New method for evaluating the value of flexibility and new services for DSOs on the LV network

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***Abstract*— Distribution System Operators (DSOs) are more and more in need of flexibility services due to variable distributed generation, particularly photovoltaics (PV), and increased electricity demand coming from electric vehicles and heat pumps connected to the low voltage (LV) network. This growth of the electricity demand as well as unforeseen bidirectional power flow pose a great risk of congestion in the LV network. However, the distributed generation and storage devices can also serve as a flexibility source. Market-based solutions like local flexibility markets (LFMs) are encouraged by the European Commission to help reduce emissions of greenhouse gases and help DSOs minimize or defer their investments in network reinforcement. In the project X-FLEX, a hybrid market platform is being developed to allow aggregators provision of flexibility services to DSOs in the event of anticipated or detected congestion. An important question for DSOs and flexibility providers is the value of these flexibility services and how to justify the investment in this solution rather than the traditional methods of grid reinforcements. This paper presents a method for assessing the value of flexibility services to the DSO from two perspectives, technical and economical. This paper also describes the simulation models used to perform the value analysis. This method was elaborated within the context of the X-FLEX project, thus taking into account the regulatory framework of two pilot countries: Greece and Slovenia.**

***Index Terms*—Congestion Management, Electricity flexibility, Energy system, Local Flexibility Market, TOTEX, Value Analysis.**

I. INTRODUCTION

In Europe, there is a push toward electrification of all sectors to achieve emission reduction goals for 2030 and carbon neutrality for 2050 [1]. This shift will impact the distribution network, mainly through the addition of electric vehicles (EVs) and heat pumps.

Each country in Europe has recently prepared National Energy and Climate Plans (NECPs) which outline their energy goals, policies, and measures from 2021 to 2030, especially in terms of installation of distributed energy resources (DER) [2]. The development of these Plans is a legal requirement under the Governance Regulation adopted in December 2018. These plans can give an idea of the direction and quantity of electric devices to be installed until 2030 in the national distribution grid and consequently the need for coordination of these devices not to overload the network.

As an evident effect on the electrical network, additional capacity may be needed to distribute the electricity required at the house connection point [1]. However, with an efficient utilisation of the grid, the DSOs grid reinforcements of line and transformers upgrades could be avoided if flexibility mechanisms are in place.

The aim of this paper is to provide a method that technically and economically justifies the procurement of flexibility by DSOs. The method was developed with a local flexibility market (LFM) in mind, but any other flexibility mechanism could be tested with this method. The scope of the flexibility procurement for this method was initially the low voltage (LV) network, i.e., the DSO procures flexibility from controllable DER connected under a medium voltage (MV) to LV substation. Nevertheless, the same method can be used for DSOs procuring flexibility from resources connected to the distribution network, all connected under the same high voltage (HV) to MV substation.

The paper is organised as follows. Section 2 describes the past/current DSO approach for solving grid issues such as congestion or voltage violation and proposes a new approach that considers long-term operating costs and redefines the value assessment of investment for grid reinforcement and flexibility procurement. Section 3 details the steps of our method and the specificities of different national grids. Section 4 discusses the advantages of this novel method, its prerequisites, and its barriers. Section 5 concludes and provides future research areas for flexibility value assessment.

