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SOCIO-TECHNICAL MODELLING OF CUSTOMER ROLES IN DEVELOPING LOW VOLTAGE DISTRIBUTION NETWORKS

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ABSTRACT

The transition of low voltage (LV) distribution networks towards more intelligent and smart microgrids is dependent on both technical and behavioral factors, thus forming a socio-technical systems change. Socio-technical aspects need to be taken into account when developing concepts and models to establish and manage successful niche experiments. This paper presents a new framework to model actor (customer) evolution and engagement in the process of developing smart LV Microgrid distribution networks as socio-technical systems. The framework is based on combining the Multi-level perspective (MLP) and the Strategic niche management (SNM) approach with the Unified Modeling Language (UML) tool. Customer engagement is an essential element in SNM, wherefore understanding their and other actors' different development paths is invaluable to uncover the dynamics of the Microgrid transition in the societal and the technical contexts. The proposed framework could be applied to other key actors such as DSOs and energy retailers. The benefit of the models created by the developed framework is the articulation of expectations and visions as well as building up the networks in the SNM.

INTRODUCTION

Understanding and managing energy transition processes such as the microgrid evolution, calls for a multi-level perspective (MLP) approach. The MLP approach claims that technological change needs to be seen as one component of a broader set of institutional, behavioral and cultural changes that co-evolve [1], [2]. Thus, transitions are processes happening in socio-technical systems and involve technologies, actors and institutions that interact through niches, regimes and landscapes over long periods of time [3]. Niches form the micro-level, where the new innovations and experiments emerge [1]; they are models of the relationships between the functions, roles and actors of novel systems. The regime level is the "ruling system" supported by practices and institutionally stabilized systems (e.g. the current distribution system) where the new niche innovations (e.g. microgrids) are trying to enter. The regime and niche levels receive pressure from the landscape, macro-level, which includes demographic trends, political ideologies, societal values and macroeconomic patterns [4]. In the case of microgrid evolution, the early phases are according to the MLP approach niche experiments. In Strategic Niche Management (SNM) framework the first step is the articulation of expectations and visions, second one is building up the network of actors, third comes voicing and shaping by case studies and pilots and last step is learning from the pilots. After successful learning, niche experiments are complete for adaptation at the regime level [3].

A recent literature review [5] indicates that the main stream of smart grid research focus more on the general electric systems than the customers. Still, the socio-economic features are crucial for understanding the feasibility of Smart Grids and also have an impact on the development of the technologies.

The MLP approach opens an opportunity to test different methods for transition management [4]. In this paper the Unified Modelling Language (UML) tool is used to capture customer evolution in association with the other key actors (services and technologies) in the microgrid evolution phases, linking it also to the SNM discussion. Special focus is on explaining customer roles in the different LV development phases, as customer engagement is a fundamental driver of smart grid initiatives [5], [6] and [7]. Identifying customer segments such as early adopters and prosumers [6], understanding their needs and providing the right solutions e.g. products and services are of key importance for the future development of microgrids.

SOCIO-TECHNICAL EVOLUTION OF MICROGRIDS

Defining the concept

Decentralized energy systems suggest a paradigm shift in the way energy is produced, delivered and consumed [5]. In this paper we propose a new framework model for analyzing the transition of the developing low voltage (LV) distribution networks towards Smart Grids by different levels of system analysis as described above. This is done by combining the MLP [4], [8] and SNM [3] approach with the UML tool as a new framework model to better capture the systemic co-evolution of electricity consumers and technology [6], [9].

Evolution theory of LV distribution networks

To understand customers in the context of evolution phases this model was built up as follows. The evolution of LV distribution networks can be defined by four evolution phases in sub-urban areas (e.g. niche experiments), which are Traditional Network, Self-sufficient in Electric Energy, Microgrid and finally Intelligent Network of Microgrids phase. The Traditional Network describes the state of the art of the LV distribution networks, Self-sufficient in Electric Energy are introduced when the amount of the distributed generation (DG) mostly exceeds the demand of electric energy. The microgrids are formed within a secondary substation area for a solution to operate as an islanded network in addition to the parallel operation with the utility grid. Multiple microgrids interlinked together are introduced as the Intelligent Network of Microgrids, where the operation of microgrids interests various stakeholders and the operation strategy of the network can be flexibly chosen from economical, technical, environmental or combined modes. [10]
These evolution phases was developed based on the the use cases, which illustrate the different operating scenarios between the actors operating the system [11]. The actors in the model can be the above-presented key elements in their fundamental relevance (customers, service providers and technology) but also their roles. Thus, actors also comprise of systems, programs and stakeholders for the applications (like network monitoring and control, protection, energy generation and -storage, energy management and home automation).

