpected load changes and/or generation contingencies; it is divided in primary, secondary (f/P) and tertiary control; these services are provided by both generators that are already synchronized to the grid, with additional capacity available (spinning reserve), and generators that can be synchronized to the grid in different time frames;
- *reactive power support/voltage control service*: it is essential for the system operator to maintain an acceptable system voltage profile by setting the voltage magnitudes; in some Countries, it is divided in primary and secondary control;
- *black-start generation*: capability to restart a grid following a black-out.

Today, at the distribution level, AS are not considered at all, because they are typically provided by large generation plants, but for the future new trends are showing.

2.4 Ancillary Services Market (ASM)

The Ancillary Services Market (ASM) is the market where Terna procures the resources needed to operate and control the system (procurement of the reserves and real-time balancing, also called “load following”). This market consists of a scheduling stage (*ex-ante* Ancillary Services Market) and of a Balancing Market (real time balancing). Primarily, during the scheduling phase and after the closure of the day ahead market, the TSO operates to procure the necessary reserve margins and to solve potential congestions. During the real time phase the TSO can re-dispatch the generators by modifying their outputs (increase or decrease of injections), in order to solve any real time network congestion and to maintain the balance of the system. Terna accepts energy demand bids and supply offers for the ASM in order to provide its service of secondary control and balance energy inputs and withdrawals into/from the grid at any time and in any node of the grid.

Participation in the ASM is mandatory, but restricted to units that are able and authorized to supply AS and bids/offers may only be submitted by their dispatching users.

In the following table the main features of each ancillary service are listed.

<i>Service (resource)</i>	<i>Mandatory/Voluntary</i>	<i>Remuneration</i>	<i>Ancillary service market</i>	<i>Extra costs covered by</i>	<i>Type of intervention</i>
Frequency control (spinning reserve for primary control)	<i>Mandatory</i> for relevant units of production [UP] (P>10MVA) eligible for service	No direct remuneration. If a UP is not able to furnish that service, it has to pay a substitute fee	N	-	Automatic
Frequency control (spinning reserve for secondary control)	<i>Mandatory</i> . UP qualified had to present their bids to ASM	Market	Y	Uplift of electric tariff	Automatic
Frequency control (reserve for tertiary control)	<i>Mandatory</i> . UP qualified had to present their bids to ASM	Market	Y	Uplift of electric tariff	manual intervention under TSO directive
Voltage control (reactive power for primary control)	<i>Mandatory</i> for UP eligible for service	No direct remuneration. If a UP is not able to furnish that service, it has to pay a substitute fee	N	-	Automatic
Voltage control (reactive power for secondary control)	<i>Mandatory</i> for UP eligible for service	Direct remuneration	N	-	Automatic
Black start generation	<i>Mandatory</i> for some kind of relevant units of production (P>10MVA) eligible for service	No direct remuneration.	N	-	manual intervention under TSO directive

Currently, as can be seen from the table above, all the ancillary services are to be provided mandatorily, when technically possible. However, at the distribution level, they are not considered at all, because they are typically provided by large generation plants. In the Smart Grid framework, instead, and depending on the increase of RES penetration, such services are expected to be provided more and more by small/medium size plants connected to the distribution level, and maybe in the future, even paid according to market principles.

3 Distributed Generation: the grid side of the problem

The growth of Distributed Generation¹ (DG) must be included in the regulatory framework briefly outlined in the previous chapter.