II. TRADITIONAL AND NEW DSO APPROACHES

Traditionally, the distribution network has been designed for unidirectional power supply, from the HV network to MV and then LV with very low peak power at the end-user premises (around or lower than 1 kW) [3] and a low simultaneity factor. However, with the deployment of renewable energy sources, especially photovoltaics (PVs), and storage devices (stationary batteries, EVs, heat pumps) the distribution network experiences higher peak demands as well as voltage spikes and drops which were not experienced in the past. To solve these issues, DSOs have traditionally reinforced their network, i.e., added or replaced lines and upgraded transformers [4]. These upgrades increase the thermal capacity of the components which allows higher currents, i.e., higher peak loads but they also provide more stable voltage fluctuations. This is an option which is capital intensive and enables DSOs to invest all in CAPEX (capital expenditures) and reduce drastically their OPEX (operation expenditures) by avoiding power quality noncompliance which would lead to penalties. This reinforcement approach usually leads to oversizing, which means that the grid is built to cope with any demand peak, regardless of its frequency, leading to a not optimally utilised network. And as the electricity demand and local production grow, reinforcement will be needed once the peak reaches the new limit of the network. By grasping the opportunity of coordinating flexibility sources, the DSOs can avoid investing in such reinforcement if the total demand can be met with the existing capacities of the network over the timespan under study (for example over 10 years). The problem is presented in the next two figures where long-term needs for reinforcement are depicted in Figure 1 in function of the flexibility mechanism which is implemented. While the peak power occurring in a network is forecast to continuously increase in the next year, if no specific mechanism is implemented, the maximal capacity of the network will be soon reached (Y1), calling for reinforcement. If no action is taken, some other parts of the network may also be subject to reinforcement needs as the demand grows (Y1'). However, if flexibility mechanisms are deployed by the DSO, the peak power can be reduced through load shifting or load shedding and thus postpone the reinforcement need (Y2). With the hypotheses of knowing the yearly increase of electricity demand and the amount of flexibility available onsite to reduce the peak load, an estimation of the postponing time for network reinforcement can be performed.

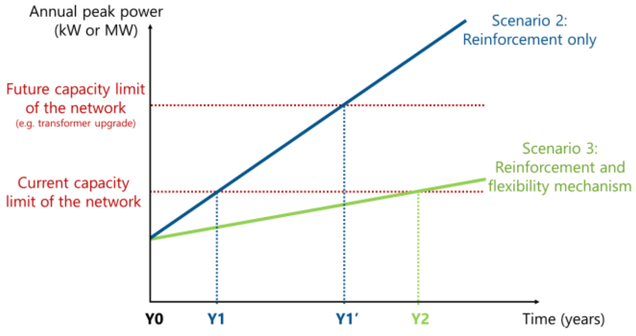

Figure 1. Graph showing the reinforcement deferral potential of flexibility services

Figure 2 presents the economical aspect that should be considered when assessing the value of flexibility mechanisms. As mentioned before, DSOs have two components in their investment budget: CAPEX and OPEX. These two components need to be considered jointly to correctly calculate the cost and revenues of flexibility provision. This approach is called TOTEX (Total Expenditures) and is gaining recognition among DSOs [5]. Using the TOTEX approach is especially interesting for DSOs if they consider flexibility mechanisms which would maximise the grid utilisation given that it would create a higher ratio of peak power over grid capacities, thus rendering the reinforcements much more cost-efficient. In Figure 2, we represent the overall gain in reinforcing the grid (Scenario 2) over not taking any action (Scenario 1) and the overall gain of combining flexibility mechanisms with the necessary reinforcement (Scenario 3). Operation costs, if no action is taken, increase in function of the number of power quality violations that occur in the grid. As the demand is expected to increase every year, it is reasonable to think that the operation costs in Scenario 1 will steadily increase, reaching high values due to high penalties associated with power quality deviations.

If only grid reinforcement is considered by the DSO, most of the TOTEX will consist of CAPEX. The interest of Scenario 2 is to keep the OPEX low. Finally, allowing flexibility provision in the distribution network enables to decrease the amount and proportion of CAPEX in the TOTEX. However, the operation costs will increase due to the DSO employing specific tools and agents for such flexibility mechanisms.

