Enabling New Tehnologies for Demand Response Descentralized Validation using Blockchain

Keywords—Demand Response, Blockchain, Energy, Smart Contracts,

I. Introduction

In the past few years the electricity grids have been part of revolutionary transitions towards more intelligent systems that incorporate smart grid concepts [1] such as: distributed renewable energy sources, smart metering, communication, automation and optimization mechanisms. The emerging grid technologies pave the way to new opportunities in terms of services and business models regarding the client demand management. An improper management of the energy supply and demand can threaten the stability of the entire grid. Variations of the energy production and consumption can lead to overloading the network, and then to power outage. With the integration of distributed renewable resources in the smart grids, more efficient load management mechanisms are required, as solar and wind energy sources are intermittent [2]. Since the current techniques regarding energy storage capabilities are limited, the only affordable solution is to motivate the energy consumers to shift their energy demand according to the renewable energy production peaks to avoid imbalances in the energy grid. Thus Demand Response (DR) programs were defined, where the Distribution System Operator (DSO) is responsible to prevent grid imbalances by issuing regulation signals and use different pricing schemes to motivate the consumers to follow these signals.

Demand side response (DSR) is widely recognized as a key element in the development of the future optimized, smart grid, incorporating a wide range of both centralized and distributed renewable and conventional power sources. This is particularly relevant in the context of next generation Virtual Power Plants (VPP) as well as the presence of multiple decentralized micro-grids, where managing demand from diverse and complementary loads, or distributed generation sources across different portfolio, means to obtain more flexibility in achieving a reduction in peak grid demand and lower costs to the community behind these available virtual resources. Dynamic pricing, incentive-based including direct coupon-based DR programs [10] appear to be very promising in such application scenarios according to a number of meta-analysis collating findings [11], [12], [13] from many DSR trials that indicate that economic and other incentives are effective in changing the operation momentum of smart grid of the future, offering new opportunities and challenges in the whole value chain. *Despite the many advantages of DR applications there are very few examples of the successful deployment [7] of DSR technologies that consider Virtual Power Plants as well as decentralized approaches [8], [9], towards achieving a reduction in peak grid demand and real savings for final consumers.*

The large scale deployment of smart metering devices together with the prospect of integrate a large number of distributed small scale renewable energy sources *challenged the most concerning limitation of traditional energy systems which is their centralized nature.* Beside technological scalability problems it may also generate higher fees and overall energy prices. This has lead towards the adoption of a decentralized energy networks where typical consumers can be also energy producers (i.e. prosumers) for selling excess energy back to the grid thus being involved in peer-to-peer or aggregated sale/purchase fashion. It is predicted that there will be an increasing number of end-users that will aim to become active in the energy sector leading to a huge pool of trading instances. Nowadays it has been discussed that blockchain technology can provide the required secure and reliable mean for communication and data persistence between such energy prosumers [14]. It allows the immutable and not deniable consumption/production data storage in a replicated distributed archive automatically synchronized. This can be validated by the development of new stable platforms for implementing blockchain based applications such as Ethereum [15]. Being based on the same principle as bitcoins, blockchains for smart contracts are considered the emerging technology that can be used for a decentralized grid topology enacting the required distributed transaction mechanisms [16], [17]. Among the benefits of such innovative technology we can find lower lines losses, better load management, and lesser outage hours, secure energy transactions and increase proportion of distributed generation within global energy mix [18]. This way energy networks will be more robust due to the fact that every smart grid node will be working towards the grid stability.

In this paper we will present a robust, democratic and scalable demand response framework which will: a) provide a near-real time autonomous demand response management system and a democratic market driven pricing scheme b) maximize the community potential by aggregating groups of prosumers and develop new financial/business models and c) integrate forecasting and optimization services that will offer the opportunity to follow different policies for maximizing the prosumer’s benefits in terms of: renewable energy usage maximization, cost minimization, etc. The framework will feature a blockchain based near-real time closed-loop DR validation, fully autonomous, secured and decentralized. This will enact each prosumer with the possibility to verify the authenticity and integrity of all DR events and bid notifications. In this envisioned blockchain driven framework DSOs and aggregators cooperate with a view to exploit to the largest possible extent the flexibility potential of a large variety of heterogeneous third party stationary and movable load assets, while keeping system reliability within prescribed limits and preserving continuity and security of supply. At the same time the blockchain approach to DR and energy transactions will pave the way for secured cryptography based decentralized management of energy markets.

II. Concept and Approach

A. *Framework Layered Arhitecture*

Figure 1 presents a decentralized layered architecture for tackling the challenges of distributed smart grids and the stakeholders involved in the DR added value chain.

