NOVEL TECHNICAL SOLUTIONS AS A SMALL-SCALE DEMAND RESPONSE ENABLER

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ABSTRACT

The paper presents an overview of the present technical barriers and triggers on the utilization of small active resources in demand response (DR) market and suggests requirements to novel technical solutions enabling extensive penetration of such services. The paper describes the present status of the DR in the Finnish power system. The key technical triggers stalling the wide spread roll-out of the small-scale DR units are lack of sufficient light weight protocol, capable of handling privacy and security issues, and cost-efficient client hardware.

INTRODUCTION

In the past years, power systems were mostly based on the centralized production units that were flexing among the varying demand. System operation has been feasible in such a way as the majority of the production was capable adjusting output based on varying demand. The present trend drives the systems towards renewable production types that are often considered less flexible and more dependent on renewable energy sources such as wind and solar irradiation. The transition is setting new requirements to power systems and especially to loads in the power system. The present trend is well visible in statistical data and is shown by many researchers in the past years [1]-[2].

There is also strong political will that is driving us towards green alternatives, and the changes can already be seen in the power systems all over the world. The latest IPC climate report illustrates clearly that human kind is to meet a great challenge in the coming decades in pursuit to carbon free energy production and transportation [3]. It has also been shown by studies that 100% renewable system can be achieved by optimizing resource utilization and selecting suitable production forms [4]-[5]. The renewable production forms do not come with only benefits, there are disadvantages involved as well. Most of the disadvantages are solvable, but in many cases, solutions involve a cost. With the cost added to equation, this challenging to achieve, consequently, more affordable and smart alternatives receive advantage. One of the most interesting prospects is DR – currently looking opportunities to be integrated as a part of energy markets.

There are still variety of barriers slowing down DR, even though, DR has been a well-known concept in the energy sector for decades. Some forms of DR, however, exist already. For instance, distribution system operators (DSOs) in Finnish power system have had privilege to control space heating load of their customers which have night-time tariff plan. Nowadays the control of the space heating load takes place via load control relay in smart meters. Nevertheless, there are still major barriers blocking commercial utilization of the DR. The barriers are typically related to markets [6], customers willingness [7], legislation, regulatory environment [8] or technical challenges. The main question that should be asked is, if the benefit is greater than the cost. The cost of the technical solution is incorporation of clients' hardware controlling resources, communication links, middleware applications, backend software handling aggregation, server resources and other hardware required in the different levels of the process.

The topic is studied widely by the many researchers [6]-[11], but technical aspects have been covered lightly. It is notable that technical solutions are typically a major cost component in DR applications, especially when considering small-scale DR units.

The paper discusses the present state of the art approaches to utilization of small-scale DR units and aims to reveal triggering factors that may speed up the roll-out of such resources. The paper also discusses the changes required to achieve breakthrough of small resources on the DR markets and the key technical triggers, such as Internet of Things (IoT), to potentially activate the wide scale penetration of the small active resources. Finally, the paper provides insight on what might be staggering the present development of the small-scale DR. As the main outcomes, the characteristics of the novel technical solution to connect DR as a part of power system are described, and areas for future research tasks are recommended.

BACKGROUND

Finland has been seen as a forerunner in the DR activities and commercialization of the DR [12]. For instance, in Finland there is open reserve market place operated by Fingrid [13], where also, aggregated loads are accepted. The article by Annala et al. [12] describes DR market places and lists the present commercial DR pilots utilizing DR in Finland. Furthermore, Finland is not the only country where DR resources are utilized and studied.

The Finnish operation environment has provided fertile starting point to DR as the Finnish legislation (Decree 66/2009) required DSO to roll out smart meters in wide-scale by the end of the 2013 [14]. Present penetration level of the smart meters is over 99% of all electricity consumption points [14]. Even before smart meter roll-out the load have been controlled by the DSOs in order to manage distribution grid congestions and to provide night-time tariff option for customers. According to the smart grid workgroup set by the Finnish Ministry of Economic Affairs and Employment of Finland direct load control by the DSOs should not exist in future [15]. In practice, this leaves control opportunities open for retailers and aggregators. The question that remains if it is feasible to implement such system with the existing automated metering infrastructure (AMI).

