Using Flexible Energy Infrastructures for Demand Response in a Smart Grid City

Stamatis Karnouskos, Dejan Ilic, and Per Goncalves Da Silva

Abstract—**The emerging infrastructure of the Smart Grid, and the multitude of the new energy services it will offer, is expected to radically affect business relationships among its stakeholders. Beyond enhancements in existing processes, innovative approaches will be made possible by relying on a fine-grained monitoring and control capabilities over modern information-centric infrastructure. Traditional infrastructure owners will be able to take advantage of the new capabilities in order to not only better manage their costs, but also potentially increase their revenue by tapping into their flexibility of adjusting energy behaviour. The latter is of growing interest to, for instance, facility managers of municipalities who are reassessing cost-benefit issues for their infrastructures which include buildings, offices, arenas, schools, convention centres, shopping complexes, hospitals, hotels, and among other things the public lighting system. A closer look is taken on how flexible prosumer infrastructures may interact with the Smart Grid and how new revenue may be generated. The use case of using the capability-constrained public lighting system (PLS) flexibility as a new revenue source is analysed.**

Index Terms—**electronic commerce, energy management, information management, power system economics, Smart Grids, stock markets, web services**

I. INTRODUCTION

THE emergence of the Smart Grid [1] will radically change the business relationships between energy stakeholders. This change will bring new challenges [2] but also great opportunities upon which innovative approaches may be taken. The new infrastructure is expected to be information centric [3], where open fine-grained monitoring and control enables sophisticated and tailored solutions to emerge. These advances are possible due to rapid advances in networked embedded systems [4] as well as the prevalence of modern IT concepts and technologies [5] in the traditional energy domain.

Great expectations are put upon the Smart Grid, such as the promise of better management of its rapidly increasing complexity, the “greenification” of the grid itself, as well as of energy efficiency. Among these, there is an increasing effort to find the equilibrium towards achieving the objectives, while in parallel lowering the overall stakeholder costs. The Demand Side Management (DSM) attempts a more long-term adjustment of consumer demand via methods such as financial incentives and education. Although some Demand Response (DR) mechanisms have been in place since many years, due to the increasingly distributed nature of energy production as well as the introduced uncertainty of consumption (e.g. via large numbers of electric cars), new capabilities as well as new challenges are surfacing. The Smart Grid heavily invests in this direction, with the majority of ongoing trials relying upon dedicated on-premise installations (energy management systems) or on timely communication with the smart meter. Emerging infrastructure supported energy-services [6] may enable DSM and DR to significantly expand their penetration towards, for instance, residential users and public infrastructures, while market-driven approaches [7], [8], [9] may further push the interactions towards real-time.

In this emerging context, infrastructure owners of, for instance, industrial facilities, buildings, wind parks, electric car fleets, offices, arenas, schools, convention centres, shopping complexes, hospitals, hotels, public lighting etc. look for new business opportunities [10] depending on the capabilities of the infrastructure they operate. Today most of them try to minimize their costs by, for instance, turning off or reducing energy consumption [11]. However, the emergence of the Smart Grid may provide new capabilities for increased revenues for stakeholders. By making their energy footprint flexibility available to grid managers, stakeholders can charge for their energy behaviour adjustments. A typical example is the electric car fleet manager, who traditionally would try to minimize costs by charging the cars when the electricity prices are low (e.g. typical cases in Germany include the wind energy production during the night when the consumption is extremely low). However now the trend is towards a multi-constraint goal, where the customer-needed QoS (e.g. charged car) has to be guaranteed, but also take into consideration the broader context i.e. the management of a virtual energy storage facility (e.g. the sum of electric cars) that can store and feed-in energy back to the grid depending on specific Key Performance Indicators (KPIs) e.g. on cost-benefit, performance, green energy usage, etc. In the same train of thought other infrastructures such as the Public Lighting System (PLS), which although is much more constrained in comparison to other facilities, it may still be used as energy balancing party by adjusting its behaviour by, for instance, adjusting illumination according to their technical and regulatory capabilities.

The work presented here sheds some light in the new opportunities for Demand Response with the participation of prosumer infrastructures that understand and take advantage of the flexibility of their energy footprint. A general approach is presented and potential scenarios for monetizing the available flexibility are investigated. As an exemplary case, the use-case of the Public Lighting System (PLS) is looked upon as this is one of the most neglected due to limited in comparison with e.g. electric car fleets or smart buildings, but highly timely as municipalities and public authorities strive towards cost

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reduction and identification of new revenue sources.

