The Importance of Robust and Reliable Energy Prediction Models: Next Generation of Smart Meters

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Abstract: In this position paper a discussion is performed related to the importance of Energy Prediction Models (EPM) in the context of trading renewable energy in smart grids and the need to develop a new generation of Smart Meters (SMs) based on edge computing. If the electricity currently produced and consumed in the low voltage is expected to grow due to installations of PVs and the electrification of the system, we need to incentivise local energy trading and provide tools to make it possible. Currently, all energy trading mechanisms in the literature heavily rely on predictions, therefore, inaccuracy would be translated in low profitability of prosumer's investments or even worse, disappointment with the local energy markets. To guarantee robustness and reliability of predictions, we propose Flexible FIR as EPM to be used during the trading process and to integrate them in a Next Generation of SMs (NGSMs). In this document some reflections about new functionalities of NGSMs and first steps of a prototype are also addressed.

1 INTRODUCTION

One of the main drivers to reduce the impact of the climate crisis is changing the status quo of how we produce, distribute and consume energy. In the last decades, this is being redefined due to: the inclusion of renewable energies and distributed generation; new technologies such as batteries and high-efficient solar panels; and the way the energy is consumed through electric vehicles, new energy habits and so on.

All these drivers required a modernization of the electricity grid and to unlock new mechanisms that allows more interaction between players and the electricity grid. This is what is known as Smart Grid (SG). A SG is an intelligent electrical network used for improving efficiency, sustainability, flexibility, reliability and security of the electrical system by enabling the grid to be observable, controllable, automated and fully integrated (Smart Grids European Technology Platform, 2010; US Department of Energy, 2009). It allows a seamless and easy connection of distributed energy resources such as home batteries, prosumers, etc. to the grid.

The domestic penetration of small-scale renewable resources enables consumers to become producers of green energy and empowers local neighbourhoods and communities to collectively reduce their carbon footprint by trading locally produced renewable electricity. Thus, enable Local Energy Trading (LET) is a key milestone to achieve carbon emissions targets and for a sustainable scalability of the SG.

Nowadays many energy retailers apply feed-in tariffs to motivate prosumers to inject their produced energy. With the rising decentralization of renewable energy production (Lesser, 2008), it is a challenge to offer subsidies that ensure a profitable and balanced grid for all parties involved. There rises the need to design LET mechanism that aligns the objectives of individual prosumers, who are aiming for high profits from their investments, with the objectives of governments seeking long term positive environmental change. In addition, with the high penetration of wind, solar power and customers' active participation have lead LET to operate in more uncertain, complex environments. Currently, Energy

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Prediction Models (EPM) are used to get the user's electricity characteristic curve and required for proper scheduling activities, power systems planning and operations, revenue projection, rate design, energy trading, and so forth. EPMs must be robust and reliable enough to work under uncertain consumer/prosumer behaviour and with intermittent data (missing information), because LET mechanisms heavily rely on predictions.

This evolution towards a system able to manage prosumers, batteries, LET and EPMs, in an efficient and decentralized way, has called for the deployment of more advanced metering systems. Current Smart Meters (SMs) aims at monitoring several key parameters as power quality, remote service switch, outages, which are helping Distribute System Operators (DSO) in their load forecast process hence in a more effective operation of their grid. The use of SMs helps reduce metering errors and identify fraud, and reduces the gap between peak demand and the available power at any given time as well (Council of European Energy Regulators, 2017).

Nevertheless, most of first generation SMs are starting to become outdated. Several important and strictly necessary services, not included in the current generation of SMs, have to be part of them in order to be considered smart devices. Having these features is essential for the evolution towards a system able to manage prosumers, batteries, LET and EPMs in an efficient and decentralized way. From our perspective, this situation has called for the deployment of a Next Generation of Smart Meters (NGSMs). We believe that these devices are meant to orchestrate a set of new functionalities that will bring Smart Grid goals to a next level.

In this position paper we address the need to develop a new generation of SMs based on edge computing that allows not only the prediction of consumptions and net energy that small producers can provide to the local grid, but also the maximization of profits if they participate in the electricity energy market trading.