In the last decade, DG has gained great attention thanks to the significant advantages it can bring on the overall sustainability of Countries. In the EU, in particular, its benefits have been highlighted for many years and many incentives programs have been set up to reach the ambitious goals of the Union. The main advantages are: the exploitation of RES that typically is maximized by small and distributed generators (today, MV and LV grids host about 75% of the RES production [b]), the consequent reduction of the carbon intensity, the improved efficiency due to the fact that generation is usually closer to consumption and the consequent reduction of losses (the latter issue is, however, true under the assumption of limited penetration of DG). Moreover, the closeness of DG to the final loads results in an improvement in terms of quality of supply, in the sense that the overall reliability is increased; from the economic point of view, it can determine a deferring of investments in building new lines and transmission facilities. However, there is a number of technical obstacles that prevent the immediate large increasing of DG. The main barriers to the increase of the DG penetration at MV and LV levels are related to the changes in the planning and operation of such grids. Currently, distribution grids are traditionally planned and operated as passive grids, i.e., the power is assumed to flow from higher to lower voltage levels. This is because, in the past, the generation was mainly injected in the grid on the HV and EHV levels by large power plants and the distribution grids were mainly devoted to supply loads at the different power levels. This scenario holds as far as the generation connected to a distribution feeder remains much lower than the load connected on the same feeder, i.e., until the power flow does not reverse. For these reasons, the distribution grids are equipped with controls, protections and procedures that assume unidirectional power flow on the substation transformers.

¹ There is not a definition of Distributed Generation accepted at international level, anyway this term usually refers to small/medium size plants connected to LV and MV grids. In Italy this definition is generally referred to plants with capacity under 10 MVA.

From the voltage control point of view, often the HV/MV substations are equipped with tap-changers aimed at controlling the low voltage side of the transformer. This control will operate in order to set the voltage reference in such a way that all bus voltages along the feeder will be within the technical limits [c]; this can be easily predicted if the grid is passive. If a significant amount of DG is installed on that feeder, it is necessary that a coordination between the control of the tap-changer installed in the substations and the DG real and reactive power generation is achieved, otherwise the voltage on some busses could be out of the technically acceptable limits.

From the protection system point of view, typically the protection system installed in substations is such that it is able to identify the faulted feeder, and disconnects it from the remaining part of the grid; this is possible, in passive grids, by the only measure of currents. The automation substation system typically tries to automatically reclose the feeder to manage transient faults. Today, interface protection systems of DG is such that when detecting a fault the generators must be instantaneously disconnected from the grid. This is to prevent unwanted islanding, i.e., the operation of some feeders disconnected from the main grid. Unwanted islanding could result in out-of-synchronism re-closing of breakers and in safety problems for the personnel of the DSO. As far as the DG penetration is not large, the disconnection of large amount of DG causes a small imbalance that can be easily managed by the power system. When the DG penetration increases, a large disconnection from the main grid could cause larger imbalances and result in a larger perturbation for the main grid.

The significant penetration of DG can also cause, with the protection and control systems in operation today, false tripping of protection devices, blinding of protection, change of short-circuit power depending on the connection and disconnection of DG.

Also fault search procedures, today based on opening and reclosing of feeders, cannot be implemented easily in the presence of significant DG along the distribution feeders.

Last, but not least, RES are typically intermittent sources and therefore can cause large variations on the imbalance of the bulk grid, resulting in large reserve requirements unless large storage resources are available, even locally; also in this case, however, coordination of all resources is a strict requirement that must be put in place.

Technical solutions for increasing RES and DG penetration are the so-called *Smart Grids*. In Europe, one of the most popular definitions of the Smart Grids (SGs) today has been proposed by the European Smart Grid Technology Platform. It defines the intelligent network as:

"a power grid that can intelligently integrate the actions of all users, and its related generators, consumers and prosumers (neologism to describe those who are at once producers and consumers) in order to deliver efficient, safe and sustainable supply electricity".

In the SG environment, many techniques already in place in transmission EHV and HV systems are exploited also for distribution grids, with the goal of overcoming as much as possible all the technical barriers listed above. In particular, communication systems play a paramount role because they allow the coordination between the protection devices installed at the DSO substation, at the generation plants and even at final consumers. They will allow to dispatch all available resources at any level in order to exploit, in any operating condition, all RES for generating electric energy, all control resources (real and reactive power, reserves, storage, etc.), while maintaining reliability, security, and quality of supply. The diffused properties of DG, however, make it necessary to adopt low cost communication systems, due to the capillarity of the distribution grids; at the same time, such communication systems must be reliable, secure (also with respect to cyber security) and cheap. This is why the public Internet is often adopted, together with ZigBee, WiMax and other similar communication systems.