The major part of that question is what the technical solution to access active resources in the changing environment is. It is likely that second generation of smart meters is still equipped with similar load control relays and there is AMI maintained by the DSO. The main question is how the interface to smart meter or to AMI is defined and on what layer of the smart grid architecture it appears to the relevant players.

The DR in power systems has system wide impact and it can have impact on each layer of the smart grid reference architecture illustrated in the Figure 1. Major drivers are generated by the business layer, and implementation of the control takes place on the communication and component layer.

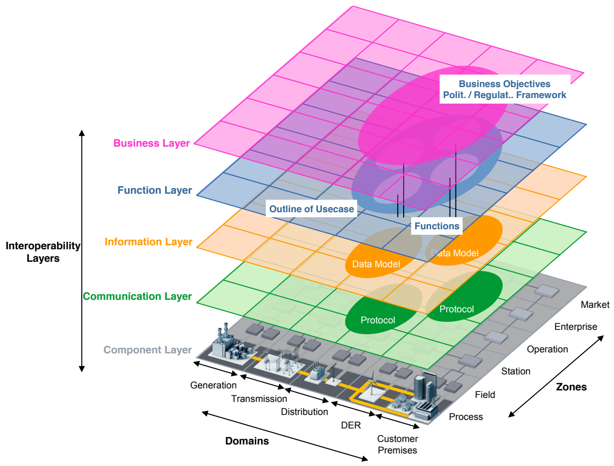

Figure 1. Smart Grid Reference Architecture (SGAM) [16].

In theory, present system allows controlling customer loads via AMI managed by the DSOs, but the integrations rarely exist. The main issue with the present system structure is lack of sufficient data from the customer loads. The type of the load and load reduction capability are rather well known, but the effect that it may cause to living comfort are unknows if control differs from the designed patterns. The main problem in the present smart meter architecture is that whole consumer premises falls behind single metering point creating single metering entity. Loads that are connected to the smart meters load control relay are often space heating loads or water boilers that have unique and potentially unknown thermal storage capacity.

The issue with the structure is that we need complicated analysis methods to learn what is load reduction capability of each consumer. Even if the load reduction capability is known the customer comfort level or living environment has no indicators what so ever, thus the full potential of the DR is difficult to utilize. There are also many survey studies investigating asking customer willingness to participate to DR [17] and in many studies it is assumed that comfort level can be measured and quantified with some method.

COMPETING STRUCTURES

The competing technologies on the table are of a high interest as those can be potentially seen cannibalizing the existing structures. The most interesting prospect that may rise is that most of the competing technologies entering the game are highly flexible and agile. The main concern is how those structurers should be integrated with the existing power system. These new devices and services may be related to smart devices such as smart lighting and other smart home appliances or EV charging in detached houses or parking places of block of flats. It is also likely that we see increase in penetration levels of home automation systems or home surveillance systems gathering household resources and under the single control and monitoring domain. There are already clear indications of such systems from the major players of IT sector. It is also noteworthy, that those big players are providing open resources for developers to create novel integrations for the gateway devices [18]-[20]. In addition, these systems allow to integrate the variety of smart devices and appliances under the single control entity that can be accessed securely via public network.

The major game changer is that those smart devices are about to appear in the grid due to other reasons than driven by the DR. Drivers are likely increased comfort, security, green values and energy saving goals or even technology enthusiasm. Often such devices are shipping with the software than is not purely proprietary but rather opensource. There are also many integration possibilities to integrate platform to other providers systems to gain greater befits for the customer or for the system provider or for the third party benefiting of the data system collects.

