

DISRUPTIVE POTENTIAL AND BUSINESS MODEL INNOVATION THROUGH ELASTIC MICROGRID-AS-A-SERVICE (MAAS) PLATFORMS

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ABSTRACT

We identify an emerging category of microgrids, called dynamic microgrids, which are a result of the combination of elastic platform technologies and flexible business models of microgrid-as-a-service providers. Such dynamic microgrids are already transforming parts of the distribution system by incorporating existing distributed generation with storage and controls, and matching generation with increasingly dynamic local or neighbouring loads. It is this new category where we see various forms elastic microgrid-as-a-service platforms and protocols already being applied. We detail important characteristics of such elastic, i.e., scalable, fault-tolerant, platforms and conclude with a discussion of possible business model innovation by new players and positioning of incumbents.

INTRODUCTION

There have been debates about what constitutes a microgrid. As per a widely adopted definition by the Department of Energy, “a microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and that connects and disconnects from such grid to enable it to operate in both grid-connected or “island” mode.” Microgrid-as-a-service provisioning additionally requires advanced control and data-driven automation. This enables the providers of a microgrid-as-a-service to cost-effectively operate (in many cases also finance or own) multiple sites starting from a few to many. We want to create an understanding what a microgrid can mean in the near future versus what it meant by strict academic definitions a few years ago. It is helpful to categorize typical microgrid projects and emerging undertakings.

In this paper we present a form of typing of the currently active players in an emerging category of microgrid-as-a-service or more generally can be described as dynamic microgrids, since they are not of a fix size from the beginning. We shortly describe how they evolve; touch upon the disruptive potential and what type of hardware and/or software platforms facilitate the characteristics of the new. We elaborate on the building blocks of these elastic microgrid-as-a-service platforms, which from a software architectural perspective could be combined into any desired constellation or morph for serving one type or the other over time or location of service delivery. Elasticity for our

purposes means scalable, fault-tolerant and secure computing and communication platforms that seamlessly integrate increasing numbers of multiple applications, users and microgrid physical and digital automation and control resources. We will conclude with a discussion of business model innovation that such elastic platform technologies enable for new players and how incumbent utilities and retailers can position themselves.

DISRUPTIVE POTENTIAL OF DYNAMIC MICROGRIDS THROUGH MAAS

The typical microgrid deployments can be described in five categories: community or utility microgrids, commercial or industrial, institutional or campus, remote off-grid systems like islands, and military microgrids. We identify a sixth emerging category, which is transforming parts of the distribution grid by incorporating existing distributed generation with storage and controls, and matching this with local loads. It is this new category where we see various forms of elastic microgrid-as-a-service platforms and protocols already being applied. Microgrids in the traditional five categories are conceptualized and realized as large monolithic projects. They are planned and configured upfront with one or more specific goals and do not significantly change over their lifetime. We see typical early adopters of microgrids in these five main categories, which value the robust characteristics of a microgrid such as resilience and autonomy in case of grid disturbances. Such characteristics are operations critical for large data centres and military, for example. Increasingly, also an improved mixture of renewable, combined heat and power, and storage become new objectives, if they happen to be in areas with renewable friendly regulation or where renewable and fuel-independence are important topics like on islands. Another characteristic of these early adopters are that there is one customer per microgrid, i.e. the owner and user is the same entity, although the installation itself may serve hundreds of users. In many cases such microgrids are operated by the utility. In others, the microgrid has a dedicated energy manager working for the owner entity, operating it according to the objectives and mostly connected to the utility, i.e. in-synch. If the microgrid’s sole objective is resilience, typically it receives all its energy in traditional way, i.e., via retailer or local utility, with the on-site generation capability being only for backup power in case of necessary islanding from the grid.