II. ENERGY BEHAVIOUR FLEXIBILITY

Every prosumer on the electricity grid is introducing a certain load. Independently of the load's nature (consumption or production), this may have a time-dependent flexibility associated with it, which depends on the nature of the underlying task producing or consuming energy. Shifting loads is a fundamental aspect in the global Smart Grid vision, and a typical example often given is that of being able to turn devices ON or OFF for specific times. However, there are many more possibilities in modern intelligent devices and systems [12] apart from a binary state, which are spread between the two extremes (ON and OFF) and in principle can be depicted with a variable load profile over time (as depicted in Figure 5). Being able to correlate the load profile with the tasks executed, and the lifecycle of the device, may enable flexible energy management [13] depending on external criteria such as performance, energy efficiency, costs etc. Any process that can be split to timeslots with distinctive loads that can be adjusted, on the time or magnitude, is a good flexibility candidate as its execution time may be extended with lower overall load or shifted load for specific timeslots. Being able to shift loads implies the capability of understanding and controlling the process itself, while the logic of doing so can depend on several operational parameters.

Typically, prosumers may enter into contracts with energy stakeholders, for instance, a distribution system operator (DSO), where the approximate load they intend to induce is specified. Deviations may occur, however, the prosumer always tries to match the contracted load. On top of this, bilateral interactions may result in variations from the originally contracted load. Usually these are imposed by a stakeholder, for instance, in typical DR cases where a request for energy reduction, or even grid disconnection is done, or as a result of malfunction. Prediction plays a pivotal role for many stakeholders e.g. for the prosumer by helping him achieving the contracted goals, as well as the DSO for anticipating potential problems and taking corrective actions for the whole grid.

Although some available infrastructures may be highly unpredictable (e.g. a wind or solar park), some others such as the public lighting system (PLS) are highly predictable due to their behaviour pattern. The PLS consumption is easy to predict as its load is usually constant (within a zone) for many hours with negligible deviations. However, from the overall consumption there is a lower limit depending on the regulatory framework (e.g. at least 70% illumination from 20:00 to 06:00). The difference between the lower limit and the maximum load that can be imposed to the grid may be flexibly adjusted. This flexibility is now becoming a potential business enabler [10] and may be used for balancing the grid while in parallel offering benefits to its owner, such as additional revenue, or contributions towards the community's sustainability goals. In the future Smart Grid city, where local energy markets may exists, such flexibility can be traded and this may lead to additional business benefits that are hardly considered today.

Let us consider the time dependent grid load expressed as $\ell(t)$ and the respective cost $c(t)$ over time. Many small processes represented in this form may be aggregated in one more complex process, or vice-versa a process may be disaggregated to simpler processes described by their own cost and load. Although aggregation of the load curve is straightforward, the aggregation of the cost curve is dependent on the footprint of the load curve. Obviously, if a load curve composes greater part of the aggregated curve, the final cost curve will be more affected by that process. The cost values are calculated as a weighted mean. Figure 1 depicts the aggregation of two discrete loads and their respective costs to a single load and cost curve. Generally the aggregated load can be calculated as a definite integral within the specific timeslot. This approach falls under general efforts in aggregating and disaggregating flexibility objects [14], one key applications area of which is the energy management.

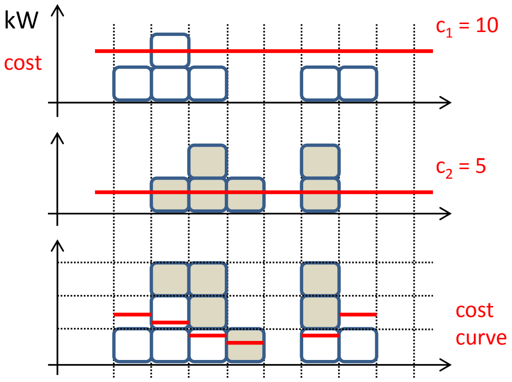

Figure 1. Example of the aggregation step for two flexible process

Each prosumer in the Smart Grid city may offer its flexibility, which comprises of loads that can be adjusted, as well as the corresponding cost that the requester will have to bear, for negotiation. Clearly, this can only be done for estimated future behaviour, and the percentage of which can be realised is up to the specifics of the involved stakeholders. Furthermore, in some cases additional input may be necessary, for instance, the cost might change if only a part of the flexibility curve is addressed, or the seller may also make bundles of it etc.