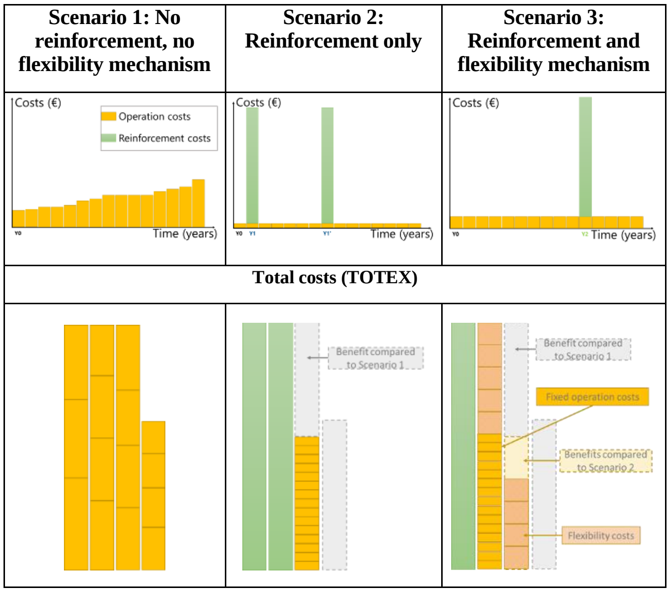

Figure 2. Difference in TOTEX for different flexibility and reinforcement scenarios

OPEX can be divided in four categories:

1. Penalties due to non-compliant operation of the network. This mostly includes voltage deviation but, depending on the national regulatory authorities, energy losses and non-continuity of supply can be penalised.
2. In case of flexibility provision: the remuneration for the agent doing the selection of which flexibility should be activated (the local market operator for example)
3. In case of flexibility provision: the remuneration for the flexibility provision service.
4. Unavoidable running costs, such as personnel and permanent equipment. This price is relatively fixed and

is not much affected by the flexibility provision mechanism, so it is ignored in our analysis.

In this paper, we present a technical and an economic approach to evaluate the added value of flexibility coordination and procurement for the DSO.

III. METHOD

We distinguish the technical value of the flexibility provision mechanism, also called "use value" to use terminology relative to the value engineering domain, and the economic value of the mechanism, also called "exchange value". To be able to calculate those two values, several parameters and data must be known: (i) the network topology for which the assessment is done, which includes the different lines connecting the loads, the historical demand for the different loads of the network, and the distributed energy sources connected to the network; (ii) long term projections on the electricity demand evolution and on the installation of new DER; (iii) the flexibility provision mechanism that is considered. This third factor is indeed important, for instance, if the flexibility would come only from DR mechanisms, a reduction of the demand would be considered as a flexibility potential. Inversely, LFMs aim at maximising the utilisation of the grid but are often based on price competition which may not accept all the flexibility units competing if their prices do not match thus leading to not optimal grid utilisation. In the case of more centralised coordination, like in virtual power plant configurations where one agent has control over the majority of the grid units, it can dispatch its units to prevent and solve grid issues while maximising the grid utilisation. In any case, the flexibility provision mechanism must be well defined in advance and correctly modelled to avoid any overestimation of the flexibility potential in the network.

A. Use value

The use value, or technical value, of flexibility provisions serves as a set of indicators which embraces the benefits of reallocating the available grid capacity. The flexibility service goal can differ from one application to another, for example some services are specifically targeted at solving capacity congestions or voltage control in the distribution networks, while some others focus on the reduction of energy losses [6, 7]. However, we can generalise the benefits of the flexibility services as an enabler of load-shifting, and a way to optimise the grid utilisation by reducing the peak power, reducing the RES curtailment, and increasing the RES injection. These benefits can be simulated through power flow studies as well as simulated flexibility provision. In X-FLEX project, a “Grid Planning Tool” has been developed to simulate flexibility utilisation for different distribution networks. The tool contains five main algorithms (Figure 3):

- Reading the network topology to study,
- Placing flexible units in the network (electric vehicles, heat pumps, static batteries, photovoltaics for curtailment),
- Generating power profiles,
- Simulating power flow in the whole network,
- Reallocating flexible demand over the day,
- Optimising grid reinforcement measures.

