Paper prepared as application to 2016 ERRA Award

Smart metering: an evolutionary perspective

Guidelines and lessons learnt from the Italian regulatory experience

Alessandro Pitì [1], Eleonora Bettenzoli [2], Marco De Min [2], Luca Lo Schiavo [2]

[1] Department of Electronics, Information and Bioengineering, Politecnico di Milano, 20133 Milano, Italy; alessandro.piti@mail.polimi.it (corresponding author)
[2] Italian Regulatory Authority for Electricity Gas and Water (AEEGSI), 20121 Milano, Italy;

Abstract

Aim of this paper is to draw some general advices on smart metering from a significant long-term regulatory experience in Italy. Smart metering systems provide benefits for the whole value chain of the power sector including new actors. it's intended to provide all the regulatory authorities with insights on a conceptual evolutionary perspective for smart metering, underlying different applications and goals according to the structure and maturity of the general change trends in electricity, like privatization, liberalization and system transformation. Three typical approaches are described, and benefits are reported according to the relevant main goals: increasing efficiency in the distribution-oriented approach, fostering competition in the retail-oriented approach and promoting customer awareness and market participation in the customer-oriented approach. Countries and NRAs that are considering or assessing to substitute traditional meters with new smart metering systems can draw some important advices driven by the Italian experience, according to their specific context, the set-up of the power system and their market structure.

Three typical smart metering purposes

In recent years, smart metering is playing a crucial role in a growing number of countries, characterized by different conditions of market structure, unbundling of activities over the electricity value-chain, renewable energy sources (RES) penetration and customer empowerment, in a global trend that moves towards more decarbonized energy systems and more competitive energy market at both wholesale and retail level. As a common *one-size-fits-all* solution does not exist in the real world, each country should identify and develop its own plan for smart-metering roll-out, instead of applying a fixed model. On the ground of fifteen years of regulatory experience in Italy, this paper provides three different approaches, driven by different sets of goals, to move towards a smart metering adoption according to an evolutionary perspective, considering the specific national power system.

The need that initially governs the migration from traditional metering technologies to automatic meter management is essentially related to network management and metering efficiency: on-spot readings and on-site operations for contractual management (e.g. new supply activation, de-activation, changes in contractual power limits etc.) are considered inefficient by both meter operators and regulators. Additionally, energy thefts and frauds may be very frequent in given contexts and smart metering is an extremely powerful tool for revenue protection. Raising efficiency, towards which privatization pushes electricity utilities, is often the key process that kicks off the deployment of smart-metering infrastructure, even without a specific mandate by regulators: this is what happened in Italy since 2001, when (after privatization of the formerly State-owned utility, ENEL, and before retail market full liberalization, completed in 2007) the main distribution company started the roll-out of new electronic meters and the installation of an advanced metering infrastructure (AMI).

Another advantage of smart metering systems is the capability to couple the measurements with the corresponding timestamps, allowing the introduction of new tariff mechanisms based on Time of Use (ToU) that fit the variability of energy prices in a closer manner than flat electricity prices. Although such a benefit may be exploited also in vertically-integrated systems and can be useful for network management as well, it may be better exploited in those power systems where the retail supply is separated from the distribution activity (unbundled system).

In an evolutionary perspective, retail competition is a second reason that pushes towards smart metering. Indeed, it enables two important pro-competitive features: first of all, it allows retailers to enlarge their commercial offer for the final customers, promoting competition, because customers may choose the offer allowing them to save money, (e.g. if they are able to shift loads towards lesser-price hours of the day); secondly, smart metering allows meter operators to collect spot reading exactly when the final customers switch to a different supplier, avoiding estimates or costly on-site spot readings.

At last, the third motivation for the evolutionary perspective towards smart metering system is about the electric networks, recently undergoing a strong revolution, mainly caused by a new "distributed paradigm". Distributed generation, intermittent renewable energy sources, storage systems and novel loads like heat pumps and, in the next future, electric vehicles, are heavily complicating the management of the equilibrium to match the energy demand-offer curves. Energy infrastructures have to change accordingly: smart grids, able to make loads and generators more flexible, are getting crucial for such a scenario but, to be efficient, network operators need to collect accurate measurements regarding power flows and network status (including voltages). Services able to ensure stability of the grid have to become more participated by all network users, from large generators to distributed ones including demand-side resources.

Hence, the way the final customers are informed in close-to-real-time about their electricity withdrawals, consumption and generation is particularly crucial. Thus, in an evolutionary perspective the introduction of smart metering systems is a key enabler of an important step forward, towards a new conception of the whole energy value chain, giving first of all a new role to the customer.

Acording to a recent ERRA position paper [1], for an effective result, the technological improvement has to be coupled with well-evaluated schedule, representative pilot projects and regulatory support. National authorities must encourage the development removing potential barriers and supplying adequate incentives to stimulate the corresponding markets. It has been proved by the experience that results are stronger in those countries with a significant regulatory push and oversight. Smart metering is not only matter of technological innovation: above all, it calls for a wide change in regulation in different fields, like data management, settlement, balancing, and billing. The first aim of regulation is extracting the benefits of smart metering and transferring them to the final customers, whether through tariff and service quality regulation of monopoly activities, or through competitive mechanisms for liberalized activities like supply and generation.

The case for smart metering in Europe

With a focus on the European scenario, Italy has been – together with Sweden – one of the first cases of nation-wide roll-out of smart metering systems in Europe and still currently is the largest-scale case in operation: more than 35 million customers have their smart meter (SM) installed and working. The Italian case of smart metering raised a large interest in scholars and a seminal study of the former President of CEER [2] was at the root of the provisions of the European Directive 2009/72/CE. According to Annex A.2 of this Directive, from 2009 all Member States have been required to make a cost-benefit analysis to introduce smart metering in large scale, in order to have an economic assessment of all the long-term costs and benefits for the DSOs, the market players (like suppliers and aggregators) and the final consumers. In those countries where roll-out of smart meters is assessed positively, Directive 2009/72/CE requires that at least 80% of consumers shall be equipped with intelligent metering systems by 2020 [3].

European Commission (EC) has supported this Europe-wide extensive process with many initiatives: among them it is worth citing the mandate to CEN/CENELEC/ETSI for smart metering standardization, that in turn produced several progresses in this field [4] [5] and the Recommendation n. 2012/148/EU, a non-binding advice that provided the list of 10 functional requirements (**Hiba! A hivatkozási forrás nem található.**) that are intended to be the minimum common set of functionalities for all Member States [6]; however, the details of the roll-out strategies on technical and regulatory criteria are defined independently by each Member State, according to subsidiarity principle.