In contrast, the microgrids that fall into the sixth category are not planned for a fixed size, but grow from one to a few to double digit units and potentially even more, consisting of

as many customers within the microgrid. Hence, these microgrids could be characterized as “*dynamic microgrids*”. They are inevitably supported by a secure, fault-tolerant, resilient hardware/software platform that can scale cost-efficiently, i.e. linearly with increasing numbers of microgrid nodes. Typically some of the customers are prosumers, around whose resources the microgrid is built, e.g., rooftop solar, storage in form of batteries or electric vehicles. They may own the microgrid nodes, but are not responsible for the operations. Such customers are merely interested in supporting the objectives of the microgrid, which differ from early adopters’, e.g., lower electricity bills, green local energy, or social aspects of sharing. In some cases, the distributed generation nodes such as rooftop solar are only leased by the customer or entirely belong to a provider that basically rents the roof and operates the solar energy generation on top. It is conceivable that in the near future such optimizable distributed energy resources including electric vehicles will be owned and operated by energy service providers. The end users then for example pay a significantly lesser amount, if at all, only for the mobility service of the electric car, whilst the car’s main purpose is mobile storage for microgrid-as-a-service operators. We gained these insights by a high level analysis of a few of these new players in the European and US markets. The players in this sixth category can be currently subdivided into the following types, which can transform to one another over time:

Grassroots community microgrid. In contrast to traditional community microgrid projects, this new type of community microgrid starts with a few closely located customers with solar energy generation and adds neighbouring consumers. Both prosumer and consumer type customers remain utility connected. Digital meters that are capable of securely imprinting the virtual exchange of energy onto a “*distributed virtual ledger*” constitute the completely decentralized elastic platform utilized by new players such as Transactive Grid¹ in US and Grid Singularity² in Austria. Initial offerings mainly concentrate on enabling the accounting for the energy exchange in the local microgrid market. Control or optimization of the available energy resources mix of the local community is not an objective yet. The incentives of the customers to participate in grassroots community microgrids reach from lower monthly electricity bills, to direct support for renewable energy and clean local air or from green lifestyle to neighbourhood assistance.

Nano- to microgrids. When it comes to new industries, technological innovation and cost reduction of technology over time are initial barriers. Solar panel costs show an impressive decrease rate in cost per watt [1]. Batteries are poised to follow a similar decline in costs. However,

innovation in business model has been to most notable recent factor in the quick market capture of solar providers like SolarCity³. Innovative financing techniques and taking risk off the shoulders of the prosumer coupled with process innovation such as efficient assembly, vertical integration etc. have made SolarCity the biggest installer in the US. The company, sometimes dubbed “solar utility company” as it is owning and operating the distributed generation and has been selling electricity to the customers, continually finds ways to expand its market, which is creating this type of “*solar-store-save nano- to microgrids*”: Existing solar installations are coupled with storage and demand saving capabilities through partnerships within the clean-tech ecosystem such as battery packs, learning thermostats, smart water heaters, etc. [2]. Such offering is regulations-agnostic, hence robust, combination of private energy service offerings. They use the enhanced optimization capability for already one customer behind the meter. Such capability diversifies with the scale and fleet of the owned and operated nanogrids. The offering is technologically enabled by a centralized dynamic monitoring and control platform, which vertically integrates with the control units of generation and consumption in the nanogrids. With such an elastic platform, one can scale to a microgrid-as-a-service model by servicing geographically close nanogrids, and/or a virtual utility model, where the owned and operated nanogrids are spread without clearly defined boundaries. This insight, from our perspective raises a critique in the academic microgrid definition. Digital platforms are capable of defining and manifesting “*dynamic microgrid boundaries*” over time and location, as need arises due to economic opportunity or grid stability.

Energy sharing platforms. A relatively new offering in the energy market is being created in the spirit of sharing economy⁴. Similar to grassroots community microgrids the sharing platforms target already installed infrastructure. Beyond rooftop solar such as on Yeloha⁵, the platforms include combined heat and power, wind and biomass energy conversion facilities located at the premises of private households and farmers (especially in Europe, e.g., Germany⁶ or Netherlands⁷, farmers concentrate the most privately owned distributed generation capacities). The sharing platforms do not impose locality constraints, and in this sense do not create microgrids according to the academic definition. However, an impressive characteristic of sharing platforms will foster creation of de-facto microgrids, which may ultimately cover electricity delivery in entire distribution systems: First, sharing is a socially motivated experience, which in the case of energy will be locally spread via word-of-mouth. Second, online platforms that facilitate the mere sharing of existing resources can