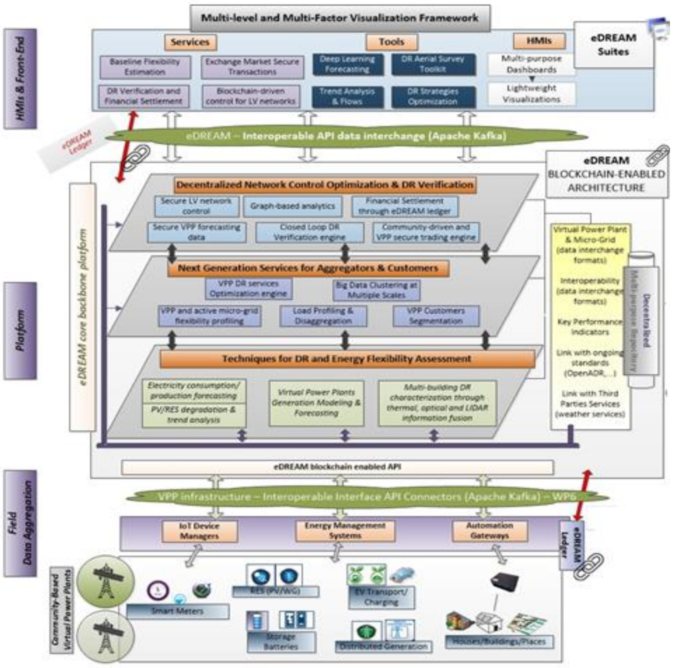

Figure 1. Framework Layerd Arhitecture

Field Data Aggregation - the bottom layer of the architecture dealing with field data collection, streaming and processing for the higher layers. A lambda-based architecture will be used assuring scalability, high communication and computing performance as key enablers for near real-time DR programs. This layer will provide access to near real-time information from existing virtual resources (e.g. VVP data collected in an aggregated manner through automation gateways), through IoT devices metering as well as the provision for third parties' information that will ensure that higher layers all the necessary data to perform their analysis.

Core Backbone Platform - consists of the different technologies and mechanisms to support the delivery of a decentralized ecosystem for closed-loop DR programs such as:

- *Technologies for DR and Energy Flexibility Assessment*. A set of novel electricity consumption and distributed energy resources production forecasting mechanisms. Moreover, a series of PV/RES degradation and trend analysis algorithms will be investigated towards improving the short-term forecasting of generation (i.e. support day-ahead and direct trading and/or coupon-based DR programs). Emphasis will be put on delivery of a group-wise association of resources towards their encapsulation in community-based VPP.
- *Next Generation Services for Aggregators and Customers*. Innovative machine learning techniques for load profiling and disaggregation at multiple scales (e.g. micro-grid level, virtual power plant and in lower loads related to Distributed Energy resources). Also big data analytics engine will be developed for analyzing large streams (including micro-batch level) collected from customers.
- *Decentralized network control optimization & DR verification*. Development of innovative blockchain driven control of the low voltage network, the demand response verification and financial settlement through distributed ledgers. Also it will offer an engine that will support automated closed-loop DR programs to be executed, verified and settled.

HMIs & Front-end - for easy-to-use and accessible HMIs for end-users and operators. They will enable vertical collaboration (from the DSOs and aggregators to prosumers/consumers) and horizontal collaboration (using virtual topologies such as the envisioned community-based virtual power plants) within the smart grid value chain.

B. *Blockchain Driven DR Management, Control and Closed Loop Validation*

We propose the development of a blockchain based infrastructure for distributed management, control and validation of DR programs in low voltage smart grids with a view of assuring high reliability and decentralized operation by implementing trackable and tamper-proof energy transactions. Using our blockchain infrastructure all interested actors (i.e. prosumers, DSO, TSO, etc.) will be able to coordinate in near real time and support fully decentralized demand–supply matching and stable grid operation.

A distributed ledger [4] will be used for storing and assessing in a secure way which share of the contracted flexibility service has been activated in reality at the grid level. *This will make the transactions trackable and tamper-proof on distributed systems without the need for centralized monitoring.* We model the grid as a network of prosumers, whose monitored energy production and consumption values will be acquired using smart meters and then will be registered, validated and mined in blocks. The blockchain structure holds the key for many problems that can arise in such open energy systems. The blockchain structure is a linked list using hash pointers. Each block contains all the transactions that occurred in the system in a short period of time. It is an append only data structure, that gathers all the benefits of the hashing and cryptographic functions and offers an immutable history of the entire activity of the network.

The blockchain ensures Byzantine fault tolerance through the implementation of distributed consensus based on mining protocols [5]. Each time a new block is propagated in the network, all the peers will check the validity and consistency of each transaction and then of the entire block. Leveraging on that, the DSO may compare the monitored values with the contracted service and identify in near real time the appropriate financial settlement and remuneration for the flexibility providers, congruent with the share of activated service. To avoid misleading transactions that correspond to false monitored data, DR verification and financial settlement will be done using distributed consensus algorithms, run by several nodes in a Proof-of-Stake manner. We will extend and specialize Proof-of-Stake algorithms for miming the next block and validating associated transactions/services in the blockchain to the specific case of DR with a view of providing novel blockchain-based closed loop DR validation which goes in the direction of increased reliability of the DR system and improved reliability of DSO operation. Each network prosumer could take the role of flexibility services or transactions validator and should own some stake in the network (e.g. the total rewarded DR incentives received so far which could be used as a guarantee of blocks validity). Thanks to the blockchain based approach the DSO will have the possibility for knowing in near real time the share of activated and validated flexibility services and associated transactions, and accordingly they can find in near real time solutions to deal with the occurred unplanned situation.