4 Features of Hydropower generation in the SG environment

Hydropower generation is characterized by some peculiar positive features that can help the DSOs in facing all the above mentioned technical barriers. Therefore, the presence of hydropower generation can be very appreciated in the deployment of *Smart Grids*.

First of all, of course, hydropower generators, and in particular small plants, are among the most important RES facilities [b]. Therefore, hydro plants are likely to be present in distribution feeders. All benefits in the exploitation of such sources are well known, but can be viewed in a new light under the *Smart Grids* environment.

Depending on the type of electric generator, ancillary services to the DSO grid can be provided:

- **Voltage control** in AC networks can easily be provided by synchronous generators: it is well known that, despite their higher cost, synchronous generators with controllable excitation can work both generating and adsorbing reactive power, thus providing the capability to leading or lagging power factor. This feature depends on the real power production level and on the voltage, according to the capability chart of the generator. On the contrary, induction generators or permanent magnet synchronous generators can provide lower level reactive services, because either they need reactive power from the grid in any operating condition or they cannot change their reactive output. Controllers able to modify the power factor set points can also be adopted. At the time being, it is in the discretion of the plant owner to choose the type of generator to install at the power plant. For the smaller sizes, the asynchronous choice is usually prevailing as it is a cheaper solution (for small, < 1 MVA

and micro < 100 kVA generators the difference is approx. 100 €/kVA; in percentage, for example, a 400 kVA asynchronous generator can be 25 % cheaper than a synchronous one).

- **Real power control** can also be provided by hydropower plants. When possible, a more or less large storage capability is highly appreciated by the DSO, as a modulation capability can be associated to the hydropower plant. This is more and more true in case of pumping storage hydro plant, that from a power system point of view, play a very important role in lowering overall electricity costs. The availability of storage also increases the **programmability** of the power plant, thus reducing the overall uncertainty level negatively affected by the other intermittent RES (like wind, PV). Actually, also run of river plants (which are the great majority of SHPs and almost the whole of the micro HPs) could play a role in the real power control service. In fact, a run-of-river plant, given a certain flow rate available for production, can be operated as a spinning reserve or at a partial load lower than the maximum of the moment, which is easily predictable on a short term basis (two-three days or more) on the basis of weather forecasts. Let us assume a run-of-river SHP with a rated flow of 22 m³/s and a minimum turbine flow of 8 m³/s. Moreover, let us assume that on the basis of a reliable weather forecasts or of a run-off method, an almost constant flow rate of 16 m³/s is expected for the energy production. Instead of operating the plant at 16 m³/s, the producer can guarantee the DSO a base output corresponding to 10 m³/s and the availability to cover peak loads up to an output corresponding to 16 m³/s (6 m³/s of additional capacity). This kind of operation makes sense in small grids where other intermittent and less predictable RES are connected (PV, wind); the latter sources in principle could give also the power corresponding to the above mentioned 6 m³/s, but in turn can easily experience a sudden or unexpected decrease of the resource available and are therefore less reliable. In this case, the SHP can immediately supply the immediate lack of capacity from other RES up to additional 6 m³/s.

Obviously this kind of operation implies to “waste” water, that is to spill water at the intakes and not to use it for hydropower generation, resulting in a net loss hydro production; however, from a system point of view, it makes it possible to maximize the sum of programmable and not-programmable RES generation. In the current system of tariffs widely spread in Europe, this results in a net loss of income for the hydro producer; therefore, the implementation of this new role for SHPs in SGs should be accompanied by a suitable new system of remuneration of the real power control service provided.