The paper is organized as follows: in section 2 an overview of LET mechanisms in the literature is presented with focus in the incentive mechanism used and its dependency in the forecasting. In section 3 we review the concept of energy models and perform a literature review of short-term load and production forecasting techniques that could be embedded in the aforementioned EPM. In section 4, we present our opinion about some of the new functionalities that a NGSMs should have. In section 5 a final discussion and conclusion is performed on this topic as well as next steps in our research.

2 LOCAL ENERGY TRADING MECHANISMS

Trading of locally produced renewable energy is mainly addressed in literature from a market perspective and under multiagent based techniques, where prosumers and consumers (or collectively: agents) participate in a double auction and trade energy on a day-ahead basis (Kok, 2005; Kok, 2012; Olson, 1999; Vytelingum, 2008; Vytelingum, 2010; Mockus, 2012; Sesetti, 2018; Luo, 2019). Buy and sell orders for energy are submitted to a public orderbook and orders are matched either in a continuous fashion (Vytelingum 2008 and 2010) or at discrete market closing times using the equilibrium price (Kok, 2012; Mockus, 2012). The advantages of this market-based control concept are that it achieves close to optimal allocation, neatly balances supply and demand and aligns the preferences of self-interested agents.

Bidding for energy ahead of time relies heavily on predictions of future supply or demand, for instance, in a recent study (Luo, 2019), the LCA (Local Coordination Agent) performs very short-term forecasting to predict the power generation and consumption over future *n* time interval. Although the forecasting method itself is not the focus of the study, it relies on these predictions and the inaccuracy of which translates to higher costs for both buyers and sellers. In addition, agents need to rely on advanced trading strategies in order to maximise profit (or minimise costs). For example, prosumers with an inefficient energy forecasting strategy may unintentionally set a too high sell price, resulting in an unmatched order for their energy. Since there is no buyer at the time when they produce and inject the energy into the grid, prosumers make zero profit, unless they invest in batteries that can store the untraded energy. Those agents can then inject the energy at the time they find a buyer. Lastly, separate energy balancing mechanisms need to be employed (Kok, 2012) to cope with real-time demand response.

Another different approach but still using multi-agents is to consider incentive mechanisms instead of support policies such as net metering and feed-in tariff. In (Mihaylov et al., 2014a) it is proposed the NRG-X-Change, a novel mechanism for trading of locally produced renewable energy that does not rely on an energy market or matching of orders ahead of time. This mechanism uses a new decentralized digital currency for energy exchange, called NRGcoin (Mihaylov et al., 2014b). All payments by consumers and to producers are carried out in NRGcoins, instead of fiat money. The currency can then be exchanged on an independent open market for its monetary equivalent, e.g. Euro, Dollar, Pound, etc. This mechanism is based on a blockchain technology.

Even in market-based mechanisms an EPM is needed: independently from injection and withdrawal of energy, NRGcoins are traded on an open currency exchange market for their monetary equivalent. Agents use an EPM based on Random Forest (RF) technique to determine the quantity to trade and the adaptive attitude bidding strategy to determine the bid/ask price (Mihaylov et al., 2014b).

3 ENERGY MODELLING

The aforementioned energy trading mechanisms have in common that they mostly rely in energy models. An energy model is a computer based model of an energy system or component, for instance, the production of a power station or a prosumer, the consumption load profiles of an entire building or an appliance, or the behaviour of an entire electricity distribution system.

Energy models are mainly used for simulations, which allows us to save resources and time. It allows us to take into account most of the variables that play an important role, such as the consumption, weather, the people, the utility rates and so on. Energy modelling allows us to represent, analyse, make predictions, and provide insight into real systems. In the case of a dwelling for instance, it helps us to choose between different usage, designs and materials. By adjusting variables, we can check their impact on the energy requirement. There are many different energy models and applications; backcasting models, scenario analysis models, integrated models, demand/supply-side models, etc. (Farzaneh, 2019). For energy trading purposes demand and supply-side models are needed.

- Demand-Side Models: These consist of a broad range of methodologies which focus on determining the final energy consumption in the entire economy or a particular sector, such as the buildings, industrial energy use, and the transportation system. The overall methodological focus of this cluster of energy system models is to consider the demand side endogenously, and the supply-side issues are not considered at all. These models mostly rely on bottom-up simulation techniques to estimate energy demand.
- Supply-Side Models: Mostly focused on energy supply technologies, with a particular focus on renewable energy systems, fossil-based power plants, oil and gas industries, etc. They are characterized by a limited spatial scale and generally consider a single piece of technology using a simulation technique or experimental work to perform the analysis, including the design and performance of the system. The models may, therefore, be characterized as calculating supply-side parameters related to technology design or, in some cases, the operation of such technologies.

