FlexPlan: a new Horizon 2020 project to include the contribution of storage and flexible resources in grid planning

Gianluigi Migliavacca
Ricerca sul Sistema Energetico
RSE SpA
Milano, Italy

Marco Rossi
Ricerca sul Sistema Energetico
RSE SpA
Milano, Italy

Dario Siface
Ricerca sul Sistema Energetico
RSE SpA
Milano, Italy

Matteo Marzoli
Ricerca sul Sistema Energetico
RSE SpA
Milano, Italy

Hakan Ergun
KU Leuven / EnegyVille,
Leuven Belgium

Raul Rodriguez
TECNALIA
Derio, Spain

Guillaume Leclerq
N-SIDE
Louvain-La-Neuve, Belgium

Nuno Amaro
R&D NESTER
Lisbon, Portugal

Björn Matthes
Technische Universität Dortmund
Dortmund, Germany

Jawana Gabrielski
Technische Universität Dortmund
Dortmund, Germany

Andrei Morch
SINTEF ENERGI
Trondheim, Norway

***Abstract*— This paper describes the main features of the new European research project FlexPlan. This project aims at establishing a new grid planning methodology considering the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to building new grid elements. FlexPlan will create a new innovative grid planning tool whose ambition is to go beyond the state of the art of planning methodologies, by including the following innovative features: integrated transmission distribution planning, inclusion of environmental analysis, probabilistic contingency methodologies replacing the N 1 criterion as well as optimal planning decision over several decades. Then, the new tool will be used to analyse six regional cases covering nearly the whole European continent, aimed at demonstrating the application of the tool on real scenarios as well as at casting a view on grid planning in Europe till 2050. In this way, the FlexPlan project will try to answer the question of which role flexibility could play and how its usage can contribute to reduce planning investments yet maintaining current system security levels. The project will end up formulating guidelines for regulators and planning offices of system operators.**

Keywords—grid planning, storage, flexibility, long-term scenarios, regulatory guidelines

I. INTRODUCTION

A recent agreement among EU Member states has fixed a binding target of 32% on the share of energy from Renewable Energy Sources (RES) for the year 2030. Massive RES deployment will make future Transmission and Distribution (T&D) grids planning more complex and affected by uncertainty. Grid investments are capital intensive and the lifetime of transmission infrastructure spans several decades: due to rapidly changing scenario hypotheses, when a new line is commissioned the foreseen benefits could no longer justify the corresponding investment. For this reason, it would be worthwhile optimizing grid infrastructure while finding other ways for compensating peak flows in the grid. On this pathway, storage can provide a good alternative to building new lines. In fact, the placement of storage devices in strategic grid locations could prove effective in preventing temporary line overloading, thus constituting a good alternative to building new lines aimed at coping with RES generation peaks (see also 2050 EC vision [1]). A similar role could be also taken by flexible consumption (e.g. deferrable consumption), especially when considering big industrial loads and tertiary infrastructures. Finally, as storage capacity and flexible load management should be mostly provided by means of private engagement, incentivization procedures should be devised and enforced by regulators also in order to incentivize settling new items in opportune locations, wherever consistent advantages are identified. All these aspects motivate the activity of the new FlexPlan Horizon2020 project, which aims at establishing a new grid planning methodology considering the opportunity to introduce new storage and flexibility resources in electricity T&D grids as an alternative to building new grid elements. FlexPlan will create a new innovative grid planning tool whose ambition is to go beyond the state of the art of planning methodologies, by including the following innovative features: integrated transmission distribution planning, environmental analysis, probabilistic contingency methodologies (in replacement of the N-1 criterion) as well as optimal planning decision over several decades. The new tool will be used to analyse six regional cases covering nearly the whole European continent (Iberian Peninsula, France and Benelux, Germany Switzerland and Austria, Italy, Balkan Countries and Nordic Countries), aimed at demonstrating the application of the tool on real scenarios as well as at casting a view on grid planning in Europe till 2050.

The FlexPlan Consortium encompasses three Transmission System Operators (TERNA Italy, ELES Slovenia and REN Portugal), ENEL Global Infrastructure (also representing the Italian distributor e-distribuzione, present in the consortium as linked third party), research and development companies and universities from eight European Countries (Belgium, Germany, Italy, Norway, Portugal, Serbia, Slovenia, Spain), including the project coordinator RSE, and N-SIDE, the developer of the European market coupling platform EUPHEMIA [11].