- The same comments can be made for what concerns the possibility to implement different **frequency control** strategies for hydropower plants. Controllability of real power is also appreciated and therefore suitable for hydropower generation also depending on inputs coming from the DSO: for example, **emergency control** at the DSO substation, in case of network congestions, can generate signals to be sent to the producers in order to decrease, but also increase in some cases and when possible (usually not for wind and PV generators) the generation level. Of course, in such cases, suitable communications and actuators must be designed and installed at the hydropower plant. Frequency control is mainly connected to the rotational inertia of the generators. It is worth noticing that wind and PV have not large inertias associated, thus resulting less suitable for this kind of AS. As this service is currently assigned to large generators, SHPs are at the time being equipped with the lighter possible generators to reduce the cost of investment. If in the future, within a SG a part of the frequency control service will be assigned to SHPs, they must have a rotational inertia large enough to contribute to this service. This implies higher costs of investment in the generator estimated in not less than 10 % of the cost of the machine.
- **Electric transients and network perturbations** can result in disruptive effects and cascading events in power systems. Therefore, it is important from the DSO perspective that generation plants and the relevant protections are robust enough with respect to such occurrences. Typically, rotating generators are more robust compared to power electronic devices, such as inverters or other similar machines. In any case, the Grid Codes recently introduced strict limits on the performances that must be guaranteed by generation plants, especially for wind and PV plants; hydro plant are generally robust enough against such events.
- In the same manner, hydropower plants are traditionally able to provide **black start capability** to the grid in case of blackouts. Of course, the design of the plant must carefully consider this possibility and put in place every device able to perform all the needed operations. At the time being, the black start capability in SHPs is an exception at it can be found in some old plants which in the past delivered the energy produced directly to workshops, factories, steel and saw mills and which kept this feature more for historical reasons than for a real need of the producer. As we said, almost all the SHPs are connected to MV and LV grids where today the black start capability is not required or even undesired. This additional service potentially required to SHPs has also additional investment and operation costs as well. The black start capability, in fact, requires at least the installation of an energy emergency system and devices (e.g., diesel generator coupled with UPS for driving HPUs, etc.) actually doubling the cost of a remarkable part of the Auxiliary Services of a SHPs. A rough estimation of those additional cost for a 2MW plants is around 50.000-70.000 €. Additional equipment implies additional O&M costs, mandatory for devices connected to the security of the energy supply.

As a general conclusion, Smart Grids and modern power systems require that the generation plants are as **flexible** as possible with respect to both local information (i.e., information coming from the measurements at the connection bus) and signals coming, through an adequate communication system, from the DSO.

5 Barriers to the penetration of Smart Grids and Distributed Generation

5.1 Incentives

The decision of the plant owners about active participation in competitive markets - which is a pre-requisite for the implementation of SGs based on DG, where a part of the AS currently supplied by large plants could be supplied by SHPs - will be strongly influenced by gain/loss evaluation.

First of all, we need to face against support schemes. In Italy we have a Feed In Tariff scheme (FIT) for small plants (capacity under 1 MW) and a Green Certificates scheme (GC) for all the other RES plants [d].

In other European Countries and also outside Europe, small RES plants are often supported by schemes such as FIT, that are linked only to energy production; an overall administrative simplification for the energy producers is also sometimes connected to this kind of schemes, because the total amount of energy produced is delivered to a single national operator that sells it on the market. Producers do not have any direct link to market. These provisions do not stimulate the market oriented generation and consequently do not drive towards a full market integration of the RES/DG generation capacities.

Maybe a different approach could be evaluated for support systems linked to GC, since it is a sort of feed in premium. In this case, single producers can directly manage the energy in the market. Unfortunately, a new piece of renewable legislation adopted in 2011 [e] has established that the system of GC in Italy will expire and also in other EU countries the GC scheme has been abandoned.

It will be useful to evaluate if the switching from FIT to wholesale competitive market is or not economically feasible and convenient. At the moment, with high FIT, market options do not seem so favourable. Maybe the new emerging market opportunities at the ASM could create a greater incentive for RES/DG plants that are not incentivized, or for plants out of the FIT period.

Another hindrance to the penetration of DG in SGs is related to the regulatory facilities granted to not programmable RES which must not deliver any program of production, have the right for the priority of dispatching and do not pay any fine, like the programmable plants do, in case they do not meet the agreements made.

5.2 Costs of adaptation of the system to new DG and SGs

5.2.1 Costs for DSOs

Currently, DSOs are the subjects which should bear a remarkable part of the costs for adapting the grid to new DG in a SG framework.

That is why in Italy, as reported in more detail in Section 6, the Regulator is financially promoting the field testing of some Smart Grids implementations, which include projects where small hydro plays an important role.

