# MICROGRIDS FOR DECENTRALIZED ENERGY MARKETS BASED ON BLOCKCHAINS

Giovanni VELOTTO
ABB – Sweden

Ritwik MAJUMDER
ABB – Sweden

Bengt STRIDH
ABB – Sweden

## ABSTRACT

*Blockchains technologies can revolutionize the economies and the business models with considerable impacts on the energy business. The introduction of blockchains opens the way to the creation of peer to peer (p2p) energy markets that can drastically change the actual business landscape and be a facilitator for the faster penetration of decarbonized and decentralized energy sources. This paper intends to present and analyse possible development scenario of such technologies in the area of microgrids. A qualitative analysis of the potential applications for some business models are discussed in combination with the expected interfacing of the control and communication.*

## INTRODUCTION

The "tokenized" economy is currently booming. The web/digitalized technologies are oriented towards the creation of the internet of value (e.g. blockchain) and not only information [1]. The strong decentralization and networking of the socio-economic systems will affect the evolution of the electric infrastructures' technologies, operation and planning. With the rise of crypto-economics a new subset of economics is hence emerging, therefore considerable research is required in the area of distribution and consumption of energy and related services in a decentralized digital economy[2]-[4].

Decentralized digital energy markets, made feasible through the adoption of blockchain technologies for example, can revolutionize the economies and the business models with considerable impacts on the energy business. The envisioned penetration of peer-to-peer transactions functionalities, mainly in the electrical distribution networks, will allow to develop new markets for services. Interesting potential are foreseen in a tighter interconnections with financial markets through the employment of tokenized investment vehicles related to energy production and consumption.

The realization of decentralized p2p markets in microgrids can allow to improve the economic profitability of energy costs for the consumers and to reach higher utilization of renewable energy [5].

In order to exploit such potential a technology upgrade is needed (e.g. SCADA, communication, cyber security as well as upgrade of hardware capability). With specific reference to microgrid electrical networks, one of the main challenges is how to address the large variety of uncertainties and variables that affect the networked electrical systems and how to match the markets transactions with physical and technical constraints arising in the operation, control and protection of electrical assets. A larger adoption of power electronics even in the distribution networks will provide further flexibilities, but it will increase the complexity and affect the reliability of the systems.

The architectures, the control algorithms, the protection strategies and energy balance capabilities need to be fitted for such scenario.

This paper intends to present and analyse possible development scenario of blockchains technologies in the area of microgrids. A qualitative evaluation of the benefits, such as improved utilization of renewables and storage, postponing grid upgrade, through employment of blockchains technologies in microgrids are highlighted.

A technological overview on a control architectures, which could be employed for the realization of decentralized markets, is presented with discussion on functionalities and potential developments.

## MICROGRIDS AND BLOCKCHAINS

Microgrids identify a set of interconnected electrical sources, distributed energy resources (DERs), storages and loads characterized by clear geographical and electrical borders and by the capability of being controllable as single entity connected or independent from a main distribution grid [6].

Microgrids solutions enable the integration of renewable power generation through the realization of scalable design options that offer cost competitiveness compared to large scale capital intensive infrastructure investments. The competitiveness is strictly interrelated to the economic and infrastructural development stage and directions of specific regional markets but its advantages can be clearly assessed [7]-[8].

The capabilities and potential developments of the control technologies give also to microgrid solutions the additional valuable advantage of being able to support, in a distributed manner, the operation of electric networks to which they are connected though the provision of stabilizing and recovery services. These features, if structured and organized within a distributed control approach of the electric network, can contribute to improve cost and reliability performances of the whole electric network infrastructures [9]-[11].

### Application potentials and problems

The realization and achievement of such potentials is highly dependent on the implementation of coordination mechanisms that can be market based. Within this objective, the blockchains technologies [1] can be surely presented as an innovation soft-piece of the puzzle that has be made up in order to conceive and realize decentralized markets in energy networks. The application contexts can range from district microgrids to, larger scale, as multiple interconnected microgrids that could profit from synergies and complementariness.