The existing system structures are likely to change if there is enough smart appliances and other resources delivered by agile IT sector companies. This may create potentially highly valuable data streams that can also benefit the player on the energy sector. For instance, customer load formation analyses can be improved dramatically, and DR resources and capabilities can be identified more efficiently. Likely there might be access to energy resources behind the customers smart meter interface.

Blockchain

Blockchain is currently one of the hottest topics on the energy system sector, covering both market and system operation areas. The blockchain technology is seen to enable many novel applications to the present smart grid that were thought too complicated to commence. Blockchain could also be the answer to many problems related to systems transparency, data security and integrity, while keeping the system somewhat simple. Many see that such a blockchain structure is needed to enable the peer-to-peer market between neighbours [23]-[25], for instance.

The meaning of the digital asset has been well defined and understood way before the invention of the blockchain technology [26]. The most important matter with the digital asset is managing double spending issue – meaning that cash or any other asset cannot be spent twice. In a traditional banking sector application, this is assessed with the centralized trusted party (ledger) that manages accounts, account balances and handles transactions. The traditional digital approach is somewhat like the banking system that has been used with physical assets for ages.

The blockchain technology offers distributed solution that allows transactions to take place without any centralized database or ledger used to manage transactions, accounts and balances. The blockchain basically offers two different approaches [27]. Firstly, *permissionless blockchain* that allows any anonymous transaction to take place and involves participants solving cryptopuzzles as every single transaction is verified by the blockchain. Secondly, there is *permissioned blockchain* where mutual trust between participants is required.

With some cryptography involved in the process, trust between participants can be neglected almost totally. Bitcoin uses shared ledger called “blockchain” to keep track of transactions and validate transactions initiated by the users [23], for instance. Of course, this comes with a cost – eventually size of the public blockchain may come the burden as it stores huge amount of data.

MAJOR DIFFERENCES ON THE APPROACHES FOR IOT

There are two major paradigms of intellectual property ownership: opensource (OS) and proprietary (PR). The concept of opensource originated form software development, but nowadays is expanded to all types of IP including hardware and system design. Either choice has its consequences for development of DR system.

Opensource

Opensource software has gained momentum in recent decades. The obvious benefits include security of invested resources - if you rely on opensource software you can modify it to your needs including porting it to new platforms and hardware without any additional expenses, ability to crowdsource development to broad public in exchange for non-contractual obligations (grants) or additional support for the integration of publicly-developed features, which eventually benefits your customers. The reputation of additional security, coming from opensource approach has been recently damaged due to poorly implemented protection from malicious or malfunctioning code inclusions in projects with extremely complex dependency hierarchies. A recent survey of NodeJS developers indicates that only eight percent are concerned with security when including dependencies on trivial packages [21]. This, however, is not an issue in a system with adequate levels of review for included code as opensource licensing always warns people to be aware that opensource software comes without warranties.

Proprietary

Proprietary software has its benefits in part where company, owning the copyright, is generally motivated to develop the software into the best of interests of its users. It also promotes stable development teams, that have good understanding of the codebase, which reduces risks of introducing poorly developed code. In addition to that, the company has financial responsibility or at least some risks, that can be caused by poorly developed software. However, in a market where both proprietary and opensource option exist the proprietary option tends to cover market share, that consists of less demanding userbase, and thus, has been shown to have a tendency for degradation of quality over time [22].

General cyber security issues

The cyber security issues can be classified as the authenticity, malleability, availability and protection of personal information. Each of the these is critical when considering systems that may cause physical damages or violate personal data privacy.

Authenticity

The communication happens across weak communication channels and the transmitted data can be observed by third parties. The issue is not unique to energy systems or Smart Grids and has established practices for risk mitigation: encryption, asymmetric key-based authentication. However, even when the data is encrypted, the fact of communication is still public information and can be a potential security weakness.