5.2.2 Costs for the producers

As we said above, the producer should bear for sure direct costs related to the adaptation of the energy production equipment to an operation within a DG over SG system. Some of them depend on the size of the generating unit and other are more or less independent from it. In any case, the order of magnitude is from 50.000 to 100.000 € or more.

As the operation within a DG over SG system has as a pre-requisite the active participation on the market, additional costs must be borne:

- metering and equipment costs for the use of the system;
- trading fees for having access to the market portal;
- personnel costs for trading;
- additional operation costs (if a tertiary control is required - made by a simple phone call - the real time availability of the operator at the plant is necessary).

As already mentioned, there are also indirect costs related to the lost production, in case the plant is required to supply the real power control service and the lost production, in case the generating unit is required to be operated for long time far from the optimum efficiency point as well.

6 Perspectives

In Italy, the Regulator issued in 2010 the Order [f] to give Distributors incentives for the field testing of some Smart Grids implementations. This resulted in the financing of 8 pilot projects that will start a larger scale development, as also a law document of 2011 [e] states.

The general technical solutions adopted by most projects are aimed at the following issues:

1. Increasing the reliability of the protection system of DG by means of remote tripping: in order to avoid the mis-operation of protections based on local measurements, the DSO issues a signal to be sent to the DG. When the signal is present, it enlarges the setting of the DG protections (especially the frequency protections) and allows the generator to remain connected in case the fault can be cleared successfully by other grid protections; in case the signal is absent, the setting of the protections is more restrictive (stand alone logic).

2. Local improved voltage control: when the bus voltage reaches an upper threshold, it switches to a voltage control able to drive the generator to under excitation conditions (e.g., power factor equal to 0.95) and vice versa. The voltage control can be improved making the generator able to receive signals coming from the DSO that can coordinate all reactive generation resources on the feeder: tap-changers, capacitors switching, etc.
3. Monitoring/control of real power generation: this will allow the DSO to communicate to the TSO the real and reactive power injected in the DSO grid and forecast on the power exchanged at the interconnection substations. This makes it easier to operate the power system at both the transmission and the distribution levels, keeping security and efficiency.
4. Possibility to modulate (increasing and/or decreasing) the DG production level depending on the operating conditions of the grid. The modulation can take place if the generation plant can reduce and/or increase its output; the worst case is that modulation cannot be applied but only the complete disconnection of the generator or of the complete power plant can take place.

In all cases, the communication system is of paramount importance. In many project presented for this program, the public Internet is exploited through the DSL or WiMax technologies. In some cases, dedicated links using Wifi, optic fibers or optic fiber ADSS (all dielectric self supporting) are adopted. The communication protocol adopted is the IEC 61850.

Beside of the technical issue an important step to the integration can be made by suitable payments of services to attract SHP producers to actively participate in the energy market (assuming that the current incentives system is radically modified).

The so called “capacity payment” mechanism - that is a mechanism which rewards not only the energy produced, but mainly the capability of a plant to match the instantaneous capacity requirement from the grid – can be a first step.

7 Conclusions

The penetration of the Smart Grids in the electrical system is universally considered as a fundamental step towards the sustainability of energy production and consumption in the near future.

Within Smart Grids deployment, energy production from renewables is expected to play a crucial role with special reference to small hydro, which could adapt to the new requirements of the operation in a Smart Grid much better than any other renewable source.

Assuming that the distributor should bear their own costs of adaptation, the integration of small hydro into SGs should require remarkable costs of adaptation for the producer also.

It makes sense that these additional costs (both investments and operation costs) are borne by the producer only if an economical benefit results from.

The profitability of an integration in SG/DG system strongly depends, as rather obvious, on the regulatory and tariff framework where the plant is located in. With reference to the Feed In Tariff system - which is the prevailing one in Europe for supporting small hydro – the higher and certain is the tariff, the lower is the motivation of the producer to undertaken an investment oriented to a SG/DG adaptation.

That is why in parallel with the deepening of the technical issues, the creation of a suitable regulatory framework favorable to the integration of RES in the Smart Grids is mandatory, in order to overcome the current barriers which induces to conclude that at the time being the play is not worth the candle.

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