Blockchains technologies can be seen a technological layer capable of providing several functionalities, for example: secure database for tagging electricity productions, qualities and sources, transactions records, tokenization of assets and value exchange among the subjects of the market through crypto-assets. These functionalities can clearly open the way to realization of advanced p2p markets structures even with the employment and introduction of financial tradable assets, in real time, that could help to manage the risks connected with market operation.

An example of a layers' architecture is elementary represented in Figure 1. The blockchains layer will overlap the microgrid physical layer and they will need to exchange information for the trading operations. The key technical challenge identified is the coordination of the two layers in a way to reliably optimize the energy and the assets' utilization. The architectures, the control algorithms, the protection strategies and distributed energy balance capabilities need to be fitted for such scenario.

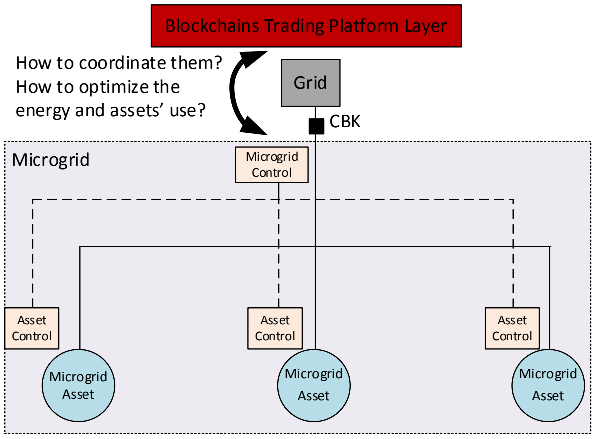


*Figure 1 Blockchain and Microgrid Layers*

## MICROGRIDS CONTROL ARCHITECTURE AND FEATURES

A typical microgrid power system with a distributed control architecture and high penetration of renewable sources is represented in Figure 2 [12].

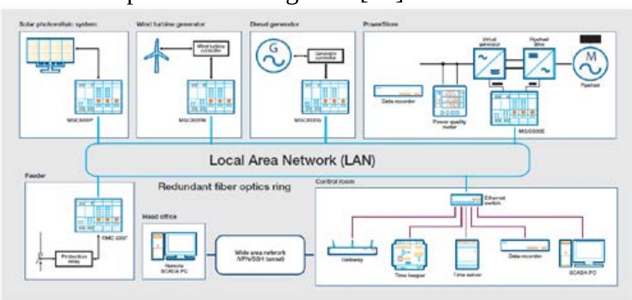


*Figure 2 ABB Renewable Microgrid Controller schematics*

The advantages of having such a distributed control system are, among others:

- Scalability
- Commissioning time
- Failure resistance

In a scenario with a blockchain based trading platform such benefits will persist but a coordination mechanism is required [12].

In Figure 3, for example, a typical architecture of the distributed control of a microgrid made of power sources, storage and loads, is represented. Each of these entities is controlled through a local controller MGC-X, even the connection to the main grid is controlled through a network controller that mainly supports the PCC power flow control, microgrid voltage droop and grid connections functionality e.g. islanding, resynchronization etc. Microgrid Plus in such an architecture has the function of aggregator through the communication structure. The control architecture is designed in a way that even in case of loss of communication the critical functionalities (e.g. power balance, voltage and frequency control) can be delivered only with local measurements.