Customers

The dissemination of socio-economic features (e.g. customers, services, providers and pricing) is crucial to demonstrate the benefits of smart grids (microgrids) to overcome associated barriers [5]. Customers can be both consumers and producers (i.e. prosumers) in future microgrid systems [7]. Especially, these prosumers are expected to have a much more active role in future electricity markets [12] — [14]. Still, apart from a small group of forerunners who actively seek new solutions, most customers' choices are an outcome of habits and practices (routines), enabled by the existing infra-structure and institutional structures [13], [14]. The evolution of microgrid customers is still in its infancy and for the 'normal' customers to accept and support the transition to microgrids, service providers (aggregators, DSOs i.e. Distribution System Operators, energy companies) and policy makers must communicate the benefits effectively [14]. As the number of consumer engagement projects in Europe is increasing [6] the key findings pinpoint the importance of understanding consumer response to the information about energy consumption and source, dynamic pricing and other incentives. Especially, from a business/developers/ technical perspective exploring consumption profiles and consumer segmentation are pivotal to be able to provide correct information and services [5], [16].

ANALYSIS SPECIFYING POSSIBLE CUSTOMER ROLES

Customer evolution in the developing LV distribution networks influenced by the technical and the social dynamics is presented in the Fig. 1. Referring on the research presented in [10], [13], [17] — [19] the technical and social dynamics of the distributed energy system is adapted to the developing LV distribution network system. In addition to this interaction, customer evolution is mapped to the system by classifying customers with UML technique according to the four evolution phases of the system. The classified customers are Consumer, Responsive Consumer, Prosumer, Partner and Strategic Partner.
In the first phase the customer is classified into the user class. A user exists in the present system, and it has its own value of the connection capacity, tariff type, demand profile and the amount of passive loads. A user can consume electricity. The main actors a user interacts with are DSO, energy retailer, smart energy meter and customer grid. When the boom of DG appears, the Consumers evolve. Exchange value becomes important as well as social and ethical issues.
In the self-sufficient of electric energy phase a consumer has assigned some amount of passive loads to DR markets, and to do so, started to use building automation system (BAS) and home energy management system (HEMS). The contract participating to demand response (DR) markets is made with a DR aggregator. Consumers make individual choices regarding price, product attributes, services and values. The Prosumer differs from the consumer profile by producing electricity (own generation and storage unit) and selling the excess to the market. The prosumer can also buy this service from an aggregator or other business.
The Partners of microgrids are the key operating actors. A partner has also dynamic loads like V2G (Vehicle-to-Grid) type of electric vehicles. Because of the enhanced control and electricity distribution system of the Microgrids, a partner can participate also to the ancillary service markets. The importance of cooperatives or other types of cooperation between different actors grows.
The last phase in customer evolution is the Strategic partners, who participate in the Intelligent Network of Microgrids. A strategic partner operates as one actor in a dynamically operated network of microgrids and has a more strategic role as a system actor. In the Intelligent Network of Microgrids, the operation mode can be selected based on economical, technical, environmental or combined modes of various stakeholders in real-time between all the parties. This also means that several operation modes can be selected in strategic partners' premises.