3 www.solarcity.com

4 en.wikipedia.org/wiki/Sharing_economy

5 www.yeloha.com

6 microsite.sonnenbatterie.de/en/producer/arthur-kolb

7 www.vandebbron.nl

1 www.consensys.net/ventures/joint-ventures

2 www.gridSingularity.com

scale highly effectively as demonstrated by sharing platforms in other sectors such as accommodations [3] and transportation [4]. This sheer pace of scaling can be very disruptive in areas where cost of the shareable resource is inefficiently high such as accommodation costs or transportation costs (including cost of time spent in traffic) in dense cities. Translated to the energy sector, this would mean that energy sharing platforms are likely to scale quickly to de-facto (micro-)grid-as-a-service in areas with older and amortized distributed generation, or with structurally high energy costs such as on islands or remote off-grid locations. Additionally, such platforms could enable commercial microgrids to easily market their excess energy. Nano- to microgrid installations with resources, which are purchased after the lease-term, are also typical candidates for sharing on these platforms. Regarding the high cost of financing microgrids, there are even players like Mosaic⁸ applying the crowd financing model to providing the electrical infrastructure. The centralized solutions supporting such disruptive scaling today are typical examples of elastic web-based digital service platforms. These platforms, by facilitating the sharing of distributed energy resources, in a highly scalable way, can dynamically create microgrids-as-a-service areas.

CHARACTERISTICS OF ELASTIC MAAS PLATFORMS

The business model generation capabilities of the new players creating dynamic microgrids are highly correlated with their technological capabilities. Whilst some players regard grid technologies as given, i.e. operate on top of existing physical infrastructure as is the case with grassroots community microgrids and energy sharing platforms, others install, own or finance, and operate microgrid's energy resources entirely as a service. In both cases the end user of the service is relieved of operational and/or transactional costs of a microgrid and only receives the benefits, such as resilience, green local energy, lower monthly bills to name a few. In this section, we extract the elastic platform characteristics and types of manifestations of these, which results in the dynamic microgrids we previously discussed:

Scalable Computing and Communication

Multi-tenant, multi-user, multi-device support

The types of dynamic microgrids we discussed exemplify the heterogeneity which microgrid-as-a-service platforms need to facilitate into seamless interworking. The nano- to microgrids type require the integration of multiple applications (tenants) provided by the ecosystem, such as battery management or smart thermostats. All such interactive applications additionally need to support multiple users. The multi-tenancy and multi-user accommodations on platforms have been successfully streamlined in cloud computing environments [5]. In fact, these are a main characteristic that enable globally scalable software-as-a-

service offerings in other domains today.

“Multi-device” is also a description borrowed from today's web-based service offerings on various end computing devices such as various smart phones, tablets, with differing operating systems and capabilities. In the cases of our microgrid-as-a-service examples, we see various simple to complex integrations of one or multiple types of devices: Digital meters and solar PV was the simplest case of integration for grassroots community microgrids. Digital meters and various types of distributed generation were the main aspects in energy sharing platforms. Finally, a sophisticated mix is geared towards dynamic control and optimization of the smallest scale of nanogrid to the microgrids-as-a-service operation. The devices here, in addition to meters, are power electronics in form of smart inverters for solar PV and battery management, as well as smart controls for dynamic demand, especially for heating/cooling which makes the largest demand source.

The multi-device coupling in industrial domains such as energy will be the innovation trigger at large in the coming years. Depending on the objective it can greatly differ from solutions that are being developed for the Internet of Things: Complex cyber-physical systems incorporating both electro-mechanical and digital components require supervision and control that must assure safety of humans and expensive assets. For this purpose, Siemens researchers are developing the technical elements of the so-called “*Web of Systems*”. [6]. Siemens will be embedding these app-capable components into its products and solutions. The intelligence in the system can be distributed as needed between computing resources embedded in the automation infrastructure as well the enterprise backend infrastructures. This yields improvements in fail-safeness and in protecting customers' process data. In the domain of elastic microgrid-as-a-service provisioning, the type and efficiency of multi-device support will be the differentiator of the platforms, determining degree of user acceptance as well as cost-effectiveness of scalability. In the examples of grassroots community microgrids and energy sharing platforms, where control is not an objective, a more loosely coupled Internet of Things connectivity is demonstrated albeit at the opposing ends of the spectrum, i.e. centralized versus decentralized platforms.