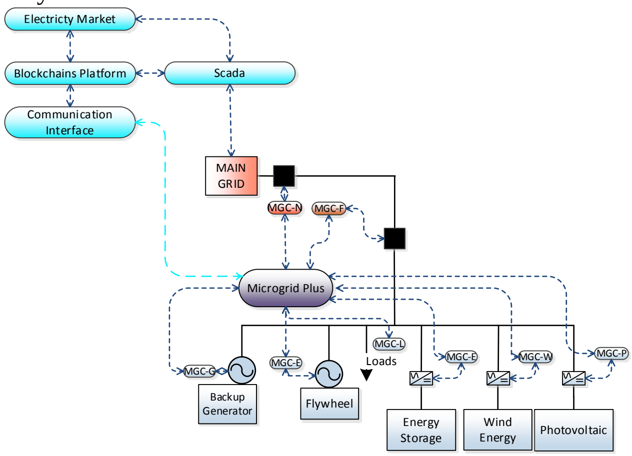


*Figure 3 Integration of blockchain in control architecture of microgrids*

The trading platform will need be integrated in the communication layer in order to provide information on the transactions performed, on the electricity markets and, on the other side, on the state of the networks and on its technical limitations.

In Figure 3 the communication between the trading platform and the microgrid's local controllers is represented through the Microgrid Plus as data aggregator, SCADA interface, remote access etc. This solution can be one of the possible options for the communication architecture but not the only one. It is clear that for the implementation of a secure and efficient trading platform the requirements on the communication technologies as latency, security, availability, and reliability are critical. The risk of communication losses needs to be evaluated and mitigation strategies have to be set-up, minimizing the impacts on the customers and preventing cascading phenomena. The risks of unplanned islanding during transactions with the main grid may pose challenges to be faced in order to keep the system in operation if not adequate strategies and reserves are in place.

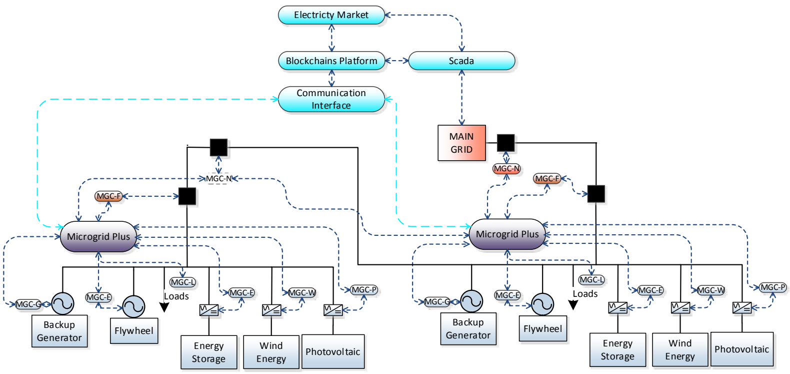


*Figure 4 Multi-microgrids scenario with blockchain based trading platform.*

The integration of blockchains trading platforms, allowing the expansion of p2p market in the distribution networks will require to expand, as well, the functionalities of the SCADA. These systems have to fulfil similar requirements to the ones that nowadays are employed at transmission level. The need of implementing, within the distribution networks, new functionalities through an active role of the final customers within digital contracts framework can be challenging as the scaling factor could be a limitation [13]. Within this scenario a particular attention goes to the storage system within microgrids and distribution networks. It is clear, from the technical point of view, that reliability and security will play a critical role for the implementation of p2p electricity markets [14]. Transactive power flows within microgrid and between the microgrid and the main grid require to implement management and operation strategies that must fulfil the power availability requirements and the security targets.

It is also interesting and easy to note how the expansion of the p2p markets to the distribution networks will open and require several “services” to be delivered to the networks as active and reactive power reserve, black start, etc. For some of them (e.g. storage) it is reasonable to think on scale economics that can allow the integration of new business models and operators as service providers [15].

This evolution needs also a considerable support from the regulating authorities that have to provide an adequate framework for the expansion of such markets to the distribution networks.

The complexity of the technical problem is also related to the modularity and expansion possibilities of microgrids architectures. In [16]-[17] it has been shown benefits of employing multi-microgrids or nested architectures.