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784

The following sections are going to clarify the regulatory framework (section II), the modelling characteristics of the new planning tool (section III), the analysis being carried out on storage and flexibility characteristics (section IV) and the scenario hypotheses for the six regional cases upon which the planning model will be tested (section V).

II. THE REGULATORY FRAMEWORK

The recent "Clean Energy for all Europeans" package has confirmed the Pan-European political determination to employ energy flexibility services as a consistent part of both operation and planning of the electricity network. Already in the opening lines it is specified Distribution System Operators (DSOs) should be incentivised for using distributed resources in order to avoid network expansions [2]. The common paper of ENTSO-E and several DSO-representing organisations, known as Active System Management report [3], states that flexibility services can be used as a complement while planning grid reinforcements for dealing with congestion. Grid expansion should be carried out when affordable and when providing a better business case than market-based flexibility. Following the same direction, EURELECTRIC [4] points out that the use of flexibility services will rightly compete with traditional investment options for DSO grid reinforcement or upgrades. Therefore, in the future, DSOs will need to adapt their development plans and include available sources of flexibility among others as an alternative to standard network investments. This is however an extremely challenging task, because it requires a comparative evaluation, based on future scenarios with several uncertainties and monetary representation of several indicators, as it has been outlined in the recently published guidelines by ENTSO-E [5].

The above-mentioned difficulties are further complicated by the present very dynamic change of the European regulatory landscape. It important to notice that the most recent recast of the European Directive on internal market for electricity [2] specifically refers to "demand response through aggregation", term presuming that aggregation is a firm prerequisite for considering demand flexibility. Furthermore, the European Commission has started the formalisation process of several new business actors, by indicating their roles and responsibilities in the directive.

As we have shown, there is a strong indication from the European Commission to introduce flexibility services as a viable alternative to network expansion, and this initiative appears to be strongly supported by key stakeholders as ENTSO-E and DSOs' associations. However, establishing practical methodologies and materialising them in a functional tool is still an "unchartered territory", complicated by several externalities as new actors, new roles and responsibilities. This highlights the importance of FlexPlan as a timely and dedicated project initiated by the leading European experts in the field.

III. AN INNOVATIVE PLANNING TOOL

As already hinted at in the introduction, the main goal of FlexPlan is to develop and implement a grid expansion optimization tool able to incorporate flexible grid elements: conventional network assets on one hand and flexibility sources (such as storage and demand side management) on the other. The tool will be applicable to both transmission and distribution systems, also providing the possibility to optimize investments in both networks at the same time.

Fig. 1 shows the outline of the optimization model and the input parameters. A number of candidate grid investments, flexibility and storage options are provided as an input for the tool. These expansion candidates are characterised both technically and economically (see section IV). Additionally, RES generation and demand time series are assumed by using the scenario analysis outlined in section V. Transmission network data (based on the Ten Years Network Development Plan – TYNDP) and distribution network data (synthetic or real ones) are also managed in order to provide grid constraints for the optimization problem.

As a first step, grid expansion and flexibility candidates are analysed in order to quantify their costs based on landscape impact (air quality, life-cycle assessment and landscape). For this purpose, approximate linearized models to link the monetarized emission and air quality impact to the dispatch of generators have been developed, as well a life cycle analysis based quantification of the carbon footprint of new grid. The landscape impact related costs are determined using the optimal transmission routing approach provided in [6]. These environmental impact costs are included into the optimized objective function, such that the best trade-off between T&D system investments and operational costs is found by also considering environmental externalities.

The optimization is carried out in parallel for the three scenarios defined in the Ten-Year Network Development Plan by ENTSO-E (https://tyndp.entsoe.eu/tyndp2018/), whereas yearly climate variants are accounted for in the framework of a Monte Carlo process.