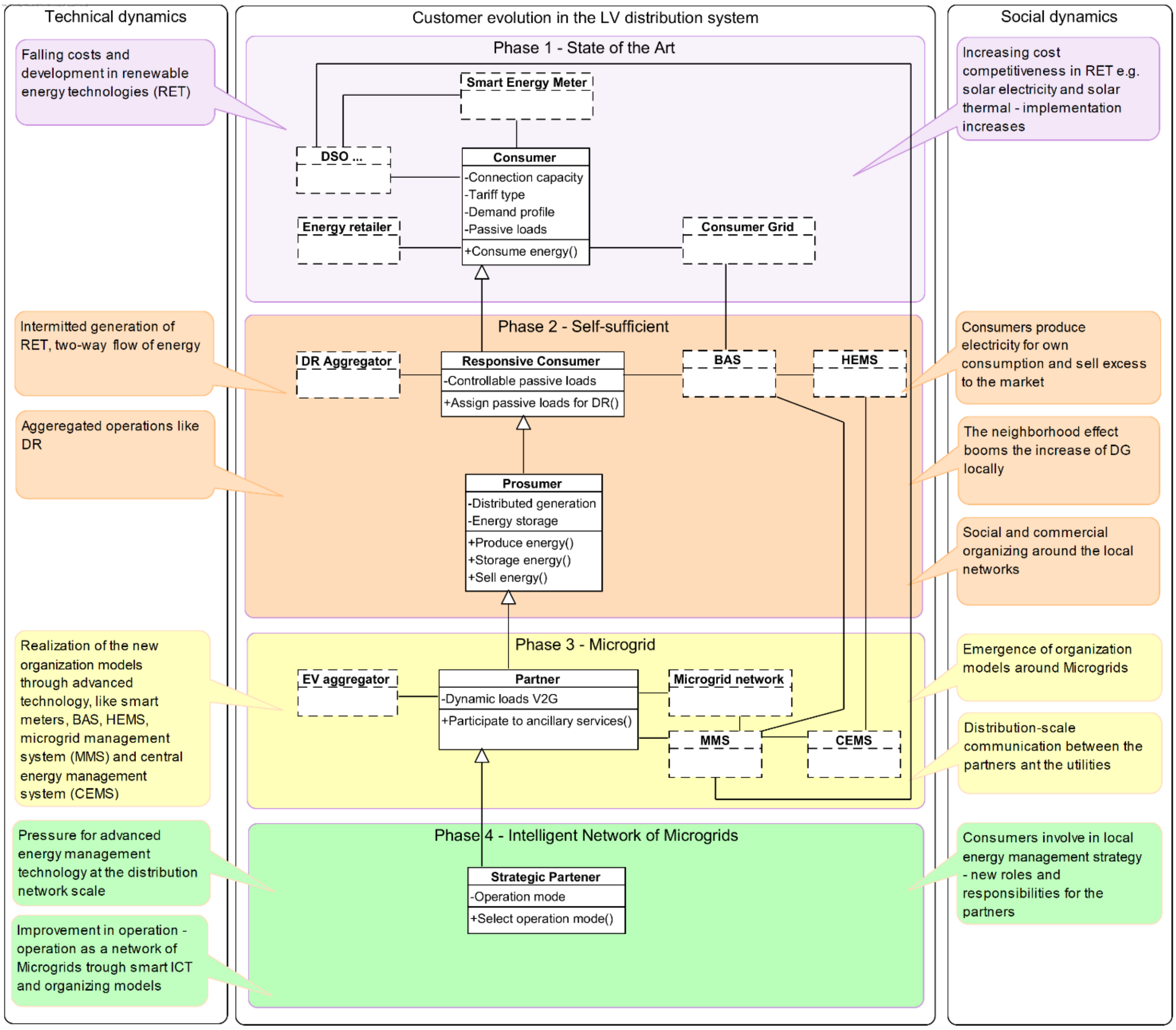

Figure 1. Customer evolution in the developing LV distribution system based on UML class diagram modelling.

The Fig. 1 presents the technology and the socio-economic aspects integrated to the customer evolution; also the associations or connections between the main actors and the customers are presented. This is the first step to illustrate the relationships of the key actors in a socio-technical manner.

CONCLUSIONS AND DISCUSSION

In this paper we have introduced a new framework to harness the full potential of developing smart grid markets. Consequently, there is a need for specific niche experiments (or so called living labs) to design, test, learn, and to validate social and technical functions that enable the microgrid evolution. This comprises how customers use and perceive the new systems, and which kinds of services are needed to further the evolution phases. We propose that using the UML tool, we can visualize and describe important interactions derived from using the MLP approach, and with special focus on SNM. This opens new horizons to develop a truly socio-technical understanding about microgrid transitions and the needed practices. Importantly it creates new understanding about how to enable microgrid experiments or living labs development. We suggest that the UML is a tool to create a system level understanding of both the existing system and it evolution paths.

As the result in this paper, the classifications of the evolving customers are introduced in the four evolution phases of LV distribution networks. This result can be exploited in the SNM for understanding the development path of the customer and its related actors in the dynamics of the societal and the technical environment. This framework could be applied to other key actors, at the very least to DSOs and to energy retailers, which affect strongly to customer engagement [6]. The benefit of the models created by the developed framework is articulation of expectations and visions as well as building up the networks in the SNM projects, like developing Microgrid concepts.

Furthermore the analysis can be applied to the Smart Grid Architecture Model (SGAM) framework -tool, which includes a methodology about the development of use cases, reference architectures, communication technologies as well as data- and information models [20]. The 3D SGAM -model represents "the functional information data flows between the main domains and integrate several systems and subsystem architectures [21]".

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