As depicted in Figure 5, the offered flexibility may only partially fit to requester's needs; hence several negotiation steps are inevitable. Once a prosumer offers his flexibility, the requester may accept the offer, or propose to accepts only parts of it. At the end of the negotiation, the final negotiated load, as well as the corresponding price curve, are agreed. The complexity of managing very large numbers of processes and costs (a typical task of an aggregator [15]), as well as considering the specific conditions of each stakeholder, can be a daunting task [14] which is not in the context of this investigation.

III. FLEXIBILITY-DRIVEN DR SCENARIOS

Being able to disaggregate, assess and adjust energy behaviour at process or device level, may yield significant benefits in the Smart Grid era. Such flexible prosumers can participate in various DR scenarios [10], at a level that either was not possible before or was done only at small-scale proprietary systems and uniformly controlled infrastructures. We focus here on three example scenarios to show how the energy flexible infrastructures may be utilized within a Smart Grid city. While some parts of these scenarios may be partially realizable today, the most sophisticated version of them assumes the existence of diverse energy services [6] available to the stakeholders.

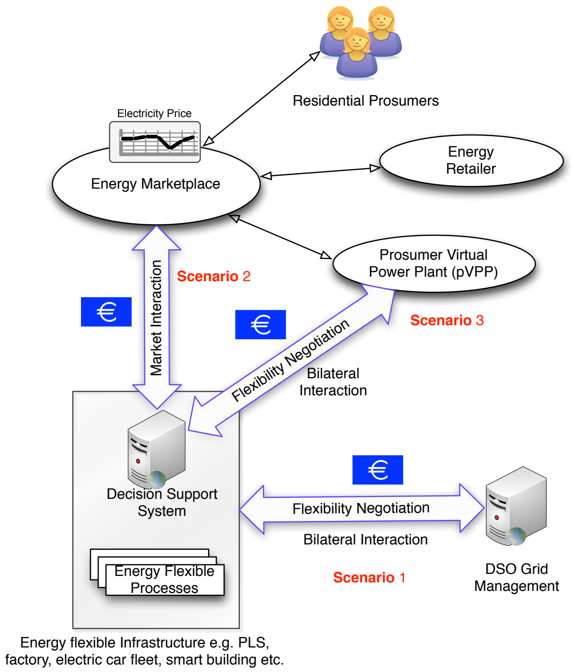

Figure 2. Scenario overview for interacting with flexible energy systems

As also depicted in Figure 2, we focus on three key scenarios i.e.:

- *Scenario 1* – Bilateral negotiation of flexibility
- *Scenario 2* – Market-traded flexibility
- *Scenario 3* – Energy flexibility outsourcing

These scenarios are indicative on the new capabilities and interactions that are possible over a service-based Smart Grid infrastructure and its stakeholders. All of these (and many more), are not exclusive and can coexist depending on the business models, available means and goals of the respective participating stakeholders. While one may recognize partially current practices in industrial energy management, our aim here is to address it from the viewpoint of flexible energy infrastructures. The latter usually are considered to be larger prosumers e.g. PV parks, wind farms, smart buildings, public lighting systems, public facilities. However, in the Smart Grid era, such infrastructures may be composed from a (very) large number of prosumers (e.g. residential users), who as standalones do not have any real impact, however once grouped, may significantly impact the grid and its operations as they can act as a prosumer virtual power plant (pVPP) [10]. How these pVPPs are created e.g. based on social, economic, geographic or other criteria is beyond the scope of this research; however these should not be neglected as they may empower third party service providers that act on their behalf (as for instance depicted in *scenario* 3).

A. Scenario 1: Bilateral Negotiation of flexibility

The first scenario (depicted as *scenario* 1 in Figure 2) aims to bring together flexible prosumers and those who can benefit from an adjustment of the energy load in the network. Typically the main stakeholder is the DSO who aims at keeping the network in balance and may use large flexible prosumers (usually industrial facilities) as balancing partners. However, in more advanced scenarios this role could also be assumed by others, e.g. an energy retailer that has over-provisioned energy within his network and seeks to reduce energy consumption of a large player in order to guarantee uninterrupted supply to residential users, or not significantly deviate from his contract with the DSO (which may be costly due to penalties).