Table 1: ten common minimum functional requirements recommended in EC Recommendation n. 2012/148/EU [6]**.**

Area	Functional requirement
Customer	a) Provide readings directly to the consumer or any designated party
	b) Update readings frequently enough to use energy saving schemes
Metering operator	c) Allow remote reading by the operator
	d) Provide two-way communication for maintenance and control
	e) Allow frequent enough reading for networking planning
Commercial aspects of supply	f) Support advanced tariff systems
	g) Remote On/off control supply and/or flow or power limitation
Security – Data protection	h) Provide secure data communications
	i) Fraud prevention and detection
Distributed generation	l) Provide import/export and reactive metering

In 2014 the European Commission published a benchmarking report [7] showing the first results of the Member States in smart metering deployment. In most of the European countries where a smart metering system has been already installed or is going to be, the benchmarking shows that almost all the implementations satisfy the above common set of functionalities. Due to the complexity in matching all the requirements and the different power system set-up of each Member State, the cost-benefit analysis showed very differentiated results as reported in Figure 1. As shown, in some countries the estimated high costs coming from the analysis blocked the roll-out decision (e.g. in Germany for customers below 6.000 kWh/year). Italy has a remarkable cost leadership position, mainly due to large scale economies of the dominant DSO.

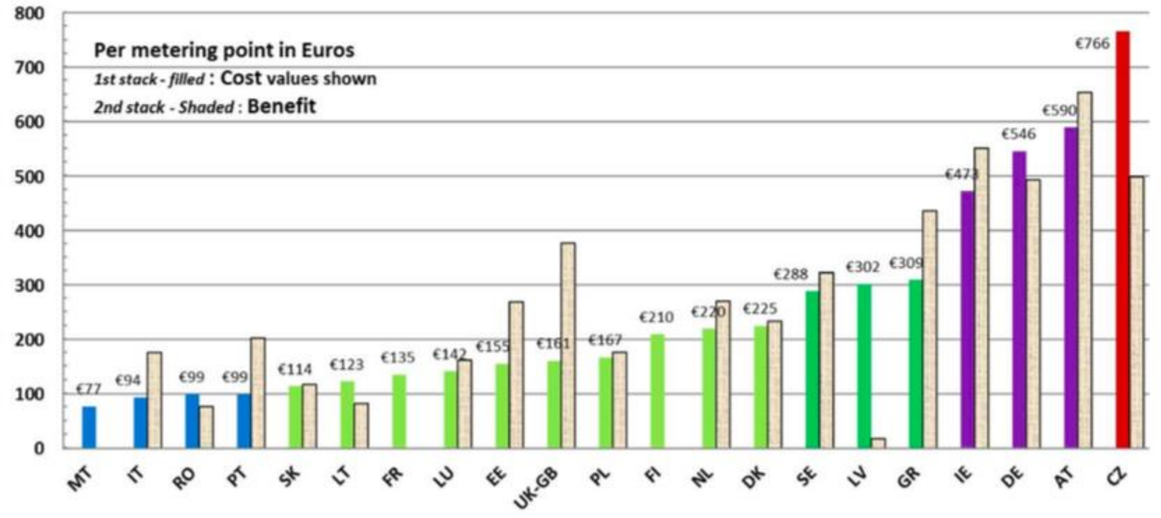

Figure 1. Results of the cost/benefit analysis in the EU Member States according to **[7]**.

As a last development, both Italy and Sweden are now coping with the challenge of replacing the "first generation" (1G) of smart meters that have reached the end of their expected life for regulatory purposes. In both countries, public consultations have been conducted to analyze the needs for additional functional requirements [8] [9]. In Italy, the Regulatory Authority for Electricity, Gas and Water (AEEGSI) took a formal decision (87/2016/R/eel; an unofficial translation is provided as an annex to this paper), defining not only the *functional requirements* for "second generation" (2G) low-voltage smart meters but also *performance levels* expected for second generation *smart metering* systems, A specific tariff regulation, based on Total Expenditure (Totex) approach, in order to avoid different treatment of capital costs (CAPEX) and operational costs (OPEX), has been devised for Italian distribution companies that have to launch their 2G substitution plan, in order to get a further upgrade in the technology of smart meters and consequently deploy benefits (decision 646/2016/R/eel).

Moving from the Italian experience, in the rest of this paper features and benefits of three different cases for smart metering are reported following the evolutionary perspective described above. Countries that are still using electromechanical meters can first focus on those benefits more related to the distribution management, in particular regarding the reduction of the reading costs as well as of late payments and frauds, in favor of a more efficient distribution system (*Distribution-oriented approach*); secondly, in a more liberalized context for retail market, smart metering can be introduced also as a support for enhancing competition (*Retail-oriented approach*). Lastly for those countries that have reached a more advanced level in renewable energy sources (RES) penetration and system transformation, the 2G Italian experience can help as a benchmark for making the final customers more aware about their energy consumptions thanks to the introduction of dedicated services and for integrating their distributed generations (*Customer-oriented approach*).

It's important to recall that all the below considerations are valid for countries where the metering activity is carried out by the same company that operates electricity distribution activity (also named DSO, *Distribution System Operator)*. This is the most frequent condition throughout Europe, where only in Great Britain the metering service is managed by retailers instead of DSOs. The way for introducing smart metering in similar countries is totally different; it's worth noting that authoritative British experts have risen doubts on the efficiency of such weird business model for metering [10].

Distribution-oriented approach

The distribution-oriented approach is well exemplified by the initial decision of introducing smart metering taken by (former) *Enel distribuzione* (currently *e-distribuzione)*, the distribution and metering company belonging to the vertically integrated group ENEL, the former monopolist and currently the major incumbent in the Italian electricity market. As a matter of fact, *Enel distribuzione* decided to start the substitution of electromechanical meters simply led by cost efficiency reasons.[1] The results, in terms not only of efficiency but also effectiveness were promising, and in 2006, when the distribution company had already rolled out smart meters for its own whole customer basis (85% of the total number of electricity customers in Italy), the national regulation authority (NRA) AEEGSI decided to mandate all the remaining distribution companies to roll out smart metering in their licensed areas[2].

After the incumbent DSO's decision to roll out the first generation of SMs, big efforts were conducted by the Italian NRA in order to identify the proper regulations for DSOs exploiting smart meter's functionalities that were not introduced autonomously. For instance, in case of non-payments, the regulatory authority decided that smart metering had to be employed in order to leave a minimal service to the final customers (0.5 kW for an ordinary household customer, normally supplied with 3 kW of contracted power) for a given period, before proceeding with remote disconnection if non-payments persists. In case of payment by customers that are either disconnected or with a reduced power capacity due to non-payment condition, DSOs are mandated to re-establish the normal service in 24 hours once received the payment; if DSO fail to comply with such a standard of 24 hours, a guaranteed reimbursement is ensured to final customers.

As for the architectural configuration of smart metering systems, the first Advanced Metering Infrastructure (AMI), that we refer to as "first generation" smart metering system, or "SM-1G", was designed in order to let the DSO collect and validate customers' metering data and let the smart meters execute some actions remotely. To do so, each SM-1G is connected to a common network and can communicate with a data concentrator, an intelligent device in charge of pre-processing and compressing metering data coming from different meters before sending them to the DSOs' head-end system. Data concentrators are located in the Secondary Substation where the MV/LV transformer is placed. As for the majority of the Member States [7] the technology selected by DSOs for data communications was the power line communication (PLC), which exploits the pre-existing low-voltage electric network and, thus, ensuring excellent

---

[1] According to the Italian regulation, the DSOs' investments in smart metering have been recuperated adjusting the tariff component that corresponds to capital investment (taking into account also the stranded value of residual depreciation, if any, of existing traditional meters). On the other hand, the efficiency factor which governs the reduction of operating costs has been hugely increased (from 5% per year in the regulatory period 2008-2011 up to 7.1% per year in the regulatory period 2012-2015)

[2] Even DSOs with a small customer base are obliged to install electronic meters: customers served by small DSOs should have access to the free market and to ToU tariffs, with the same opportunities as customers served by larger DSOs.

coverage levels and minimal infrastructural costs. Moreover, the experience showed a 96% success rate for remote management using this technology. Once metering data reach the central system through the data concentrator, the validation phase can take place: metering data of each customer are compared by the corresponding DSO with historical values and missed data can be reconstructed thanks to advanced algorithms. Finally, validated metering data leave the DSO's domain and are forwarded directly to the customer's energy retailer responsible for the billing phase.