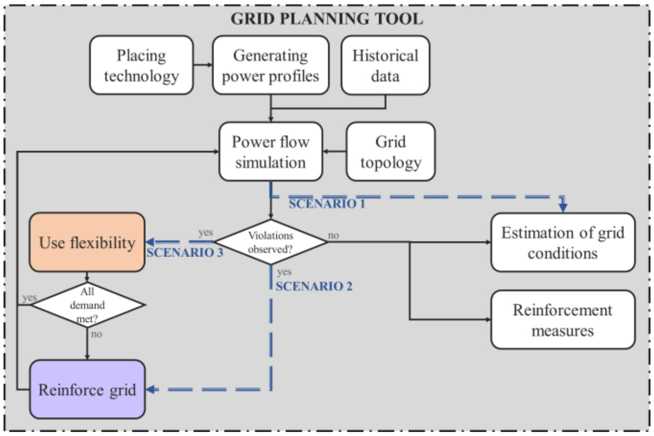

Figure 3. Diagram of background architecture of the Grid Planning tool

Figure 3 represents all the algorithms present in the tool. Scenario 1 is executed without checking grid conditions violations, i.e. without running the flexibility utilisation and grid reinforcement algorithms (orange and purple boxes in the bottom left of the figure). Scenario 2 is executed as the execution of the simulations without running the flexibility utilisation algorithm (orange box). Scenario 3 is executed by simulating flexibility utilisation and adding grid reinforcement if needed.

The outcome of the Grid Planning tool is set of indicators that can be further analysed to define the flexibility potential and value in the studied network. The direct outcomes of this tool are the following:

- Active power profiles of each connected load, feeder and of the transformer,
- Voltage profiles of each connected load and of the transformer,
- Energy losses at the transformer level.

When observing these parameters over a certain period (e.g., a week, a month, or a year), other important indicators can be obtained, such as peak-to-average ratio and network utilisation. By smoothing the aggregated power profile of a network, the network utilisation can be increased without increasing the peak load in a feeder or at the transformer level. A national study conducted by Piclo showed that in a scenario where EV charging and heat pump storage is smartly used, the average utilisation of a distribution network could on average increase by 20% at the transformer level [8].

B. Exchange value

What is called "exchange value" in this paper is the maximal price at which the DSO could purchase the flexibility services to be economically justified. As presented in Figure 2, the operation costs increase when employing flexibility as the DSO needs to pay the agent operating the flexibility procurement mechanism (second category of OPEX) and the service of flexibility provision (third category of OPEX). The price for the former service should be a fixed price and represent a small proportion of the operation costs. The price for the latter service can vary, depending on the DSO's provision mechanisms: the flexibility provision remuneration can be defined in advance or it can also fluctuate with the market equilibrium price.

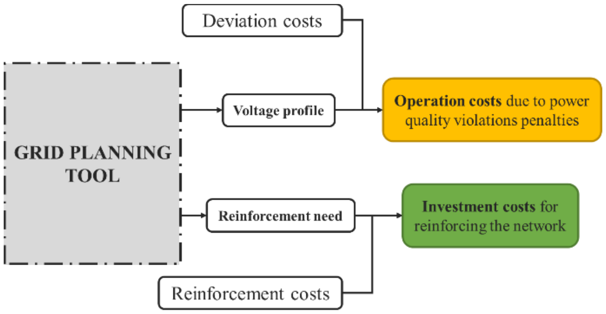

Figure 4. Method for estimating costs from technical simulations

For the DSO to make a thoughtful decision on the amount of money they are ready to spend for procuring flexibility, they need to know what the other costs are, i.e., the operation costs related to non-compliance penalties and the reinforcement costs. To properly evaluate these costs, we propose to use the outcomes of the Grid Planning tool, add costs inputs and, for each scenario, assess the reinforcement costs (CAPEX) and the operation costs for non-compliance, as shown in Figure 4.

Finally, the total price that DSOs can legitimately spend in flexibility procurement needs to be within an acceptable range, i.e., lower than the price they would invest for reinforcement in Scenario 2. In other words, the economic benefits of the flexibility procurement mechanism can be evaluated by the following Equation (1).

$$\begin{aligned} Flexibility\ benefits &= \Delta TOTEX = \Delta CAPEX + \Delta OPEX \\ &= CAPEX_{Scenario\ 2} - CAPEX_{Scenario\ 3} \\ &\quad + OPEX_{Scenario\ 2} - OPEX_{Scenario\ 3} \end{aligned} \tag{1}$$

As long as additional operation expenditures in the Scenario 3 do not exceed the reinforcement cost avoided, it is always a justified measure to make use of distributed flexibility.