The interaction between the stakeholders may be based on long-term contracts and be controlled by one side. For instance the typical case is that the DSO may always reduce (or even cut-off from the grid) prosumers in order to guarantee stability. Although this implies direct control of the one side (DSO) to the other (prosumer), there can be also multiple other levels of interaction that may be negotiation driven. Assuming that the prosumer is able to disaggregate his energy related processes, he may enter into a negotiation process where the amount of energy to be shifted (e.g. reduced or increased) and timeframe are mutually agreed. The benefit of this is that the prosumer, based on the mapping of the energy relevant processes and their energy needs, may be not only in place to accurately specify the energy behaviour to be negotiated, but also be able to assess the financial benefits of adjusting his energy profile. Hence, he may shift parts of a process if it results in a financial gain when compared the current plan for the process.

For this scenario to be realised, real-time energy monitoring, management and assessment services needs to be in place. Additionally, micro-contracting should be possible and legally binding. As this approach assumes bilateral interactions, any stakeholder seeking a comparative analysis with similar contracts offered by other stakeholders would have to contact them directly. The absence of standardized workflows and interaction protocols may hinder him and lead to an integration nightmare. Furthermore it is questionable to what extend open behaviours may be realized as each stakeholder will have to develop his own system, and also heavyweight stakeholders may impose their offers. Although such approaches can be implemented today, one has to consider several aspects in order to create open systems and standardized interactions that may be able to accommodate new business models in the future.

B. Scenario 2: Market-traded flexibility

A key vision in the future Smart Grid is that of energy prosumers to be able to trade [10] their energy online e.g. in local smart city wide marketplaces [9]. This vision is the core of *scenario* 2 (as depicted in Figure 2), where the user knows his energy behaviour (potentially assisted by advanced prediction services), and buys or sells energy he needs on a local market. If the prosumer knows and can shift his energy signature by, for instance, deferring or cancelling processes (or parts of them), he could benefit as he can offer this flexibility as a tradeable good in the market. Although a single prosumer may not have significant impact (e.g. if it is a residential user), large numbers of them transacting on the market may do as they can be considered collectively as a prosumer virtual power plant [10].

In the market, over production of energy would lead to lowering the price (due to availability), which would then lead to increased user consumption, if they rush towards buying the cheaper energy and shifting their processes to execute in this timeframe. Similarly peak-shaving can be achieved if prices are high, which may force prosumers to shift part of their processes to other timeframes. Energy flexibility can be traded, i.e. the prosumer may offer the option to consume less or consume more depending on the benefits, such as additional revenue that he can get. Such a market based negotiation is possible, however, it entails the agreement on future behaviour among the participants.

Although this constitutes a more longer term approach, it has significant benefits as it enables the applicability of economic models and strategies towards shaping future energy behaviour on the prosumer side. Sophisticated approaches may be realized, while economic products similar to what we are accustomed from the stock exchange may be created. Since these will be well-known platforms that will handle such transactions, one can expect them to evolve rapidly and integrate functionalities (e.g. compliance, payments, micro-contracting) that may be made available to its participants. On the stakeholder side, no numerous bilateral interactions are needed as in scenario III-A, but an “one-stop-shop” will be available. This simplifies the integration and potentially learning curve and best practices to be considered. On the down side, the complexity may be significant, and such market platform services will need to be offered by a globally trusted stakeholder.

C. Scenario 3: Energy Flexibility Outsourcing

Another interesting way to approach DR of energy flexible prosumers is *scenario* 3 as depicted in Figure 2, which complements both *scenario* 1 and *scenario* 3. As discussed, pVPPs may arise in the Smart Grids, and may act as a larger prosumer. The overall behaviour of the pVPP may be disaggregated to the specific users (or groups of users) constituting it. Based on the flexibility knowledge for each of these users, the pVPP will be able to adjust its overall behaviour and offer this flexibility (the continuously changing sum of the flexibility of its members), in a local energy market. Third party service providers will be needed to manage such pVPPs and provide the basic services needed e.g. for users to join/leave, informational services, energy monitoring, energy management, prediction, billing etc. These service providers will act on behalf of their members and ensure benefits on their behalf.