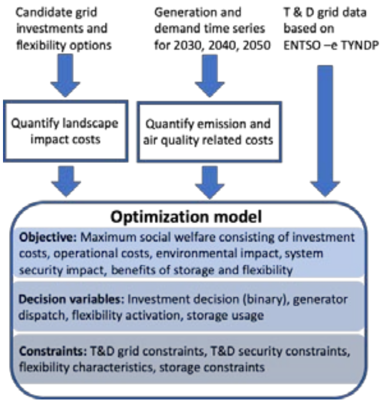

Fig. 1. High level outline of the optimization model

The objective of the optimization is to maximize the system social welfare. This is obtained by minimizing the sum of T&D grid investments, operational costs bound to system dispatch and environmental impact costs, while maximizing the benefits achieved by the use of the flexibility sources and storage. The general structure of the objective function is defined as

$$min \sum_{y}\sum_{t}\left[\sum_{i}(C_{y,t,i}) + \sum_{j}\alpha_{y,j}(C_{y,t,j}) + \widetilde{U}_{y,t,c}\Delta t\sum_{c}C^{voll}_{u,t,y}\,\Delta P_{u,c,t,y}\right] + \sum_{j}\alpha_{y,j}I_{y,j}$$

where i is the set of existing assets in the system and $C_{y,t,i}$ corresponds to their operational cost in each hour t of each planning horizon y. The emission and air quality impact costs are modelled as part of the operational costs. Binary investment decision variables α_j are used for all grid and

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784

flexibility investment candidates j. $C_{y,t,j}$ is the hourly operational costs of the candidate investments whereas $I_{y,j}$ represent the capital investment costs adjusted according to the investment planning year y. The carbon footprint and landscape impact costs are considered as part of the investment cost $I_{y,j}$. Costs related to reliable power system operation are approximated using the expected cost of lost load in the system consisting of the product of curtailed load and the value of lost load ($C_{u,t,y}^{voll}\,\Delta P_{u,c,t,y}$), probabilistically weighted over a set of contingencies c, using their contingency probabilities $\widetilde{U}_{y,t,c}$. The weighted costs are added into the objective function of the optimization, in order to find the best trade-off between additional grid and flexibility investments to avoid congestions during outages versus the expected impact of such grid outages.

The optimization is performed jointly for three target years, namely 2030, 2040 and 2050, and each year is characterised by a continuous time series of 8760 hours, which is necessary to model storage and flexibility activation accurately. As a result, a step wise investment plan for new grid connections and flexibility investments is obtained.

Considering the three target decades and the detailed characterisation of each planning year, a large-scale mixed integer problem optimization is obtained.

The power flow equations and technical constraints for flexibility sources and storage are formulated in a linear way, in order to maintain tractability of the model notwithstanding its huge dimensions. Security constraints are included only for critical contingencies.

In order to make the model applicable to both transmission and distribution networks, the underlying network model is decomposed in two components, namely the meshed and the radially operated networks. This distinction is made independent of the juristic definition of transmission and distribution networks, as these are significantly differing among European countries. The optimisation model is applied in the full extend to meshed networks, where besides flexible elements, classical AC overhead line and underground cable investments are considered, along with phase-shifting transformers and possible new primary substations. The possibility of expanding the system with point-to-point and meshed HVDC connections is considered according to [7].

As the modelling of all radially operated systems would result in an unmanageable problem size, the expansion of such networks is considered as a planning candidate for the meshed system. For this purpose, a four-step approach is chosen. In step one, the optimal expansion plan of the radial network is determined with the objective of solving only local congestion in the most economical way. This marks the least-cost expansion scenario of the radial network. In step two, the same optimisation is performed with the objective of providing the maximum amount of flexibility in terms of delivering and absorbing active power to/from the meshed network. This option, marks the highest-cost scenario. In an optional third step, the optimal expansion of the radial networks with intermediary flexibility requirements can be determined. This way, a set of flexibility levels are obtained with their corresponding cost of radial system expansion. Eventually in the fourth step, these radial grid expansion options are provided as expansion candidates to the for the meshed system, modelled as a general flexibility source with the technical limits as obtained in the previous steps. In this way, the best trade-off between the flexibility level of the radial network and the expansion costs of both, the radial and meshed networks are considered. As the expansion problem for the radial systems can be performed independently, the optimisation problem can be solved much more efficiently.