Fault-tolerance, availability, and security

Fault-tolerance, availability, and security are main aspects of the matured software development and deployment techniques that enable internet-scale delivery of software-as-a-service. The hardware/software of the computing infrastructure needs to handle component and communication failures seamlessly, migrating current applications onto newly spawned server processes, recreating required data from source via replication or lineage. Again, these techniques can be considered best practices in the IT domain, at least for providers of resource

⁸ www.joinmosaic.com

and software management solutions in the infrastructure-/platform-/software-as-a-service domains.

In the energy sector, however, real-time availability of energy usage and feed-in data to the multitude of stakeholders in a fault-tolerant, cost-effective way is a very new technological opportunity [7] [8] now reaching maturity. One of the main hurdles until now has been the required installation of digital meters for data acquisition. Neither US nor Europe has found a sustainable incentive plan that kick-starts this area of the markets. Additionally, these cyber-physical systems can hardly be compared to the user experience with smart phones with easy setup, transparent software updates and a plethora of apps and service providers. The cyber-physical components that connect digital to the physics such as meters and inverters are a long way from being plug & play safely and dependably in a multi-tenant, multi-user environment. Nonetheless, the examples we cited as types of microgrid-as-a-service providers do have a strong incentive to improve on the technological opportunity. Once installed these cyber-physical components should optimally show similar characteristics regarding, fault-tolerance, availability, and safety as backend clusters of servers. Here, it is important to note that today in computing clusters these characteristics are reached via common-off-the-shelf hardware, which account for the internet-scale scalability and cost-effectiveness of cloud computing infrastructures. We will see more trading off of hardened components with cheaper but redundant components, accompanied by the ability of resource and software management layers to migrate data and functionality across available cyber-physical hardware within a microgrid-as-a-service installation. This brings us to the discussion of how these scalable computing and communication capabilities manifested in our selected examples of microgrid-as-a-service capable elastic platforms, which are typically centralized or completely decentralized.

Manifestations

Centralized

The centralized manifestation of the scalable computing and communication infrastructure encompasses distributed intelligence in the controllers of the microgrid-as-a-service resources, which however are coordinated through a central system. The distributed controllers capture real-time monitoring data, which centrally is analyzed by algorithms that additionally incorporate portfolio-wide dynamic forecasts and optimization objectives for delivering in turn the dynamic control parameters for the controllers in the many microgrid-as-a-service fleets. Distributed communication is typically realized by lightweight, scalable publish-subscribe mechanisms. These protocols can be proprietary as in GridLogic⁹ or based on industry standards such as the real-time Data Delivers Service (DDS). Newer

DDS versions support data exchange with cloud-based centralized applications as utilized by GreenBus [9]. Although publish-subscribe mechanisms can be described as machine-to-machine communication middleware, in this centralized manifestation they are merely utilized as data exchange mechanism between distributed controllers and the central coordination system of the microgrid-as-a-service platform. Nevertheless, this scalable, real-time middleware accounts for the elasticity of the platforms, i.e., seamless integration of increasing numbers of microgrid nodes.

Decentralized

As mentioned previously, real-time machine-to-machine communication middleware is already being utilized. Such publish-subscribe mechanisms enable the handling of the system without central servers. However, since providers deal with physical transactions of energy, it is of utmost importance that all transactions are accounted for. Hence, the grassroots community microgrid types of providers are leveraging a technology called blockchain. Blockchain¹⁰ is a distributed database, which contains all transaction being conducted in the distributed system. Since it is a cryptographic protocol all records are hardened against tempering and revision.