In Figure 4, as simple example is reported the case of two nested microgrids that are intended to implement a p2p market through the blockchain platform. Even in this example the microgridplus is used as the communication interface.

In case of more elaborated topologies of the networks a p2p market will require the adoption of technical equipment (e.g. power electronic converters) and operating methods that should allow higher flexibilities in the power flow control among interconnected microgrids and with the main grid. In Figure 5, for example is reported the case when the storage from one microgrid supplies the critical load in another microgrid with loss of main grid. The optimization of the energy flows through the storage devices and their utilization is an important requirement for releasing the expected potential benefits of p2p market. The coordination and availability of the blockchains trading platform, the SCADA and the local controller of the assets is critical for the correct operation of the networks.

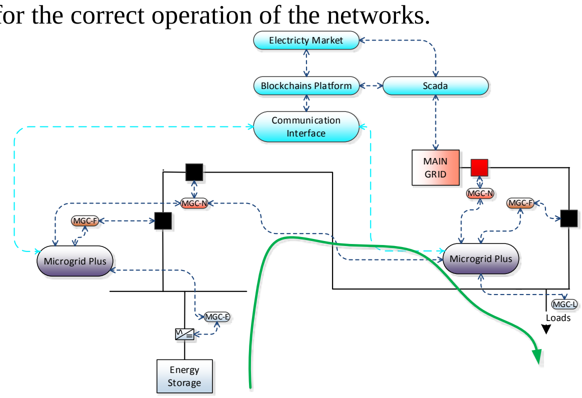


*Figure 5 Example of inter-microgrids power flow*

## CHALLENGES AND OPPORTUNITIES IN THE PRESENT MARKET REGULATIONS

The blockchains applications, at present, pose a lot of uncertainties for their industrial implementation as they are still in their early stage. The lack of a regulation framework also can be considered as a challenge and an opportunity. In this paper for example is reported the Swedish case. Nowadays for a typical residential customer who has PV systems installed there are economic benefits dependent on the governmental subsides. A typical installed PV power is about 3-5 kW. Some of the produced electricity would be self-consumed and the excess electricity is fed back into the grid and sold to an electricity trader. The value of the self-consumed and the sold electricity are different. Without any subsidies considered the value of self-consumed electricity is substantially higher than the electricity sold to the main grid as there are no energy taxes (0.331 SEK/kWh in 2018), electricity transfer fee (≈0.1-0.6 SEK/kWh depending on DSO and type of contract), electricity certificate fee (≈0.02 SEK/kWh) and VAT (25%). Taking subsidies into account the value of the electricity sold to the main grid is closer to the value of self-consumed electricity since a residential PV system owner usually get a taxes deduction (0.6 SEK/kWh) for the excess electricity fed into the grid. In addition, it is possible to get green electricity certificates for sold electricity without any additional costs for the PV owner. These certificates can be sold, but the market value can vary and has decreased during recent years to 0.1 SEK/kWh in early 2018 [18].

The regulations today in Sweden do not allow a PV system owner to directly sell excess electricity to a neighbor. Both must be connected to the common DSO grid and have contracts with an electricity trader to buy and sell electricity. The energy transfer over the DSO grid would impose energy tax, electricity transfer fee, electricity certificate fee and VAT as explained above.

No license is needed in Sweden to start trading electricity. However, there are obligations making it unrealistic for an owner of a residential or a commercial PV system that wants to trade excess electricity.

To improve the possibilities of p2p market between residential houses or between different buildings in a tenant-owned apartment society it is needed to review the laws ("Ellagen"). The authorization for conducting electricity grid operations and the way in which the energy tax is withdrawn should be revised to make possible and profitable to transfer electricity between independent buildings.

## CONCLUSIONS

The energy sector will be reasonbly affected by blockchains technologies even if they are still in early stage. One of the possible application is the implementation of p2p markets in microgrids. This scenario imposes considerable technological development in power systems' architectures, control algorithms, protection strategies and distributed energy balance capabilities. This evolution needs also a considerable support from the regulating authorities that have to provide an adequate framework for the expansion of such markets to the distribution networks.