We will define and use blockchain self-enforcing smart contracts for DR flexibility services and energy transactions modeling and control in low voltage grids. By including the smart contract [6] capabilities in the blockchain infrastructure, the system will offer much more than just energy asset transitioning. It will offer the medium for developing strong business models over the registered transactions. The self-enforcing smart contracts are defined in distributed fashion at the level of each prosumer and specify the contracted baseline energy consumption or energy production levels (curve). For each value provided and stored to a specific blockchain by the prosumer associated energy metering device, the associated smart contract is evaluated by estimating the difference between the expected baseline curve and actual sample values. If significant deviations are found actions are taken to rebalance and match the energy demand and supply thus the smart contract will act as a decentralized control mechanism and energy assets balancing towards the DSO. Incentives or fees will be applied for following, violating the commitment. The DR agreements will be defined using another set of contracts that will specify regulation signals according the imbalances occurred in the grid and the information received from the forecasting services. Similarly, the prices will be settled considering all the energy bids and offers, in a decentralized marketplace fashion.

III. Conclusion

In this paper we have presented an innovative vision of blockchain technology for energy grid control leveraging on the delivery of a closed-loop DR framework that will incorporate novel near real time demand response verification assessment mechanisms (addressing the share of the contractual services effectively delivered through DSOs). This concept and framework is in line with the recommendations recently reported by European Commission [19] in respect to DR by: (i) ensuring a smooth transition towards a novel market scheme (i.e. closed-loop and more localized DR scheme simplifying today's multi-layered ecosystem, provided a secure end-to-end ecosystem) and (ii) enabling consumers/prosumers to effectively participate in community-based virtual power plants concepts, allowing from one hand aggregators to maximize the group's joint potential as well as the possibility for direct trading of the aggregated load through new business/financial models (e.g. direct trading of the aggregated flexibility through self-enforcing smart contracts).

Acknowledgment

The work presented in this paper was partially supported by the EU-funded Project H2020 eDREAM project Grant number 774478.

References

[1] Energy Independence and Security Act of 2007 (EISA-2007), Available online at https://www.gpo.gov/fdsys/pkg/PLAW-110publ140/pdf/PLAW-110publ140.pdf

[2] Lueken, Colleen A. Integrating variable renewables into the electric Grid: An evaluation of challenges and potential solutions. Diss. Carnegie Mellon University, 2012.

[3] Antal M, Pop C, Valea D, Cioara T, Optimizing data centers operation to provide ancillary services on-demand. In: Interneational Conference on Economics of Grids, Clouds, Systems and Services (GECON) 2015

[4] Distributed Ledger Technology: beyond block chain (PDF) (Report). UK Government, Office for Science. January 2016

[5] Markus, J, . Proofs of Work and Bread Pudding Protocols. In Secure Information Networks; Springer: Berlin, Germany, 1999; pp. 258–272.

[6] Nick Szabo -- Smart Contracts: Building Blocks for Digital Markets". www.fon.hum.uva.nl.

[7] Hu, Zheng, et al. "Review of dynamic pricing programs in the US and Europe: Status quo and policy recommendations." Renewable and Sustainable Energy Reviews 42 (2015): 743-751.

[8] Flexible Electricity Network to Integrate the eXpected energy evolutions, FP7 project dealt with VPPs, http://www.fenix-project.org/

[9] Sample of European Smart Grids Projects, available at: http://www.smartgrids.eu/EU_Projects

[10] Fang, X., Hu, Q., et. al. Coupon-based demand response considering wind power uncertainty: a strategic bidding model for load serving entities. IEEE Transactions on Power Systems, 31(2), 1025-1037.

[11] Faruqui, A. and Sergici, S. (2009) Household Response to Dynamic Pricing of Electricity— A Survey of the Experimental Evidence, Harvard University, The Brattle Group, Tech. Rep., 2009, pp. 1–53.

[12] Ehrhardt-Martinez, K., Donnelly, K. A. and Laitner, J. A., Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities, American Council for an Energy-Efficient Economy, Washington DC, 2010

[13] Faruqui, A. and Palmer, J. (2012) The Discovery of Price Responsiveness–A Survey of Experiments Involving Dynamic Pricing of Electricity, Social Science Research Network, pp. 1–13, 2012; available at: http://ssrn.com/abstract=2020587.

[14] https://www.metering.com/features/smart-grids-blockchains/

[15] https://www.ethereum.org/

[16] K. Christidis and M. Devetsikiotis, "Blockchains and Smart Contracts for the Internet of Things," in IEEE Access, vol. 4, pp. 2292-2303, 2016.

[17] http://fortune.com/2016/05/15/blockchain-reinvents-power-grid/

[18] https://www.linkedin.com/pulse/internet-things-smart-grid-block-chain-gunti-vijay

[19] Demand Response status in Member States: Mapping through real case experiences, http://e3p-beta.jrc.nl/articles/demand-response-status-member-states-mapping-through-real-case-experiences