Comparing directly *scenario* 3 with the other two scenarios, one can see clearly that here is the case of outsourcing the energy behaviour, while maintaining some per customer preferences. Many surveys [16] bring up the issue of energy management automation at residential prosumers, as many users although enthusiastic at the begin, fail to be actively engaged for longer periods of time and clearly wish for automated systems that will consider both their needs (e.g. comfort preferences), but in parallel will be able to autonomously consider external information (e.g. price signals) and manage their energy signature accordingly. This scenario accommodates exactly that, i.e. the outsourcing of energy management to a third party (leader of pVPP) who act on their behalf.

Significant developments have still to be made in order to make this a reality. Issues such as privacy and security, especially when it comes to management of appliances by external entities, need to be properly addressed [4]. Additional tools to help the users correctly convey their future energy behaviour as well as the compromises they are willing to take (flexibility), will need to be developed and evaluated in different contexts. Of course incentives will need to be considered in conjunction with new business models in order to attract users to join a specific service provider. Transparency on the benefits achieved for the participants as well as simulation tools may need to be developed.

IV. CASE STUDY: THE PUBLIC LIGHTING SYSTEM

For demand side management approaches to work, some prosumers must be able to adjust their energy behaviour. This implies that each prosumer has (i) knowledge of his own processes as well as the energy prosumed associated with them, (ii) the capability to do timely monitoring on his infrastructure and (iii) the capability to apply energy management related decisions to it. The Public Lighting System (PLS) may have a maximum energy consumption level as well as a minimum level (depending on regulation or dynamic conditions such as traffic, weather etc.). The difference between these two defines the “flexibility” in adjusting the energy footprint of the system. Such flexibility can be not only be considered in order to lower costs but also to increase revenue in other settings. So the public lighting system could act as an energy balancing partner in various settings e.g. turn-on consumption in case of significant energy availability e.g. from wind parks or adjust its behaviour also in correlation with energy prices e.g. in smart city energy markets and benefit from it [10].

Providing some insights on the role of public infrastructures such as the PLS is a timely issue, as in municipalities cost-effective approaches to provide a public service but reduce the costs are sought [17] [18]. However, existing approaches typically target the reduction of usage (in order to lower the cost) e.g. in several cities in United Kingdom, public lighting system parts are simply turned off in the after midnight hours or significantly dimming the lights (as reported by newspapers e.g. in Figure I). Over England and Wales over half a million street lights are switched-off in order to save money. This approach has created in many cases a public outcry as the fear for impact on civilian safety is debated. Apart from safety

Table I
Public Lighting System turn-off to reduce costs in UK.
Source: Daily Mail Newspaper, 09 July 2011

City	# Lights	Cost Decision Taken
Buckinghamshire	1600	switched off after midnight
Cornwall	30000	dimmed
Durham	12000	dimmed
Essex	91000	switched off after midnight
Gloucestershire	15000	dimmed or switched off after midnight
Leicestershire	51000	dimmed or switched off
Norfolk	27000	switched off 00:00–05:30
North Yorkshire	30000	to be switched off after midnight
Nottinghamshire	90000	to be dimmed or switched off
Suffolk	40000	dimmed or switched off

[19], full street lighting goes beyond practical issues (e.g. road safety, crime etc.) and also addresses social aspects.

Apart from centrally controlled decisions to turn on/off the lights based on time, some others have experimented with user-driven management. For instance in some cities in Germany (e.g. Lemgo) citizens may turn on the lights across a street by sending SMS via their mobile phones (each street light has a 6-digit code that is sent to a centrally administered number). Other approaches try to reduce consumption by combining factors such as pedestrian flow with safety guidelines [20]. However, such approaches, although they prove a concept, are not fully automated, do not have a strong business model, and may even be misused.

A more pragmatic approach is that of dimming the lights, which attempts to provide a trade-off between cost and usage. Today, with the prevalence of LEDs used in public lighting systems, this makes increasingly sense, not only because of the overall energy savings (which could be in the range of 40%[18]), but also the additional capabilities they provide in flexibly managing the system. Control, by simply turning on/off specific LEDs within a street light hence dimming it, can be easily applied, and can be done instantly due the very fast reaction of LEDs on the power-on/power-off signals. Other, more advanced solutions, involve usage of street sensors and adjust overall lighting based on requirements for the lighting conditions i.e. weather, traffic, etc. and even the human visual perception [21]. However these approaches target again locally autonomous systems for reducing energy consumption according to the current conditions. The approach of trading the flexibility available as depicted in this paper is complementary to these.