Being a case of distribution-oriented approach, SM-1G had a business justification mainly based on DSO efficiency. As the cost/benefit analysis provided by *Enel Distribuzione* showed that the [11] main benefits are related to reduce meter reading costs and minimizing energy loss, frauds and energy theft. The highest money saving came from remote data reading and remote management, which prevented the DSOs from sending qualified personnel to the customer's premises. Moreover, the more frequent remote data reading enabled the possibility of invoicing customers basing on real consumption while remote management allowed to set contract parameters faster and without having personnel intervention on-site.

Due to a regulatory decision in 2009, SM-1G has been employed to support the adoption of new ToU energy prices in the whole country allowing customers to modulate their electric consumption according to infra-day price bands in order to save money (bills are bi-monthly although metering operators remotely read consumption data once per month). Households in the Universal Supply Regime (*maggiore tutela)* are billed with a two time-bands "static" scheme, the price being higher during "peak hours" - including hours between 8 am and 7 pm during working days - and lower during "off-peak hours" which comprise the remaining hours not included in the peak hours. Small business customers, may have up to three price bands using SM-1G; but a change in time bands structure requires a complex downloading procedure with all meters.

In 2010 the National Research for Electro-Energy in Italy (RSE) published a study with the aim to prove the benefits coming from the application of the ToU regime [12]. The study involved 28,000 Italian customers and showed the change in behaviour induced by price signals. 61.5% of the involved customers moved from peak hours to off-peak hours even if the monthly saving was not high, mainly due to very small economical difference between off-peak and peak hours (around 10%). Similar results have been recorded in the only other case of mandatory ToU, in Ontario [13].

Retail-oriented approach

Close to the end-of-life period for the SM-1G (15 years according to metrological Italian rules), the Italian NRA launched a consultation process around possible improvements for the subsequent generation of smart metering systems. The public consultation raised several problems affecting the existing SM-1G infrastructure, mainly concerning the interfaces between all the stakeholders of the electricity value chain. One of the findings was that the head-end system provided by the DSO was not flexible enough for ensuring scalability to larger volumes of validated-data collected from meters. Moreover, the types of data collected and, above all, their granularity (limited by static time-bands) were not sufficient for a smart usage of this information by both retailers and final customers. Finally, the customers had no easy-to-use and user-friendly tools to get aware about their electricity-consumption behaviour (and production for those customers equipped with photovoltaic roof).

Thus, the "second generation" of smart metering systems (SM-2G) has been conceived to remove the limits observed during the SM-1G phase.

The major improvement is a far greater granularity of data collected: with SM-1G technology, due to limitations in data concentrators and existing head-end systems, consumption data from almost all low-voltage customers were collected only on a monthly basis and with very limited granularity, according to three predefined price bands. Hence, with SM-1G, retailers were able to offer only contracts based on the same fixed time bands. Thanks to a more sophisticated sampling system and an advanced AMI, with SM-2G all data recorded, for every quarter-hour, have to be collected by the DSOs on a daily basis and to be transferred to the subsequent stakeholder after the validation process within 24 hours. The main differences in terms of metering data acquired by DSOs comparing the SM-2G and the SM-1G are reported in Table 2.

Table 2. A comparison between metering data recorded and collected by SM-2G and SM-1G in Italy

Metering data	SM-2G	SM-1G
Active energy withdrawn	1 value every 15 min	3 values per month (according to time bands)
Active energy Injected (for prosumers)	1 value every 15 min	3 value per month (according to time bands)
Reactive energy withdrawn	1 value every 15 min	3 values per month (above 10 kW)
Reactive energy Injected (for prosumers)	1 value every 15 min	3 values per month
Active power withdrawn (average over 15 minutes)	Peak value integrated in 15 min	Peak value integrated in 15 min (peak)
Active power withdrawn (instantaneous value)	instantaneous value (1 s), collected only through "chain 2"	No
Active power Injected (for prosumers)	15 min (avg)	No
Min/max voltage	Max and min values per week	Only occasionally and not compliant with EN 50160
Voltage in limits	Yes, compliant with EN 50160	Only occasionally and not compliant with EN 50160
Outages	On event occurrence	Available but not used, due to memory restriction

Thanks to the large amount of measurements acquired, retailers are enabled to offer more customized schemes of ToU prices, up to a Real-Time-Pricing (RTP) regime [14], in which customers can pay energy according to the same price fluctuations established by the wholesale energy market. The aim of a similar strategy is to enhance load-shifting techniques in turn of a bill saving. In addition, with SM-2G DSOs could inform final users about a network outage even in the LV network and retailers will be able to use SM-2G to certify the actual flexibility actions of customer within Demand-Response schemes, that provide extra-payment for flexibility services provided by the customers that are able to modify their consumption profile on request (according to system-balancing needs).

The other radical change regards the solution undertaken for data storage and exchange. A new entity, called *data management hub*, has been conceived with the scope of creating a centralized common interface between all the DSOs and the retailers in a decentralized or distributed electric system: once each DSO completes the validation process, it is in charge of transferring the validated information to the data management hub, where they can be stored and acquired only by authorized parties (retailers, service providers, TSO…). Moreover, all the customer's metering data are accessible and preserved over time even in case of contract switching. This hub for data centralization, already planned to deal with electricity metering data, may be also expanded to cover other commodities: gas metering data are going to be collected through gas smart metering and forwarded to the same system for similar purposes and, in future, other services like water supply and district-heating might be managed too.

Finally, one of the strongest limitation of the SM-1G was the lack of a backup channel for DSO's remote management: around 4% of the Italian customers were not read properly, mainly due to electromagnetic interferences acting on the PLC network in the frequency range 2 – 150 kHz [15] . This disturbance can be stationary or time-variant and, according to recent studies, is increasing over time. This is mainly due to new devices installed by the customers themselves on the electric network such as inverters for photovoltaic plants, led bulbs, chargers for electric vehicles or even certified appliances that are downgraded or damaged. This kind of disturbance is usually not perceived by the final customers but the PLC communications can be strongly affected, even by neighbours.