## REFERENCES

[1] Waelbroeck, P., 2018. *An Economic Analysis of Blockchains*(No. 6893). CESifo Group Munich.

[2] Long, C., Wu, J.Z., Zhang, C.H., Thomas, L., Cheng, M. and Jenkins, N., 2017. Peer-to-peer energy trading in a community microgrid. In *IEEE PES General Meeting*.

[3] Babar, M., Kamphuis, I.G., Hanzelka, Z. and Bongaerts, M., 2017. A blueprint for the combinatorial strategy in transactive energy based control mechanism by using energy flexibility platform and interface. *CIRED–Open Access Proceedings Journal*, *2017*(1), p.1597.

[4] Sijie, C.H.E.N. and Chen-Ching, L.I.U., 2017. From demand response to transactive energy: state of the art. *Journal of Modern Power Systems and Clean Energy*, *5*(1), pp.10-19.

[5] Mengelkamp, E., Gärttner, J., Rock, K., Kessler, S., Orsini, L. and Weinhardt, C., 2018. Designing microgrid energy markets: A case study: The Brooklyn Microgrid. *Applied Energy*, *210*, pp.870-880.

[6] Hatziargyriou, N. ed., 2014. *Microgrids: architectures and control.* John Wiley & Sons.

[7] Morris, G.Y., Abbey, C., Joos, G. and Marnay, C., 2011. *A Framework for the Evaluation of the Cost and Benefits of Microgrids* (No. LBNL-5025E). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

[8] Hanna, R., Ghonima, M., Kleissl, J., Tynan, G. and Victor, D.G., 2017. Evaluating business models for microgrids: Interactions of technology and policy. *Energy Policy*, *103*, pp.47-61.

[9] Gu, Y., Xiang, X., Li, W. and He, X., 2014. Mode-adaptive decentralized control for renewable DC microgrid with enhanced reliability and flexibility. *IEEE Transactions on power electronics*, *29*(9), pp.5072-5080.

[10] Yazdanian, M. and Mehrizi-Sani, A., 2014. Distributed control techniques in microgrids. *IEEE Transactions on Smart Grid*, *5*(6), pp.2901-2909.

[11] Liegmann, E. and Majumder, R., 2015. An efficient method of multiple storage control in microgrids. *IEEE Transactions on Power Systems*, *30*(6), pp.3437-3444.

[12] Renewable Microgrid Controller MGC600,https://library.e.abb.com/public/d66c5a59934a10b7c1257c37002cc707/9AKK100580A2552_Microgrid%20Controller%20600_EN_LR(Dic2013).pdf

[13] Shang, D.R., 2017. Pricing of emergency dynamic microgrid power service for distribution resilience enhancement. *Energy Policy*, *111*, pp.321-335.

[14] Habib, H.F., Lashway, C.R. and Mohammed, O.A., 2017. A Review of Communication Failure Impacts on Adaptive Microgrid Protection Schemes and the Use of Energy Storage as a Contingency. *IEEE Transactions on Industry Applications*.

[15] Fisher, M.J. and Apt, J., 2017. Emissions and economics of behind-the-meter electricity storage. *Environmental science & technology*, *51*(3), pp.1094-1101.

[16] Kariniotakis, G., Martini, L., Caerts, C., Brunner, H. and Retière, N., 2017, June. Challenges, innovative architectures and control strategies for future networks: the Web-of-Cells, fractal grids and other concepts. In *CIRED 2017-24th International Conference on Electricity Distribution* (p. 1287).

[17] Majumder, R., 2014. Aggregation of microgrids with DC system. *Electric Power Systems Research*, *108*, pp.134-143.

[18] Energimyndigheten.Cesar.cesar.energimyndigheten.se.