Malleability

The information, that is transferred via weak communication channels must be protected from external modification including replication or replay attacks. As with authenticity the general handling of this criterion is well established in modern IT. The messages are expected to be encrypted, signed and in some way protected from the possibility of replay attack, i.e. by including nonce values.

Availability

This is apparently a weak spot for all modern open (non-governed) communication systems. The DoS and DDoS attacks have potential to disrupt any publicly accessible networks and systems. Hence, the critical parts of power grid systems should have additional means of establishing communication between each other and certain emergency protocols should be developed, so that all system participants can ensure safe operation when public communication is disrupted.

Protection of personal information

Misuse and inappropriate handling of information by authorized parties became recently the matter of public debate in the western world. Even legal definitions of what constitutes personal data is yet under heavy scrutiny, and legislation is not properly developed in this aspect. However, the stated intent of having data protection by design is something worth including in a newly designed Smart Grid system. One way of such inclusion would be to utilize anonymization of data on consumer side metering device with new anonymous identity generated for every calendar day and artificial noising of data performed, to avoid positive identification by comparing anonymous samples. I.e. a possible attack vector is through the analysis of the heat output profile of a heating system which would have a strong correlation with the outdoor temperature of the certain region.

Consequences for DR

From the perspective of DR, the crucial factors are: the broad adoption of IoT-enabled devices, capable of participation in DR, the well-established standard and security and reliability.

The OS approach will certainly provoke the influx of cheap devices made in emerging markets, that are conforming to standards established in OS system and protocol design documents, however the reliability of these devices might require extra regulation by states.

The PR approach reduces the number of devices and adoption rates significantly as private companies are generally more cautious about rolling out new products. It will also require a large consortium to be established in order to govern the standard for IoT and DR implementation which might be more difficult to achieve, then gradually emerged OS standard based on needs of standard users. Finally, PR approach would provide better security and safety overall, with the only possible exception to potential abuses of private information.

DISCUSSION

Big data collected via Smart House control centers may be utilized to improve models of household consumption: how often and what appliances are enabled when there is no regulation (the preferred or natural mode of operation), how consumers' behavior changes under regulated pricing (day/night pricing, hourly-based pricing). In terms of DR, the important question is what appliances and comfort zones are typically sacrificed by people and which ones are rigid to regulation. One thing that probably should be avoided is blanket application of DR without considering the background of the consumer, even if this comes at a benefit of lower pricing, otherwise such regulation is essentially a lottery on whether your comfort zone would be shifted today or not. Instead a smart bid-based system can be implemented where customers might specify how much of a discount they want for degradation of quality for certain service. I.e. some customers might agree on higher oscillations in room temperature as long as it is above the minimal level, rather than small oscillations that go below the threshold of sensitivity.

CONCLUSION

The study described the present strategies and architectures to utilize DR of small unit sizes. The main technical barrier is lack of data from the resource and lack of the integration between market actors and controllable customer loads. In the present system, the loads are controllable by the DSOs, but not yet by the retailers or aggregators. The willingness to utilize the existing control link may not be high enough to trigger the wide scale roll-out of the DR, and as may studies show that other barriers related to customer behavior are also existing. Existing infrastructure would also need additional monitoring in the customer premises to sensor living environment in order to efficiently control space heating, for instance. There are technical solution already available but deploying parallel systems for monitoring secondary variables rarely makes sense. Thus, attention should be focused on the rivaling technologies that may already be entering customer premises.

Home automation or security systems integrating smart appliances and controllable resources may play the significant role in the DR in the near future. Such resources are likely to appear in the customer premises driven by other reasons than DR. The main question is if those systems are equipped with the sufficient interface to interact with the players on the energy markets.

It is the topic of further research to study the requirements of the interface that is the capable enabling integration of the above-mentioned DR asset as efficient part of the power system and energy markets. Also, the role of technologies such as Blockchain should be studied more carefully in power system environment. Furthermore, special attention should be paid on the opensource software development regarding power systems and energy markets.

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