Electricity load and production forecasting is typically divided in short, medium and long term. The long-term plan evaluates how well the short-term planning commitments fit into long-term needs. No commitment needs to be made to the elements in a long-term plan, and capacity and location are more important than timing in long-term forecast. In other words, it is more important to know what will eventually be needed than to know exactly when it will be needed. Each category is equally important in the energy sector for the correct operation of the power system. For the purpose of this paper the mid and long term are not considered because the trading between prosumers and consumers is generally in hourly basis or less.

Sort-term Load and Production Forecasting (SLPF) is highly connected with meteorological factors such as temperature, humidity, wind speed and specially typology of day. The change in holidays, weekdays, weekends, the day before and after holidays also has impacts on the load forecast (Jurado et al., 2015). The analytical methods work well under normal daily circumstances, but they can't give contenting results while dealing with meteorological, sociological or economical changes, hence they are not updated depending on time. On the contrary, AI techniques have indicated the capability of learning complex nonlinear relationships, which are difficult to model, and accordingly making them popular (Jurado et al., 2015).

There are some State-of-the-Art (SoA) review of AI load forecasting approaches classification and comparison. Hong (2016) offers an impressive review of most important SLPF literature over the last forty years divided by conceptual and empirical studies. Moreover, the article includes a review of most notable techniques, i.e. ANN, Fuzzy Logic, SVM, Gradient Boosting, evaluation methods, and common misunderstandings. Another SoA empirical review of three AI techniques; ANN, SVM and Adaptive Neuro-Fuzzy Inference System (ANFIS) is performed by (Zor, 2017). Studies investigated in the context of this paper show that three different AI techniques have the potential for excellent forecasting. Another conceptual SoA review is performed by (Singh, 2012), where they classify demand forecasting techniques in i) traditional mathematical techniques i.e., Regression, Multiple Regression, Exponential Smoothing, etc.; ii) Modified Traditional techniques i.e., Adaptive Demand Forecasting, AR, ARMA and ARIMA model, SVM; and iii) SC techniques such as Genetic Algorithms (GA), ANN, Fuzzy-Logic and Knowledge-Based Expert Systems.

An implementation of these technologies for a massive deployment and/or for its usability in other processes such as in the LET, features such as robustness and reliability are an essential. The information that arrives from the different sensors in the home area network and/or the SM, have problems that may hinder or even prevent the forecasting and hence an optimal electricity trading.

Jurado et al. (2017) have done important steps in this direction. Flexible FIR is an improved version of FIR, a hybrid methodology based on fuzzy logic and inductive reasoning, which has been demonstrated to predict under scenarios of high number of missing values and therefore, uncertainties. Moreover, Flexible FIR uses a kNN optimal selection algorithm (Jurado et al., 2019) during the FIR prediction phase that allows the model to select the most suitable number of nearest neighbour, improving the accuracy and almost without impact in the model parameter selection.

These are remarkable feature because it could help for instance, in energy trading where missing data is present and using hardware with limited specifications.

Additional information about FIR, Flexible FIR and its applications in the energy domain and experiments performed can be found in (Jurado et al. 2013, 2015, 2017, 2019)

4 EDGE COMPUTING AND A NEXT GENERATION OF SMART METERS

Every home in Europe should be offered a SM from their energy supplier in the next few years. The government of Britain, for example, has pledged to offer all households the option of a SM by 2024 (Uswitch, 2020).

The main advantages of SM with respect traditional meters from final customer perspective are:

- Increase bills accuracy, since no more estimations and no more meter readings are necessary;
- Reduce the problems when customers switch suppliers. The SM newer models are compatible with the network that the meters talk to all suppliers through.
- Update readings frequently enough to use energy savings schemes;
- The in-home display enables the user to see how much energy is using at different times of the day. Some of them include a user-friendly App that shows current energy consumption, total balance and compares the usage performed in different months and years;
- Reduce energy bills, up to some extend. With the information that the in-home display offers (previous point), the consumer can try to cut or modify the energy usage and, therefore, be more energy efficient;
- Increase customer’s energy usage understanding. The SM allow the user to see the direct impact of the family habits on the bill.