With the purpose of covering the small fraction of customers not perfectly reached by the SM-1G communications technology (as said, PLC band A from meter to data concentrator and public TLC service from data concentrator to HES), for the second generation of smart meters the Italian NRA imposed to the meter operators (i.e. distributors) a second channel for remote management, using an alternative technology. As a result of the consultation, radiofrequency (RF) 169 MHz has been selected by the market as the most promising solution, mainly due to low infrastructural costs, unlicensed frequency and deep-indoor coverage, useful for those meters located in the basements. The same technology is nowadays used in Italy by gas smart metering systems, with very good results. This RF technology is not only used to increase the coverage of the remote management, with a benefit for the meter operator and ultimately for the rate-payer, but also to activate new services like spontaneous reporting messages, that are difficult to be promptly send through the ordinary chain. Spontaneous reporting messages can be used in several ways: as they can be sent even after a voltage interruption, in a distribution-oriented approach they are useful to prompt the DSO about a fault on low voltage networks, that are not equipped with remote control, allowing for faster reparation service (especially by night, when customer do not report immediately the lack of supply). In a retail-oriented approach, spontaneous reporting messages can be used to communicate the exceeding of predefined thresholds set in the meter; one possible application of this capability is the prepaid service management, which could be offered by retailers with special contracts, also intended as an instrument to contrast the phenomenon of non-payment.

Customer-oriented approach

During the consultation for the definition of the SM-2G features, the NRA also realized the lack in direct communication between the smart meter and the final customer: the only way enabling the customer to be aware about his/her consumption were the dedicated display of the smart meter and the bills provided by the retailer (in written or electronically). With the SM-2G, NRA imposed that validated metering data should be available to the customer (through the internet) after 24 hours, which is considered enough to give the customers the possibility of analyzing his/her consumption and reacting (including assessing the saving of different ToU offers). But 24 hours is a too long delay for any kind of immediate response, like manual management of appliances in order not to overpass the power limit of 3 kW or any home-automation system able to react automatically. Moreover, one of the 10 functional requirements for smart metering systems in Recommendation 2012/148/EU [6] states that:

"smart metering systems must provide readings directly to the customer and any third party designated by the consumer. This functionality is essential in a smart metering system, as direct consumer feedback is essential to ensure energy savings on the demand side. There is a significant consensus on provision of standardised interfaces which would enable energy management solutions in 'real time', such as home automation, and different demand response schemes and facilitate secure delivery of data directly to the customer.

Accurate, user-friendly and timely readings provided directly from the interface of customer's choice to the customer and any third party designated by the consumer are strongly recommended since they are the key to running demand response services, taking 'online' energy-saving decisions and effective integration of distributed energy resources"

The services that non-validated real-time metering data can enable have been investigated and can be grouped into four categories reported in Table 3, taking into account the use cases reported in the international standard IEC 62746-2 [16].

Table 3. Services enabled by real-time metering data sent to the customers

Customer Awareness Inform the final customers about their energy exchanges with the network (both consumption and generation) and its status. An unexpected outage could be promptly communicated to the IHD of the customer, which can take decision accordingly. The customers can be aware and evaluate possible changes in their consumption behaviour, reducing or moving their loads in off-peak moments. If the IHD is also able to receive price signals, it can also help in monitoring energy costs, with the scope of reducing the monthly electric bill.	**Advanced commercial offers** The frequent refresh of metering data allows the customer to understand the exact time of his/her energy usage, hence helping in catching the benefits induced by those contracts using ToU or RTP tariff mechanisms. Moreover, new prepaid contracts can be more effective with a frequent feedback about the residual credit coming from the meter.
Scheduling & control For those customers living in an advanced environment with a distributed generation plant (e.g. photovoltaic plant or a micro wind turbine), energy storage, electric vehicle and deferrable loads connected to an energy management system, it is possible to automatically increase the efficiency of the energy exchange with the network with no human interaction, in order to save money and be more environmentally friendly.	**Network ancillary services** Congestions, voltage constraints or faults regarding the distribution network can induce the DSOs to ask their customers for a reduction of electric power consumption or for an injection of energy produced by distributed generation plants, in exchange for some reward. The customer, even in aggregate form (each point being equipped with an energy management system) can receive Demand-Response signals from the DSO or from the aggregator through a standard communications channel, and the meter can be used for certifying the demand-response effectively operated. Even the distributed generation can be used for unbalancing problems.

Thus, a new communications chain, independent of the first one used for remote reading and remote management, has been devised to supply near real-time metering data directly to the customer. These metering data are available to the customer thanks to dedicated devices, called "In-Home Devices" (IHDs), interfacing such new communication chain the meter is newly equipped with. Plenty of types of (non-validated) measurements can be transmitted, e.g. daily energy curves, instant active power, alerts triggered by thresholds in the moment of their sampling up to one second, as well as contractual information. The choice for the selection of data to be sent and sampling frequency for data acquisition can be set and chosen according to the customer needs and the capacity of the communications channel. Examples of IHDs are simple external displays used by those customers having their smart meters in the basement, advanced local dashboards showing the daily energy curves of the past days, smart appliances (connected washing machines, electric vehicles…) and Energy Management System, or even device such dongles coupling the communications coming from the meter to the Wi-Fi router that can convey information to customer's smartphone or laptop. Moreover, IHDs can receive additional information coming from other sources (e.g. service providers, energy market, cloud services…) and couple them with the metering data aiming not only to make customers aware about the advantages of a responsible use of the energy, but also automatically control a set of deferrable appliances, thereby reducing the usage of energy during peak hours even with no direct customer intervention. It is worth underlining that data exchanged on this chain are not validated, which means that they could not be considered valid or compared to those used for the billing phase.

Customers may either own their personal IHDs or delegate a service provider to read and enrich the real-time metering data with the scope of supplying a more valuable and user-friendly services.

Real-time metering data can even be sent to a cloud service by which the customers, out of their home, or other stakeholders can access it by a device connected to the internet (laptop, smartphone, tablet…). An Italian NRA's initiative aiming to test a smart grid application [17], developed and tested on a small scale (around 5.000 customers), showed the importance of real-time metering data delivered to the customer in driving a potential saving of 3 to 4 % of yearly consumption [18]. [3] Some other studies [19] showed that real-time measurements can be well used by the final customers if:

- Displayable on different devices (smartphones, tablets, dedicated devices, etc.)
- Clear and intuitive (smart charts, aggregated results, advices)
- IHDs have a good design, are cheap and easy to install.

According to these studies, if these requirements are not respected, the customer, after a first period of strong attraction, could lose the interest for these devices.

Ensuring interoperability between SM-2G and IHDs is of paramount importance, in order to allow for free choice among devices and services offered by different subjects, that can be either electricity retailers or not (service providers, which in turn can buy devices from different manufacturers in a competitive market [20]. For this reason, AEEGSI mandated the Italian electro-technical standardization body (CEI) to define with industry representatives, a standard communications protocol unified at national level.

More, it has been addressed an additional aspect which is raising more and more attention in the public arena: privacy and security of data. As even required by European Directive 2012/27/EU, performance and privacy requirements for the new architecture have been formalised by Italian NRA: both communications channels (between the smart meter and

[3] Such pilot projects were based on IHDs communicating with SM-1G through the same PLC link used for remote metering and meter management: this represents another limit of the 1G architecture, since it implies that in the SM-1G there was no full interoperability with third-parties IHDs due to a technological constraint.