The flexible demand model includes three main components and is defined as

$$P_{u,t,y}^{flex} = P_{u,t,y}^{ref} - \Delta P_{u,t,y}^{nce} + \Delta \mathrm{P}_{u,t,y}^{ds,up} - \Delta \mathrm{P}_{u,t,y}^{ds,dn} - \Delta P_{u,t,y}^{lc},$$

where $P_{u,t,y}^{flex}$ is the flexible demand defined for each consumer u, at each time point t of each planning year y. $P_{u,t,y}^{ref}$ refers to the expected reference demand of consumer u, $\Delta P_{u,t,y}^{nce}$ is the consumer's voluntary demand reduction, $\Delta \mathrm{P}_{u,t,y}^{ds,up}$ and $\Delta \mathrm{P}_{u,t,y}^{ds,dn}$ are upwards and downwards demand shifting actions performed by the consumer. $\Delta P_{u,t,y}^{lc}$ is the involuntary demand curtailment and is used to quantify the power system security related costs, as some outages in the network may lead to supply interruptions. The amount of voluntary demand reduction is limited via $0 \leq \sum_{t \in s_t} \Delta t \cdot \Delta P_{u,t,y}^{nce} \leq \alpha_u E_{u,y}^{nc,max}$, where $E_{u,y}^{nc,max}$ is the total annual energy not consumed and $\alpha_u$is the binary investment decision variable for demand flexibility. For demand shifting, the energy consumption over a given period τ needs to be balanced, e.g.

$$\sum_{t \in \tau} \Delta P_{u,t,y}^{ds,up} = \sum_{t \in \tau} \Delta P_{u,t,y}^{ds,down},$$

and an upwards and downwards demand shifting actions can only be performed for a limited short amount of time τ_u^{grace}:

$$0 \leq \Delta P_{u,t,y}^{ds,up} \leq \Delta_{u,t,y}^{ds,up,max} - \sum_{\tau \in \left\{t-\tau_{u,y}^{ds,up,grace},\dots,t-1\right\}} \Delta P_{u,\tau,y}^{ds,up}$$

$$0 \leq \Delta P_{u,t,y}^{ds,dn} \leq \Delta_{u,t,y}^{ds,dn,max} - \sum_{\tau \in \left\{t-\tau_{u,y}^{ds,dn,grace},\dots,t-1\right\}} \Delta P_{u,\tau,y}^{ds,dn}.$$

To complete the planning model, a generic storage model is used to represent different technologies:

$$E_{j,y}^{max} x_{j,t,y} = E_{j,y}^{max} x_{j,t-\Delta t,y} + \Delta t \cdot \left(\eta_{j,y}^{abs} P_{j,t,y}^{abs} - \frac{P_{j,t,y}^{inj}}{\eta_{j,y}^{inj}} + \xi_{j,t,y} - v_{j,t,y} \right),$$

where $E_{j,y}^{max}$ is the maximum energy capacity of the storage system j, $x_{j,t,y}$ and is state-of-charge at each time point t of each planning year y. $P_{j,t,y}^{abs}$ is the power absorbed from the network and $\eta_{j,y}^{abs}$is the absorption efficiency. $P_{j,t,y}^{inj}$ and $\eta_{j,y}^{inj}$ correspond to power injected into the grid and the injection efficiency, respectively. $\xi_{j,t,y}$ and $v_{j,t,y}$ represent the external energy in and outflows into the storage system, respectively, e.g. natural inflow of water into hydro storage or self-discharge of battery storage. The maximum energy capacity, power injection and absorptions are bound using the binary decision variable $\alpha_{j,y}$ for storage systems:

$$E_{jc,y}^{min} \alpha_j \leq E_{jc,y}^{max} x_{jc,t,y} \leq E_{jc,y}^{max} \alpha_{j,y}$$

$$0 \leq P_{jc,t,y}^{abs} \leq \alpha_{j,y} P_{jc,y}^{abs,max}$$

$$0 \leq P_{jc,t,y}^{inj} \leq \alpha_{j,y} P_{jc,y}^{inj,max}.$$

Figure 1 shows a simple case to illustrate the expected results of the planning tool. The test case consists of five buses and includes four candidate lines (represented as dashed lines), two candidate storage systems (indicated in green colour) and one flexible demand source connected at bus 3 (indicated in green colour). As the power transfer capacity of line 4 - 5 is limited to 240 MVA, the generation resources connected to bus 5 cannot be utilized to fully

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784

supply the demand on bus 3 and investments would be needed.