IV. DISCUSSION

The method presented here has the advantage of considering both CAPEX and OPEX together (TOTEX) and providing a clear and unambiguous economic indicator to the DSO. The method integrates many parameters both in the power flow simulation, by using a precise grid topology, based on historical data, and regulatory aspects in the performance rewards and penalties for the DSO as well as the reinforcement costs depending on the countries and local terrain situation.

One benefit of deferring grid reinforcement which has not been mentioned earlier is the time that is "gained" for innovation. Indeed, grid reinforcement is generally a non-reversible investment which is based on a specific anticipation of power flow. However, investing in flexibility mechanisms is an interesting substitute. For example, in Figure 2, even if the stacked costs can be compared between the scenarios with and without flexibility mechanisms (scenarios 3 and 2 respectively), the timespan between the reinforcements of scenario 2 and the first reinforcement of scenario 3 is an opportunity time where innovations in grid reinforcement (methods or equipment) or in flexibility mechanisms could improve and therefore further decrease the need and/or the cost of reinforcement.

This method however requires a lot of background data and tools. First, a good grid modelling is necessary, with data as accurate as possible, on the cable lengths and composition, on the connected loads (e.g., their historical demand profiles, the presence of flexibility devices) as well as on the transformer. This method is being applied in the scope of X-FLEX project on 4 LV networks: one in Slovenia and three in Greece. For the Slovenian network, a lot of historical data could be collected as the transformer and all loads have been metered for more that 2 years. This enables a well calibrated grid model that can be then reliably simulated. On the other side, the three studied Greek networks have never been metered except MV/LV transformers, the simulation of the grid is then impeded as it cannot be properly calibrated for each node.

Secondly, estimating the flexibility potential of all the units connected to that grid is a hard task as it is time-dependent, and the flexibility availability span varies depending on the flexible units; for example, an EV will have a flexibility potential for the few hours it is plugged in, while a static battery may be run with cycles long of several days. This is why we recommend making simulations for a long period of time (ideally a year). However, this is a computational burden and, even though this analysis is an offline analysis, some trade-off could be found.

On top of this, proper long-term scenarios need to be available. This is a generally hard task for DSO and it has to be regularly updated. When going down to the LV network it is hard to predict the number of EVs, heat pumps or PVs that will be installed by the end users. In the case of the Slovenian network, no local scenario was available so they have to be based on the national plan which may not reflect the reality of this small part of the national network. Inversely, the networks studied in Greece are part of municipality which publicly defined objectives for the next 10 to 30 years in terms of PV installation and electrification of the residential sector.

Finally, one difficulty that lies in the method presented here is the estimation of the operational costs as they are dependent on the timeframe studied, and highly dependant on the national regulations. For each network studied, DSOs remuneration, and penalty schemes should be thoroughly studied and the method for simulating operating costs in the different scenarios of our method presented in this paper adapted. The problem of the timeframe resonates with the first comment of this section, related to the flexibility potential: the longer the timeframe of study, the more reliable the results of the flexibility valuation.

V. CONCLUSION

In this paper, we presented a novel method to value and justify the deployment of flexibility mechanisms for the distribution network. With the large deployment of DERs, DSOs are facing more frequent and intense power quality problems and congestions in their network which either requires a massive network reinforcement leading to oversizing the grid or a smart sizing of the grid capacities and exploiting the flexibility potential from DERs. Our method proposes first to simulate the distribution network power flow with and without flexibility procurement mechanisms in order to determine the grid needs in terms of reinforcement. By adding economic inputs, such as reinforcement costs and operation costs, the budget for DSO to purchase flexibility services can be estimated. Finally, the technical requirements to apply such a method are manyfold, it requires a lot of grid knowledge, access to field data, optimisation tools, and reliable objectives and predictions for future electricity usage in order to reach an accurate estimation of the value of flexibility in the distribution network.

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