IHDs and between the smart meters and the concentrators) must ensure confidentiality, authenticity and integrity of the data. Hence, it is mandatory to use secure encryption techniques for all the data communications.
The evolution in time of the Italian energy system passing from SM-1G and SM-2G is reported in
Figure 2. In this chart four different “domains” have been highlighted, meaning the “customer-oriented approach” may evolve into two different directions: empowering final customers directly (South-West quadrant) and/or furthering the business of new service providers specialised in energy saving and aggregating demand-response.

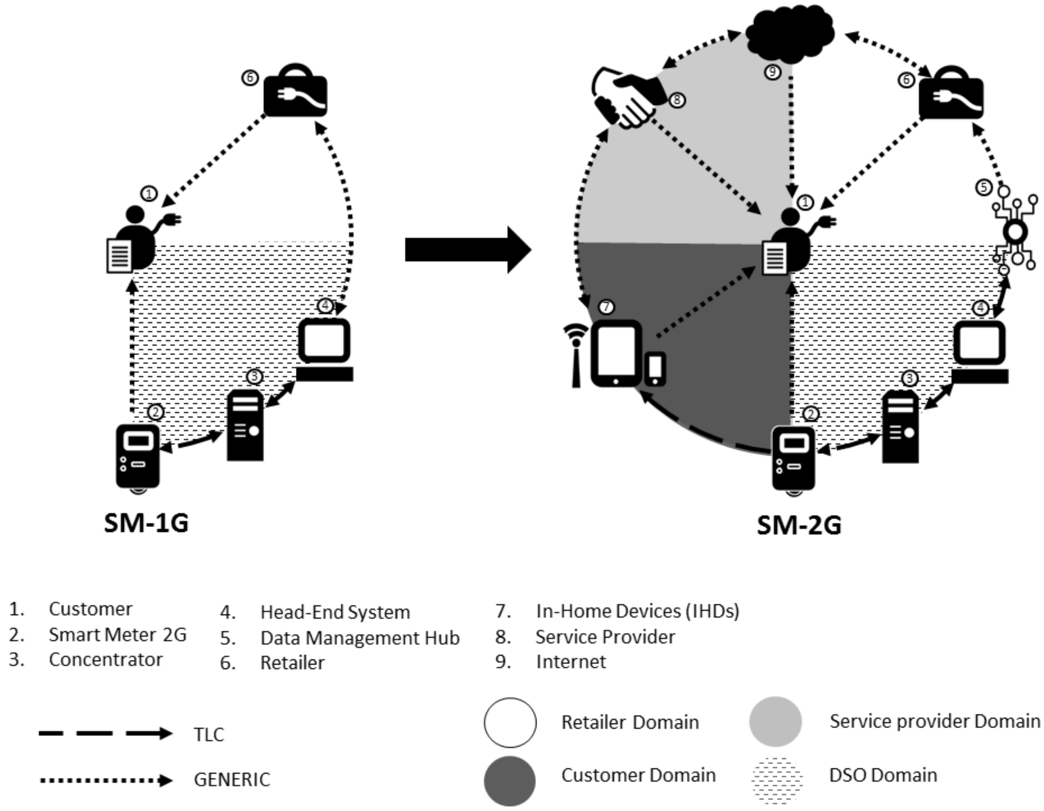

Figure 2. smart metering evolution between first and second generation in Italy

A comprehensive model for benefits of smart metering

Moving from the previously cited EC Recommendation 2012/148/UE, the Joint Research Centre (JRC) published in 2014 guidelines for cost-benefit assessment of smart metering deployment [21]. In the report, they identified a list of benefits: reduction in meter reading and operations costs; Reduction in operational and maintenance costs; Deferred/avoided distribution / transmission / generation capacity investments; Reduction of technical losses of electricity; Electricity cost savings; Reduction of commercial losses; Reduction of outage times; Reduction of CO_2 emissions and air pollution. These benefits typically appear related either to the economic efficiency of meter operator or to the reduction of electric energy absorbed from the network thanks to increased customer awareness. In the threefold framework explained in this paper, JRC benefits can be classified between distribution-oriented and customer-oriented-approach.
With its consultation paper 468/2016/R/eel [22], the Italian NRA provides a complementary solution in order to consider benefits also in the retail-oriented approach, suggesting a wider and more organic comprehensive methodological framework. At the core of this approach there is the consideration that increasing efficiency (in terms of swift availability of metering data), effectiveness (in terms of greater reliability in metering performances), and granularity (in terms of sampling frequencies) of the metering chain is likely to affect, at different levels, the whole power supply chain in the

downstream market. In particular, while considering specificity and regulatory constraints of internal market, the Italian NRA suggests the way the new SM-2G can be the enabler for major improvements in current processes of the power value chain, as:

- invoicing and billing;
- switching and other contractual services;
- demand forecasting;
- settlement of balancing services;
- enrichment of offering possibilities;

Indeed, Italian NRA also identified a wider flexibility upon which contracts may be tailored by suppliers and, at the same time, innovative services enabled by SM-2G that can be offered to the final customers even through third-party contracts. Benefits that can be extracted by smart meters are closely related not only to the different approaches described in this paper, but also to the more general context of the evolution of the power system in which smart metering is considered. Under this regards, three main possible set-ups can be identified:

1. **Vertically-integrated system:** all the activities along the value-chain, from the energy production to the final customer supply, passing through the transmission, distribution, and metering services is managed by a single, integrated entity. This configuration implies a rather passive behavior of the customers, with no choice as there is no retail market nor possibility for self-generating electricity.

2. **Unbundled system:** in a liberalized retail market, different companies provide distribution and supply separately. This configuration implies that customers can actively search for the more convenient offer and on the other side suppliers are pushed by competitive pressure to conceive different offer; but substantially self-generation is only a marginal phenomenon.

3. **Distributed system:** responsibilities and management of the value-chain services are spread over all the stakeholders. Exploiting the distributed generation, in a liberalized environment for both supply and generation, final customers become active and can exploit self-consumption as well as exchange energy with the network actively participating in the market.

The three set-ups identified are only ideal and simplified system models, but can be used to understand the application of each approach and the typical benefits that each approach addresses, which may lead to establish the necessary functionalities for the smart metering system under design, according to the scheme of **Figure 3**.