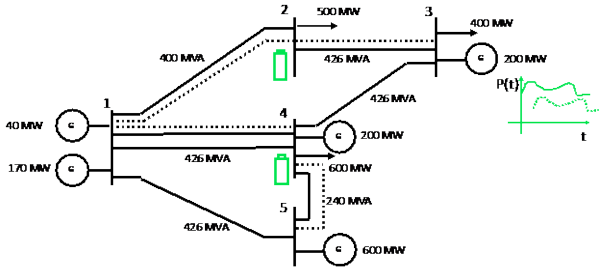

Figure 1 - Illustrative example showing the working principle of the developed model

Using only classical transmission expansion planning candidates, e.g. transmission lines, and designing the system purely for the peak load conditions as indicated in the figure, candidate lines 1-2 and 4-5 would need to be built in order to supply the demand on buses 2 and 3 (Figure 2).

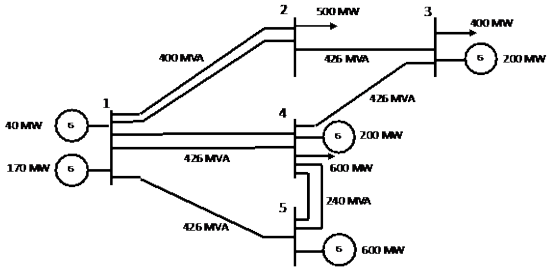

Figure 2 - Optimal expansion considering line candidates only

Considering that peak load conditions might only occur for a limited number of hours in a given planning year, and considering investing into demand flexibility as a planning candidate, the investments into a second circuit of line 4-5 can be omitted, as it the line capacity of the existing line is sufficient to supply the demand for most of the time (Figure 3). In this case the consumer is compensated to provide demand shifting and/or reduction actions,

$$\sum_{t\in S_t}\left(C^{nce}_{u,t,y}\Delta P^{nce}_{u,t,y} + C^{ds}_{u,t,y}\Delta \mathrm{P}^{ds,dn}_{u,t,y}\right)\cdot \Delta t,$$

where $C^{nce}_{u,t,y}$ and $C^{ds}_{u,t,y}$ are the revenues that the consumer gets for consuming less and reducing his demand, which is still more beneficial than investing into a new transmission line.

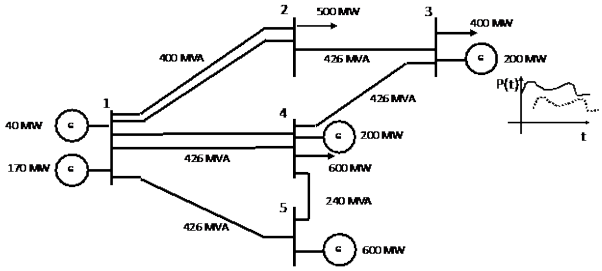

Figure 3 - Optimal grid expansion considering load variability and flexible demand

Obviously, this solution can only be applied if there is enough dispatchable generation capacity available in the system. Considering the system depicted in Figure 4, where a number of conventional generators have been replaced by wind farms, also candidate storage systems become feasible, and allow to supply demand in hours of low wind generation and high demand.

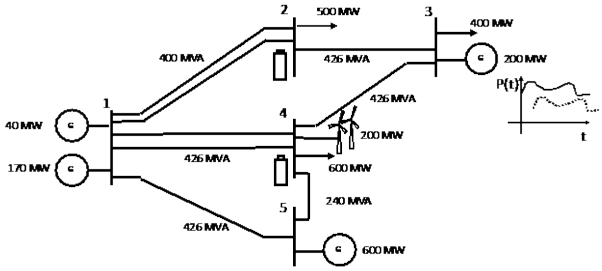

Figure 4 - Optimal expansion in presence of renewables and storage candidates

IV. Analysing in Detail Storage and Flexibility

As anticipated above, both storage and Demand Response (DR) are considered as flexibility resources in the frame of FlexPlan project. In a first step, storage technologies and DR strategies are studied and, by looking at their expected future deployment, the most interesting among them are selected to be considered as candidates in the planning process.

Once selected, the flexibility resources are modelled following two different approaches. For the storage, the objective is to define a common system model, with characteristic parameters adaptable to the specifics of each of the storage technologies. Parameters such as power, capacity, charge/discharge efficiency, losses, lifetime (calendar/cycle), etc. are considered.