As depicted on Figure 3, several steps need to be taken in the bilateral communication between the DSO and the Public Lighting System, which will lead to an agreement on the future behaviour and benefits for both of them. In the specific case, where bidirectional communication between the DSO and the PLS exists, the PLS offers its flexibility, while DSO proposes the reduction of the energy signature of the PLS. Independent of who actually initiates the communication, the PLS firstly assesses its own energy prediction, in order to understand the available levels of flexibility that it can negotiate with other parties. Subsequently it requests from the DSO potential flexibility curve as well as a price curve describing the cost range for each adjustment. The DSO makes a potential offer on the adjustment and prices willing to pay (he may coordinate with multiple other stakeholders), and then the PLS does a cost benefit analysis to asses which his situation. Finally for the cases where a positive cost benefit analysis is achieved, the PLS negotiates with the DSO the behaviour adjustment, which at the end is sealed with a micro contract for the expected behaviour.

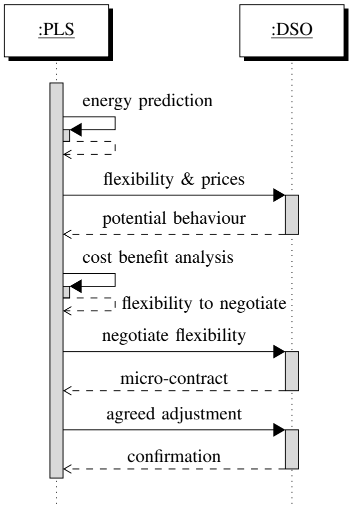

Figure 3. Energy flexibility negotiation according to *scenario* 1

```
option java_outer_classname = "NobelFlexibility";
option java_multiple_files = true;
package eu.ict_nobel.gpb.optimization;

message Flexibility {

    enum EnergyDirection {
        CONSUMPTION = 1;
        PRODUCTION = 2;
    }

    message FlexibilityPoint {
        required uint32 index = 1;
        required double quantity = 2; // number of available units
        required double pricePerUnit = 3;
        optional uint32 processCount = 4; // number of processes involved
    }

    optional uint64 flexibilityId = 1; // point of reference on IEM platform
    optional uint64 groupId = 11; // group that offered the flexibility
    required uint64 offerId = 2; // point of reference on prosumer side
    required EnergyDirection direction = 3;
    required uint64 startSecondsInUnixTime = 4; // start time
    required uint32 stepSize = 5; // seconds from start
    repeated FlexibilityPoint points = 7; // flexibility curve
    optional uint32 totalProcessCount = 8; // total number of processes involved
    optional uint64 validUntilInUnixTime = 10; // offer not valid before
    optional uint64 timestampInUnixTime = 12; // acceptance time
}

message FlexibilityList {
    repeated Flexibility flexibilities = 7;
}

message FlexibilityGroupList {
    repeated FlexibilityGroup flexibilityGroups = 7;
}

message FlexibilityGroup {
    required uint64 groupId = 1; // group that offered the flexibility
    required string url = 4; // offering location
    optional string username = 6; // if required for access
    optional string password = 7;
    optional uint64 timestampInUnixTime = 9; // group join timestamp
}
```

Listing 1. Flexibility Negotiation – Google Protocol Buffer Definition

Within the NOBEL project, such a scenario is realised, while an example of the information exchanged is listed on Listing 1. Additional information on the motivation, considerations on information exchange and technologies is depicted in the detailed view of the service platform developed [6] to accommodate such scenarios.