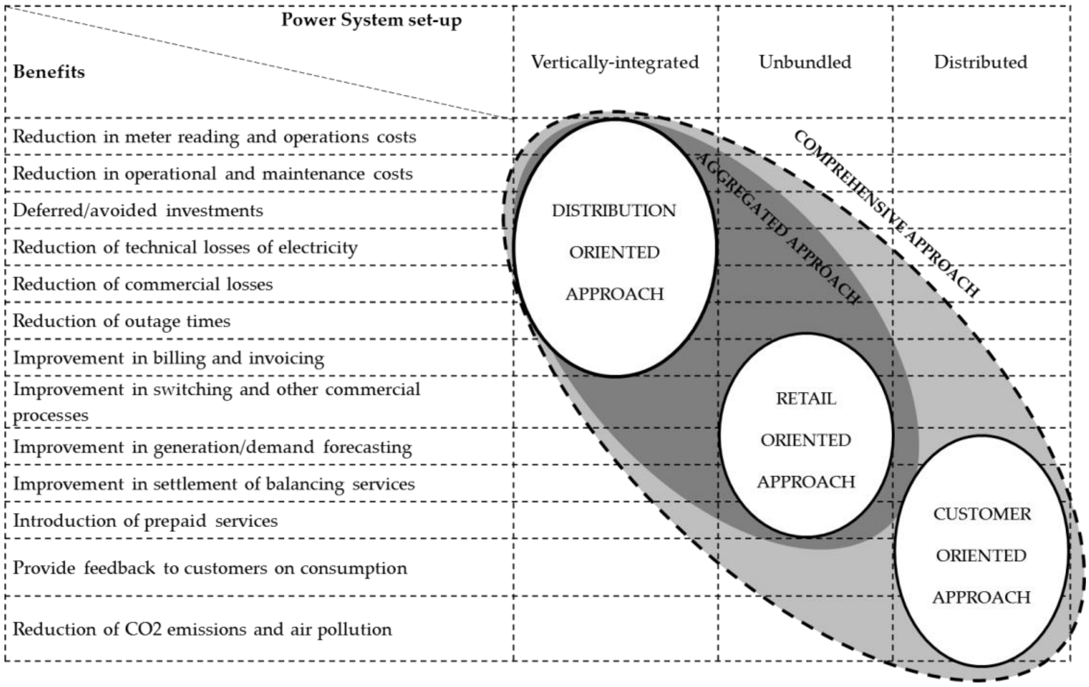

Figure 3. Benefits perceived by the three approaches for each power system set-up.

Conclusions

The Italian way of approaching the smart metering represents an effective case study of how technology can improve performances and services stemming from the distribution of electricity, and extending across the full supply chain and towards customers. The document suggests three different roll-out approaches, according to each specific power supply set-up. The three approaches can be even combined in order to collect with a single roll-out as many benefits as possible, even potential. An aggregated approach could gather all the benefits for the distribution and metering services with the ones of energy retail or customers, while a comprehensive approach considers all the stakeholders.

Surely, the latter is the most beneficial, but it may be also rather difficult to be approached at first, especially in those countries where retail-market liberalization is not fully deployed yet, nor distributed generation is adequately promoted. An aggregated approach, as the example reported in Figure 3, can be initially easier and cheaper to adopt, even if not entirely in line with the general trend adopted by the majority of the European Member States.

Annex to the paper: “Smart metering: an evolutionary perspective”

Unofficial translation of AEEGSI decision 87/2016/R/eel – Annex A prepared as application to 2016 ERRA Award

SMART METERING FUNCTIONAL REQUIREMENTS IN ITALY (ELECTRICITY, LOW VOLTAGE)

Index

version 2.0

[R-6.04] Backward compatibility with first-generation user devices

VERSION 2.0

0. TIME MANAGEMENT

[R-0.01] Clock and Calendar

- Resolution per second with maximum drift in accordance with IEC 62054-21
- Manageable calendar with days of the week, weekdays, holidays, midweek holidays, including the Patron Saint, 5 configurable extra holidays

[R-0.02] Time bands

- 6 time-differentiated time bands F1 ÷ F6 configurable by the retailer in order to assign any of the 6 bands to a maximum of ten time intervals for each day of the week

Note 1: possibility to configure time bands on the basis of the characteristics of the days (as reported in R-0.01) and according to the 24 daily hours.

[R-0.03] Freezing periods

- Hold for six freezing periods the following totalizers:
  - active energy (withdrawn and injected) and inductive energy (withdrawn and injected) totalizers
  - mean active power (withdrawn and injected) sampled every 15 minutes
  - customer number, retailer commercial name, contract start date with the retailer.
- The freezing period, except for contractual events, has a monthly duration and can start in any of the days of the month at 00:00:00.
- The freezing period starting date is configurable by the retailer separately for each smart meter.
- The current freezing period is the period not yet concluded at current time.
- Contractual events interrupt freezing periods before their natural closure.
- The new current freezing period starts at 00.00:00 of the day following the closure of the previous period (if the withdrawal point remains active).

Note 2: For contractual events, see R-5.04. For energy totalizers, the reference is R-1.03. For power totalizers, see R-1.04.

Abbreviations

The following abbreviations are used in this manuscript:

AEEGSI	*Autorità per l'energia elettrica, il gas e il sistema idrico* (National Regulatory Authority for Electricity Gas and Water in Italy)
AMI	Advanced Metering Infrastructure
CEI	*Comitato Elettrotecnico Italiano* (Italian Electrotechnical Committee)
COSEM	COmpanion Specification for Energy Metering
DLMS	Device Language Message Specification
DR	Demand-Response
DSO	Distribution System Operator
EC	European Commission
EMS	Energy Management System
EU	European Union
HES	Head End System
IHD	In-home device
JRC	Joint Research Centre
MV	Medium Voltage
NRA	National Regulatory Authority
PLC	Power Line Carrier
RES	Renewable Energy Sources
RSE	*Ricerca sul Sistema Energetico* (National Research for Electro-Energy in Italy)
RTP	Real-Time Pricing
SM	Smart Meter
SM-1G	First-Generation Smart Metering Systems
SM-2G	Second-Generation Smart Metering Systems
ToU	Time-of-Use

1. CONTINUOUS MEASURES AND TOTALIZERS

[R-1.01] Energy Measurements

- Daily curve of active energy (withdrawn) sampled every 15 minutes
- Daily curve of active energy (injected) sampled every 15 minutes
- Daily curve of inductive energy (withdrawn) sampled every 15 minutes
- Daily curve of inductive energy (injected) sampled every 15 minutes
- Daily curve of capacitive energy (withdrawn) sampled every 15 minutes
- Daily curve of capacitive energy (injected) sampled every 15 minutes

Note 3: the accuracy should be no more than 1 Watt for active energy and no more than 1 Varh for reactive energy.

Note 4: at least 38 days for all the curves storable in the meter.

Note 5: each 15-minutes sample ends at hh.15.00, hh.30.00 and hh.45.00 and hh.00.00 for each hour of the day.

Note 6: according to R-4.03, sampling time can be configured equals to 60' instead of 15'.

[R-1.02] Power Measurements

- Instantaneous active power with sampling time equals to 1 second
- Mean active power (withdrawn) every 15 minutes
- Mean active power (injected) every 15 minutes

[R-1.03] Energy totalizers (for display visualization and data transfer to user devices)

- Withdrawn active energy (all customers):
  - Totalizer of the energy withdrawal: total of the previous day (summation of all time bands) and subtotals for each time band
  - Monthly totalizer for energy withdrawal calculated according to the freezing period and for each time band
- Injected active energy (prosumers only):
  - Totalizer of the energy injection: total of the previous day (summation of all time bands) and subtotals for each time band
  - Monthly totalizer for energy injection calculated according to the freezing period and for each time band
- Withdrawn inductive energy (for withdrawal points with reactive energy pricing):
  - Totalizer of the energy withdrawal: total of the previous day (summation of all time bands) and subtotals for each time band
  - Monthly totalizer for energy withdrawal calculated according to the freezing period and for each time band
- Injected inductive energy (prosumers only):
  - Totalizer of the energy injection: total of the previous day (summation of all time bands) and subtotals for each time band
  - Monthly totalizer for energy injection calculated according to the freezing period and for each time band

Note 7: for the time bands, the reference is R-0.02. For the freezing period, the reference is R-0.03.