Ethereum¹¹ is a blockchain application platform, which facilitates the development of entirely decentralized applications that can encode arbitrarily complex contractual business logic. As such it is possible to create completely decentralized elastic microgrid-as-a-service platforms as demonstrated by Transactive Grid [10].

Hybrid

The hybrid manifestation can incorporate aspects of both centralized and decentralized systems. Although main differentiating capability is sending algorithms to the data sources in the field, instead of relying solely on distributed data exchange mechanisms. Especially for computations like system-wide analyses and predictions as well as real-time monitoring and dynamic control, same class of algorithms might need to be applied on historic and online data in the backend servers and on real-time streaming data at the embedded sources of such data within the microgrid-as-a-service installations. The hybrid manifestation of a scalable computing and communication infrastructure, hence, aims at distributing the intelligence in the system as needed between embedded components in the microgrid installations and server farms in the (cloud) backend. This yields improvements in cost-effectiveness, fail-safeness, and in protecting customers' process data [11].

DISCUSSION OF BUSINESS MODEL INNOVATION

As a rule of thumb, one can say that the cost-effectiveness

9 <https://www.solarcity.com/sites/default/files/sc-gridlogic-download.pdf>

10 [en.wikipedia.org/wiki/Block_chain_\(database\)](http://en.wikipedia.org/wiki/Block_chain_(database))

11 www.ethereum.org

and scalability of the underlying platform technologies determine the pricing structure and scalability of the microgrid-as-a-service business. However, today the regulatory confinements that such business operates in are more apparent than technological aspects. Regulations in the energy domain can still make or break new business models. This is only a temporary state while transitioning to liberalized energy markets. Additionally, over time also regulators are urged to acknowledge and facilitate technological opportunity that renders higher integration of renewables economically viable.

The business agility that elastic microgrid-as-a-service platforms can enable has been recently demonstrated, when end of net metering tariffs for rooftop solar were announced in some states in the US [2]: Through elasticity, i.e., the ability to seamlessly integrate multitude of users, applications, and devices, microgrid-as-a-service providers could offer nano-grid operation behind the meter with a self-supply tariff. Such adaptive, dynamic microgrids can fast-forward the *unbundling* of the energy market in previously unforeseen ways. These scalable privately owned monitoring and control platforms are effectively taking care of grid operations in increasing parts of the distribution systems. Completely decentralized energy data exchange platforms can dramatically decrease infrastructure costs as compared to today's fully independent vertical integration of each energy market operation. Some entry barriers to the energy market may fall entirely, such as the need to have special accounts or certifications through financial intermediaries [11]. Elastic platforms such as the entirely decentralized Ethereum, with cryptographic guarantees, make traditionally centralized intermediary market building blocks obsolete by incorporating transactions and accountability into the decentralized protocol itself.

The massive scalability of energy sharing platforms will allow addressing the *long-tail* of the market, once sufficient distributed energy resources are installed and purchased (back in case of leases) or amortized. Such platforms then can also enable a *freemium* energy business model, where the community of users are offered various other services, for which they prefer to pay a premium or membership fee. Although the pervasive availability of services within entire distribution system through energy sharing platforms seems to be a wide shot from today, experiences in the other sectors like accommodation and transportation show: in areas with high costs of an otherwise shareable resource, sharing services can reach exponential coverage.

For incumbent utilities this means that any change in pricing structure does have a counter reaction incorporated by these elastic microgrid-as-a-service platform providers. In case of ceasing net-metering, storage becomes more viable, which can easily be incorporated into the elastic platforms, which in turn enables self-supply, especially when further flexibility providing devices such as smart thermostats or

water heaters are incorporated as well. Some utilities may benefit from self-supplying customers such as on islands, which relieve the infrastructure. However, many other utilities will want to make use of peak-shaving capabilities of a combination of multiple devices such as storage and solar PVs [12]. An interesting aspect for all energy market stakeholders is that these technologies of elasticity can enable cost-effective *multi-sided platforms*, which can be optimized to the needs of the participating parties – including incumbent distribution system operators, retailers as well as new players such as energy service providers beyond microgrid-as-a-service.

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