And from a DSO/reatiler point of view (Prettico, 2019):

- Allow remote reading by the operator;
- Provide 2-way communication for maintenance and control;
- Allow frequent enough readings to be used for network planning;
- Support advanced tariff schemes;
- Allow remote ON/OFF control of power supply and/or flow or power limitation;
- Provide secure data communication;
- Allow fraud detection and prevention;
- Provide import/export and reactive metering.

More details about energy meters evolution in smart grid can be found in (Avancini, 2019).

SMs are part of the effort to create a smart grid, which is part of providing low-carbon, efficient and reliable energy to households. Households will find themselves in a position to feed supply back into the grid, as well as draw from it (Logic4Training, 2020). Therefore, trading of locally produced renewable energy becomes fundamental.

However, from our point of view, and taking into account the current services offered, the so called “smart” meters cannot be considered smart at all. Several important and strictly necessary services and features, not included in the current generation of SMs, have to be part of them in order to be considered smart devices. We believe in edge computing as a core technology of the NGSMs. Edge computing was detected as a Top 10 Strategic Technology Trends for 2018 (Cearley, 2018) and since then, the number of applications and sectors where it has been applied has increased exponentially. Edge computing delivers the decentralized complement to today's hyperscale cloud and legacy data centres. Edge computing addresses the limitations of centralized computing (such as latency, bandwidth, data privacy and autonomy) by moving processing closer to the source of data generation, "things" and users. To maximize the applications potential and user experience, DSOs need to plan distributed computing solutions along a continuum from the core to the edge.

From our point of view, the features that the NGSMs should provide are:

- Individual electricity load and production forecasting: With an EPM in each Smart Meter utilities would have information in each local node of the network, which means visibility and predictability in the Low Voltage. Moreover, the prediction at local level would be used to enable other features such as optimization of the energy trade and demand response programs.
- Trading mechanisms to allow peer-to-peer energy trading: Agent-based technology with multiple incentive mechanisms for rewarding renewable energy production and consumption.
- Demand-side management of home devices for demand response programs: Exploit and manage domestic consumer policies using the Internet of Things (IoT). Turn on/off high consumption equipment in the best price bands. Detect consumption that have been made outside the planned hours.
- Load disaggregation: This function would, among other things, allows to analyse and detect household appliances in poor conditions, appliances that consume a lot of energy or appliances and devices that have been left on. Along with the ability to interact with appliances (IoT), the smart meter could deploy a consumption optimization policy.
- Security and privacy by integrating blockchain technologies: When some sort of trading occurs between multiple parties, trust is a major concern. Traditionally, a third part trusted by all keeps the record of transactions. Using blockchain technology for energy trading eliminates the role of trusted third party.
- 5G connectivity: Interconnecting IoT with 5G networks efficiently helps to manage energy balance. This helps in the reduction of energy cost. Efficient data analysis can be done through 5G networks, which could empower cities to execute their own energy plans that would be more cost effective in accordance with demographic conditions. Moreover, 5G networks largely help the different distribution operators to reach their observability down the substation level. This assures substantial and balanced operations in the grid.

In Figure 1 we propose a high level architecture of a NGSM. The architecture is based on a Bourns SM.

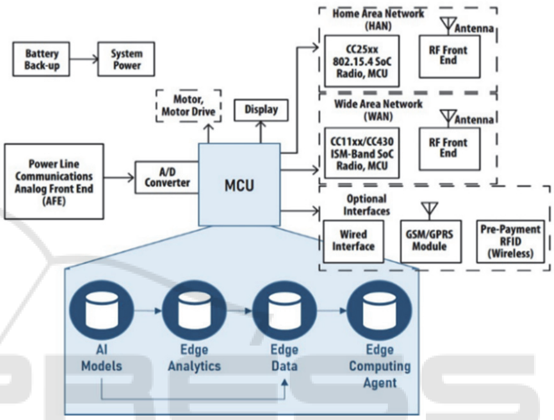

Figure 1: High level architecture of a NGSM.