[R-1.04] Power totalizers (for display visualization and data transfer to user devices)

- Instantaneous withdrawal power in 1 second: totalizer for daily maximum value
- Mean active power (withdrawn and injected) sampled every 15 minutes: totalizers for maximum values during the freezing period.

Note 8: for freezing period the reference is R-0.03.

2. VOLTAGE QUALITY INDICES ACQUISITION AND REGISTRATION

[R-2.01] Voltage Measures

- Measurements of slow voltage variations in compliance with standards CEI EN 50160 and CEI EN 61000-4-30
- Voltage totalizers (expressed in Volts):
  - Weekly minimum value among mean effective voltage values sampled every 10 minutes
  - Weekly maximum value among mean effective voltage values sampled every 10 minutes
- Totalizers of 10-minutes samples per each of the following voltage band
  - Number of samples with effective voltage value in the range -10 / + 10% Un
  - Number of samples with effective voltage value between -10% and -15% Un
  - Number of samples with effective voltage value between + 10% and + 15% Un
  - Number of samples with effective voltage value over + 15% Un
  - Number of samples with effective voltage value below -15% Un

Note 9: at least four weeks of voltage samples storable in the meter .

[R-2.02] Outages

- Outage identification (effective residual voltage less than 5%) in accordance with CEI EN 50160
- Totalizers for outages events longer than 1 second:
  - Start time (day / hour / minute / second)
  - Duration in seconds

Note 10: at least 20 outages events storable in the meter; if exceeded without a remote data acquisition, overwriting is allowed; in such a case it must be managed at least one flag indicating that some data have been lost.

3. CONTRACTUAL INFORMATION MANAGEMENT AND EVENTS REGISTRATION

[R-3.01] Contractual information

- Customer code assigned by the retailer
- Contractual rated power
- Freezing period start date
- PESSE Group (Load Shedding program for emergency rationing)
- POD Code (delivery point)
- Retailer commercial name
- Retailer call center number
- Contractual start date

Note 11: for display visualization, see R-4.01 and R-4.02 for confidentiality.

[R-3.02] Authentication data (for user devices)

- Authentication and encryption information management for user devices connected along "chain 2" (see section 6)
- Distribution system operators update the information on request of the final customer or, if delegated, the retailer or any other commercial group.

Note 12: the number and characteristics of the specific information fields related to user devices authentication and encryption for "chain 2" are defined by CEI.

[R-3.03] Power control switch (PCS) intervention events

- PSC intervention events registration, reporting:
  - time stamp referred to the event (date, time, start minute)
  - power reduction (as a percentage of contractual rated power)
  - reason of the intervention (at least 5 reasons)

Note 13: at least 10 intervention events storable; if exceeded without a remote data acquisition, overwrite is allowed; in such a case it must be managed at least one flag indicating that some data have been lost.

[R-3.04] Power control switch (PCS) operation

- The operation of the PSC trip can be implemented with a thresholds logic according to the voluntary agreement stipulated with consumer associations (2003)

4. LOCAL DISPLAY

[R-4.01]] General information and totalizers

- 1-tier structure (1 button) or tree structure (1 button with pressure duration)
- Current date and time
- Current time band
- Contractual information
  - Customer code
  - Contractual rated power
  - PESSE Group (managing customer groups which cannot be disconnected)
- Values for the current freezing period and for the previous six freezing periods of the following parties:
  - Withdrawn active energy totalizers (sorted by time bands)
  - Injected active energy totalizers (sorted by time bands) for prosumers
  - Withdrawn inductive energy totalizers (sorted by time bands)
  - Injected inductive energy totalizers (sorted by time bands) for prosumers
- Maximum value of withdrawn active power in the current day (power sampled every 15 minutes)
- Maximum value of injected active power in the current day (power sampled every 15 minutes) for prosumers
- Power limit current status (expressed in kW, contractual value or lower value due to payments in arrears, load shedding management or other reasons)
- Messages to the customer

Note 14: the active energy totalizers are displayed in kWh (without decimal places) rounded by truncation; reactive energy totalizers are displayed in kVARh (no decimal places) rounded by truncation; power totalizers in kW (three decimal places).

Note 15: measures and totalizers visualization sorted by freezing period have to be displayed after the freezing period date, retailer commercial name and call center number (if allowed, see R-4.02) .

Note 16: In addition to the load curves visualization, the meter must be able to display the totalizers sorted by time bands. The visualization of the load curves must be confirmed by the customer by pressing the button.

[R-4.02] Custom information (configurable and reservable)

- Possibility for the retailer to configure whether and which of the following information can be shown on the display or omitted for confidentiality:
  - POD code
  - Retailer commercial name
  - Retailer call center number
  - Contractual start date
  - Reason of the intervention of the power control switch (PCS) if different from the contractual rated power

Note 17: this information will not be shown on the display, except with an explicit retailer request.

[R-4.03] Hourly energy curves

- Ability to configure the curves of active and reactive energy with intervals of 60 'or 30', instead of 15 ', in order to display the individual values of these curves on the display, where necessary

5. MEASURES AND TOTALIZERS REMOTE ACQUISITION (“CHAIN 1”)

[R-5.01] "Chain 1" communication channels (remote reading / remote management)

- Availability of two independent channels for "chain 1" (technology chosen by the distributor), in accordance with the following constraints in case of concession passages between distributors (interchangeability):
  - In case of power line technology (PLC): use of band A with standard protocol, unified at national level.
  - In case of unlicensed radio frequency technology (169 MHz): protocol at the physical level corresponding to what established for the use of smart metering for gas.
  - In case of other technology: use of public telecommunications networks or standard protocols available in the market which ensure the interchangeability under the same conditions.

[R-5.02] Security measures for "chain 1" communication channels

- For both channels, use of security measures to ensure, along the communication chain, at least:
  - the confidentiality of the data exchanged, through the use of appropriate security measures;
  - the integrity and authenticity of data exchanged, through the use of appropriate standard encryption protocols.

Note 18: in case the selected technology involves the use of concentrators or anyway communication segments on private networks owned by the distributor, unified protocols are selected from the Cenelec standard protocols, as a result of a joint proposal of distributors and their associations.

[R-5.03] Remote reading and smart meter status acquisition

- Acquisition of the status and alarms for irregularities / anomalies
- Daily availability to entitled parties (e.g. retailers) of load curves and power totalizers sorted by time bands for the current day and all the previous days not yet collected, up to the previous 38 days
- Daily availability to entitled parties (e.g. retailers) of the maximum instantaneous power of the previous day (or all the previous days not yet collected, up to the previous 38 days)
- Daily availability to entitled parties (e.g. retailers) of the outages events, if detected in the previous day or at least not yet collected, with the relevant parameters associated with the event
- Possibility of weekly acquisition of voltage totalizers (or any previous weeks not yet collected, up to the previous 4 weeks).