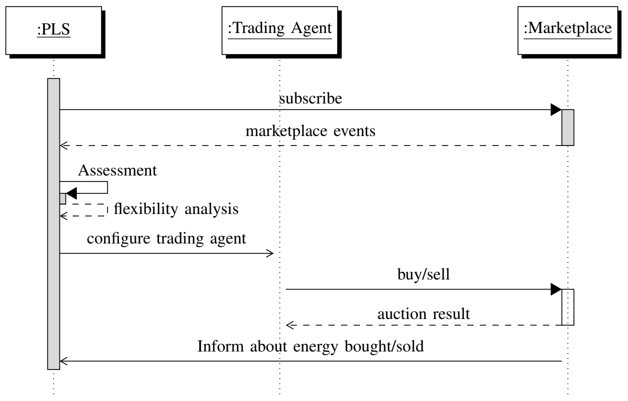

Figure 4. Energy flexibility negotiation according to *scenario* 2

In *scenario* 2, the overall goal of trading the flexibility available on the prosumer side (in this case the PLS) in order to create new revenues is investigated. In the NOBEL project, prosumers make use of a local energy marketplace where energy can be bought and sold. A service platform, globally available to all prosumers, is offering energy services for real time monitoring, management, billing etc. as well as a marketplace [9] has already been implemented [6]. Here several interactions are possible, and one such is depicted in Figure 4. The PLS system may subscribe to informational events coming from the market itself and delivered via the energy platform services. Such information includes current energy prices, historical information, available buy/sell offers etc. Together with information obtained from the PLS, e.g. flexibility assessment, a cost benefit analysis can be made and then a trading strategy is defined. Once the decision is taken in the PLS side, it can configure an agent (as offered by the platform) who takes over and tries to satisfy the behaviour defined by the PLS. This could be for instance a way to procure energy at the lowest possible price or sell the flexibility of the PLS at the highest possible one. The PLS manager can receive the notifications and performance of the agent in his monitoring screen, while the automated PLS management system adjusts the behaviour of the PLS to correspond to the results of the auctions on the marketplace.

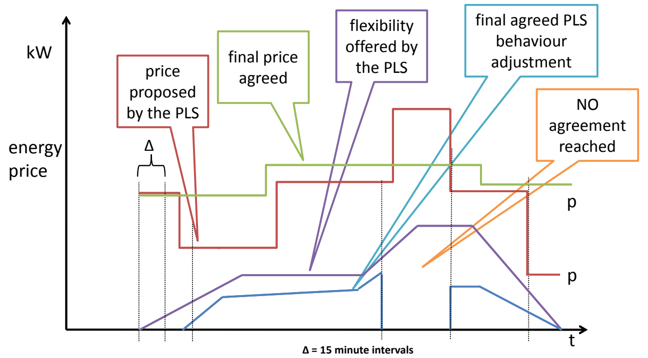

Figure 5. Public Lighting System negotiation example

Figure 5 depicts a result of such scenario interactions. As shown, although the PLS was willing to adjust its behaviour at a much lower price, the final agreed price was generally higher, which yields out some additional financial benefits for the PLS. For some slots where no consensus was achieved, as there was a significant difference on the conditions the transacting partners had set. For the latter, no flexibility has been traded (although available from the PLS side), as it is not a financially viable solution for the PLS, hence no adjustments on the energy signature of the PLS will be done.

While several other scenarios are possible with a varying degree of complexity, it is important to understand the huge potential brought by *scenario* 2. Not only sophisticated strategies may be defined but also market/economic models and strategies can be utilized similar to what is done in stock exchange. Hence we move towards a highly dynamic system that may readjust itself according to the interactions of its stakeholders and is business driven. Additional levels of interactions may be introduced between the stakeholders with the pros and cons that they bring with them e.g. as shown in *scenario* 3 where prosumers enable aggregators to act on their behalf. All of the example scenarios mentioned are complementary and can co-exist.

V. CONCLUSION

We have investigated the new role that existing infrastructures can play in the Smart Grid era, provided that they are able to accurately assess and adjust their own energy behaviour. To do so, apart from fine-grained monitoring and control, assessment tools must be in place in order to realize in near real-time what are the available flexibility capabilities, and for which of them it actually makes sense (e.g. financial) to proceed towards adjustments (e.g. load shifting). The existence of a platform enabling the information exchange and realisation of short-term contracts among the stakeholders is indispensable.

It has been shown how flexibility-driven scenarios can be realised with various degrees of interaction e.g. bilateral interaction among interested stakeholders or even flexibility trading on envisioned energy marketplaces. By taking into consideration available capabilities and Smart Grid energy services, existing infrastructures, even with limited capabilities such as the public lighting system, can not only procure their energy from local resources (potentially also at better prices), but additionally generate new revenue by trading their own flexibility. This may be a significant decision point for stakeholders such as the municipalities who administer public infrastructure and now can consider new revenue-generating scenarios in their effort to optimize their costs and benefits.

VI. ACKNOWLEDGEMENT

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