The three main internal areas of a SM design include the power system: it has a switched mode power supply and battery backup to ensure that the metering electronics remain powered; MicroController Unit (MCU): typically includes an Analog-to-Digital Converter (ADC), Digital-to-Analog Converter (DAC) and in blue tones we have added the proposed components in the architecture that would allow the features previously mentioned; and finally, communications interface (HAN, WAN and Optional Interfaces): a wired or wireless communication interface allows the meter to interact with the rest of the grid, and in some cases the end user's network.

The new architecture is inspired in the edge architecture of IBM (Iyengar, 2019). The NGSM is equipped to run analytics, apply AI rules, and even store some data locally to support operations at the Edge. The NGSMs could handle analysis and real-time inferencing without involvement of the Edge server or enterprise layer. This is possible because devices can use any Software-as-a-Service (SaaS). Driven by economic considerations and form factors, an Edge device typically has limited compute resources. It is common to find Edge devices with ARM or x86 class CPUs with one or two cores, 128 MB of memory, and perhaps 1GB of local persistent storage

Having these features is essential to be able to trade renewable energy on smart grids. Some steps in this direction has been already done by some of the authors of this paper. Under the demonstrations in simulation environments of the NRG-x-Change and the NRGCoin concepts (Mihaylov et al., 2015) a prototype of SGSM was created, using Raspberry Pi to unlock edge computing capabilities. Prosumers were represented as software agents running on individual Raspberry Pi boards and 56 consumers' agents where running in individual threads on two Raspberry Pi boards. NGSMs were connected to the Internet, which allows agents to submit orders for buying and selling NRGcoins, allowing agents to trade energy through their SFSMs. Orders were matched in real-time using continuous double auction, as employed by the New York Stock Exchange. All software agents were developed in Java and implemented inside the Raspberry Pi, while the exchange market was developed in C# using Azure Service Bus for synchronizing actions. All components communicated using the RESTful Microservice architecture.

Agents used an EPM based on RF technique to determine the quantity to trade and the adaptive attitude bidding strategy to determine the bid/ask price. We are currently working to implement agents based on Flexible FIR, which has been proven in other studies to predict in a more robust and reliable way electricity load of multiple characteristic curves. With this new implementation we believe we will be able to improve negotiations between agents which will be translated in a major profitability of customer investments in renewable energy.

This implementation is being done using Raspberry Pi (Raspberry Pi Foundation), which simulates a NGSMs. We are aware that this hardware is not compiling with industry standards, however, the communication protocols, operating system (open-source software implementations for the agent, trading strategies and EPM) CPU, memory and storage are hardware and software requirements easily integrable.

We are now working with EPMs based on different techniques; ANN, RF, ARIMA and Flexible FIR, and how the performance in predictions directly affects to the objectives of individual prosumers.

5 DISCUSSION AND CONCLUSION

We believe new generation of SMs must provide citizens new ways to interact with the energy markets and services that helps the society to achieve the challenging energy goals we have in the next 20 years. SMs are in a unique position to technologically enable new features such as energy trading strategies for a local peer-to-peer in neighbourhoods and communities. However, if we want to increase local production and allow for LET, we need new hardware and software implementations. We believe that this has to be addressed from a decentralized point of view, for example with edge computing in a SGMSs. A key component inside SGMS will be the EPM, because it has to provide not only accurate predictions to the DSO but also robust and reliable forecasting for the individual (agent) participating in a local energy markets to achieve an optimal solution. to the agent collaborating in a local energy market.

A first proof of concept of the NGSMs has been implemented, however, the EPM used is far from being an optimal solution. We propose to use Flexible FIR for the EPM. RF has been already applied in this hardware. Our proposal is to bring the negotiation to a next level by implementing Flexible FIR. Its performance has been demonstrated for different consumption profiles and can cope with missing information in the input values, as well as during the prediction phase. Moreover, it works well in an "isolated" approach like in edge computing scenarios. It does not rely on deep learning or high computational cost plus it has been demonstrated to seemly choose autonomously some FIR input parameters.

It is important to highlight that there will be processes managed through cloud computing apps and others must be considered. However, we see cloud computing and edge computing complementary, rather than competitive or mutually exclusive. We believe that organizations that use them together will benefit from the synergies of solutions that maximize the profitability of both centralized and decentralized models.

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