Note 19: the term "daily availability" refers to the process of making measures available to the entitled parties (e.g. retailers, aggregators, etc) through the “Sistema Informativo Integrato” (National Data Management Hub). The term "acquisition" refers to data and information managed by the same distribution company.

[R-5.04] Remote management

- Clock / Calendar Synchronization
- Reading on request of:
  - energy and power totalizers
  - outages events, voltage variations

    - power control switch (PCS) intervention
- Contractual Events and configuration of the contractual parameters:
    - Editable contractual parameters configurable by the retailer (e.g. time bands scheduling, freezing period start date setting, confidentiality, etc.)
    - Editable contractual events (e.g. contract transfer, retailer switching)
- Activation / deactivation of the meter and load-shedding (programmable) controls
- Reduction / restore contractual power limit (payments in arrears)
- Sending messages to the display
- Setting of the power control switch thresholds for tripping
- Remote configuration, parameterization and not metrological firmware update
- Configuration parameters for authentication of user devices

Note 20: contractual events include changes applied to the supply contract referred to the withdrawal point, including all the parties involved in the contract. Contractual events may not require supply disconnection.

Note 21: for authentication parameters for user devices, the reference is R.3-02

6. MEASURES AND TOTALIZERS TRANSMISSION TO USER DEVICES ("CHAIN 2")

[R-6.01] "Chain 2" communication channels (data to user devices)

- At least one channel for data transmission from the meter to user devices:
  - In case of power line technology (PLC): use of C-band CENELEC between meter and user devices.
- Standard communication protocol, unified at the national level, between the meter and devices.

[R-6.02] Security measures for "chain 2" communication channels

- Use of security measures to ensure, along the communication chain, at least:
  - the confidentiality of the data exchanged, through the use of appropriate security measures;
  - the integrity and authenticity of data exchanged, through the use of appropriate standard cryptographic protocols.

Note 22: the standard protocol for "chain 2" is established with CEI technical standard which also defines fields required for communication between the meter and user devices (network name, password, receiver's address, ...), according to R-3.02.

Note 23: data transmission to user devices is activated only upon customer request, through the remote control system of the meter.

[R-6.03] interface with user devices

- Compliance with EN 50491-11-8, with reference to "H1" interface
- Imminent intervention of the power control switch alarm reported to user devices, calculated according to the instantaneous power derivative increase
- customers or, if delegated, the retailer or any other commercial party, can select:
  - data to be transferred to the devices, as part of the collected measures and recorded events;
  - instantaneous power sampled every 1 second and sent with maximum frequency compatible with the capacity of the transmission channel.

Note 24: sampled data up to 1 second can be grouped in a single frame (according to CEI protocol) in order not to saturate the channel(e.g. 1 frame every 30 seconds). Transmission rules will be defined within the definition of the "chain 2" protocol in compliance with CEI specifications.

[R-6.04] Backward compatibility with first-generation user devices

- Management and compatibility resolution of external devices, used by customer at the time of meter replacement, communicating through power line (band A) with first generation meters.
- LEDs flashing according to active and reactive energy withdrawals must be compatible with those of the first generation meters replaced

References

[1] I. Táczi and G. Szörényi, "Smart Metering: Cost Benefit Analysis of Potential Dissemination and Results of Pilot Projects," Budapest, 2016.

[2] J. Vasconcelos, "Survey of Regulatory and Technological Developments Concerning Smart Metering in the European Union Electricity Market," Robert Schuman Centre for Advanced Studies, Florence, 2008.

[3] European Commission, "Directive 2009/72/EC concerning common rules for the internal market in electricity - Annex 1," Official Journal of the European Union, 2009.

[4] European Commission, *M/441 EN: Standardization Mandates to CEN, CENELEC and ETSI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability,* Brussels, 2009.

[5] CEN/CLC/ETSI/TR , *Technical Report 50572: Functional reference architecture for communications in smart metering systems,* 2011.

[6] European Commission, *Commission Recommendation of 9 March 2012 on preparations for the roll-out of smart metering systems,* Official Journal of the European Union, 2012.

[7] European Commission, *Benchmarking smart metering deployment in the EU-27 with a focus on electricity,* Brussels, Belgium: Report from the Commission, 2014.

[8] Energimarknadsinspektionen, *Funktionskrav på framtidens elmätare,* 2015.

[9] Italian Authority of Electricity, Gas and Water (AEEGSI), *Consultation paper 416/2015/R/eel: Sistemi di smart metering di seconda generazione per la misura di energia elettrica in bassa tensione,* Milan, 2015.

[10] A. Henney, *Written evidence submitted to Energy and Climate Change Committee of UK Parliament,* 2013.

[11] European Commission, *SWD(2014)188 - Country fiches for electricity smart metering accompanying the document: Benchmarking smart metering deployment in the EU-27 with a focus on electricity,* Brussels, 2014.

[12] S. Maggiore, M. Gallanti, W. Grattieri and M. Benini, "Impact of the enforcement of a time-of-use tariff to residential customers in Italy," *22nd International Conference on Electricity Distribution,* pp. 10-13, 06 2013.

[13] A. Faruqui, R. Hledik and J. Tsoukalis, "The Power of Dynamic Pricing," *The Electricity Journal,* vol. 22, pp. 42-56, 04 2009.

[14] Agency for the Cooperation of Energy Regulators and the Council of European Energy Regulators, "Annual Report on the Results of Monitoring the Internal Electricity and Gas Markets in 2015," ACER/CEER, 2016.

[15] European Committee for Electrotechnical Standardization (CENELEC), *Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range below 150 kHz, Edition 3,* 2015.

[16] International Electrotechnical Commission, *TR 62746-2:2015 Systems interface between customer energy management system and the power management system - Part 2: Use cases and requirements,* 2015.

[17] L. Lo Schiavo, M. Delfanti, E. Fumagalli and V. Olivieri, "Changing the regulation for regulating the change: Innovation-driven regulatory developments for smart grids, smart metering and e-mobility in Italy," *Energy Policy,* vol. 57, pp. 506-517, 06 2013.

[18] M. Lombardi, S. De Francisci, L. Pizzoferro, L. Di Stefano, S. Di Carlo and B. Zito, "Enel Smart Info after one year on

field: lessons learned, evolution and results of the pilot," Rome, 2014.

[19] T. Hargreaves, M. Nye and J. Burgess, "Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors," *Energy Policy 38*, pp. 6111-6119, 2010.

[20] International Electrotechnical Commission, *IEC 62056-7-5:2016. Electricity metering data exchange - The DLMS/COSEM suite - Part 7-5: Local data transmission profiles for Local Networks (LN),* 2016.

[21] V. Giordano, I. Onyeji, G. Fulli, M. S. Jiménez and C. Filiou, "Guidelines for Cost-Benefit Analysis of Smart Metering Deployment," JRC Scientific and Technical Research, 2012.

[22] Italian Authority of Electricity, Gas and Water (AEEGSI), *Consultation paper 468/2016/E/eel: Sistemi di smart metering di seconda generazione per la misura di energia elettrica in bassa tensione e il rilascio dell'impronta energetica (energy footprint) al cliente finale. Benefici potenziali e orientamenti per il conseguente adeguamento regolatorio,* Milan, Milan, 2016.