On the contrary, DR refers to a set of strategies modifying the consumption profile of end customers, who may have both storage and local generation behind the meter (i.e. active customers). DR modelling addresses the ways in which the consumption profile will be modified by customers, and it is defined by parameters including the available power to be shifted during constraint periods, participation/response rate of participants, etc. The DR capacity depends on the behaviour of customers and on their flexibility and willingness to modify their habits, including business processes and/or domestic use of electricity. The actual response characteristics (when, how much power, with which certainty rate, etc.) are also affected by the requirements of the DR programme in which customers are enrolled.

Storage operation can be motivated by the participation of a customer in a DR programme, but not only. Depending on where the storage is located within the power system (generation, transmission, distribution, load), several operative motivations are possible. For example, storage might be operated to reduce the congestion in a network node, or utilized to optimize electricity sale through price arbitrage, when connected to a RES generation plant. The scenario characteristics (e.g. RES production level, electricity flows through the lines), triggers the storage operation in accordance to the control algorithm which defines its operational strategy.

Taking all these aspects into account, the FlexPlan project develops a specific software tool to evaluate performance and impact of selected flexibility resources (storage and DR), under specific scenarios and operative conditions for specific network nodes. Such tool acts as a

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784

pre-processor of the planning tool described in the previous section. The analysis is performed through the following steps:

1. nodes potentially affected by network congestion are identified from the results of the Optimal Power Flow (OPF) simulation of the scenarios adopted for the three grid years 2030, 2040, 2050 (see section V), proposing a ranking based on Lagrange multipliers' values;
2. the flexibility resources analysis tool (pre-processor) proposes a short list of storage and DR solutions to solve congestion in the identified nodes, based on congestion characteristics and on the geographical constraints related to the location, while providing sizing and cost insights of each of the selected technologies;
3. the proposed solutions become candidates for grid congestion support, along with lines for conventional grid extension, and are passed to the planning tool, which, in turn, assesses the best planning option for the power system in the timeframe of the study.

V. An Ambitious Scenario Analysis Supporting Long-Term Planning View

FlexPlan applies a multi-step modelling approach. In a first phase, pan-European scenarios are set up for the target years 2030, 2040 and 2050. For each year, three divergent scenario variants are considered, resulting in a set of nine scenarios in total. These diverging scenario variants are derived from major political drivers in coherence with ENTSO-E TYNDP. A European market coupling simulation is carried out in order to derive trans-regional border conditions. In a second phase, regional case studies are carried out. These case studies include a by far more detailed representation of the grid, but must necessarily have a smaller geographic scope, e.g. only one to three countries.

With regard to the pan-European model, the electricity market and transmission grid simulation framework *MILES* (Model of International Energy Systems) is applied. The regionalization module of *MILES* [8] calculates time series for feed-in of RES and the electrical load for 34 countries in Europe. Based on historical load profiles and historical weather data, *MILES* spatially disaggregates time series data (typically on country level) to regional clusters. For this purpose weather data from the regional model *COSMO-EU* of Germany's National Meteorological Service is processed to generate spatially disaggregated feed-in profiles of RES. To spatially disaggregate the installed capacity of RES, the national territory of each country is divided in sub-regions and various statistical figures for every region are analysed carefully. The electrical load is separated in household load and the load of the business sector. As there are correlations between the number of households and load of households as well as between the population of a region and the load, these parameters are used as parameters for the distribution of the household sector. The business sector is describes mainly by the parameters gross value, area of commercial buildings and related open space as well as the working population of the region.

The market simulation module of *MILES* [9] runs an integrated unit commitment and dispatch model resulting in a long-term security constrained unit commitment optimization problem with the objective to minimize the total variable generation costs. Technical and economical requirements are considered as mathematical constraints. The problem is formulated as a mixed integer linear program with a rolling planning horizon. Using a rolling horizon of 10 days, the simulation with hourly resolution is divided into intervals of 240 hours. These intervals are solved consecutively with an overlap of 72 hours in the simulation horizon. In the whole system the electric load and control reserve have to be covered for every zone and every time step, while operation limits of the generation units, as ramping limits, storage capacities and minimum up and down times have to be considered as well. The model determines power plant and storage schedules as well as cross-border exchanges between European countries.

The trans-national exchanges are then used by the new innovative planning tool as border conditions for running the considered regional cases throughout Europe (which feature completely different weather conditions, grid characteristics, different renewables integration, etc.).

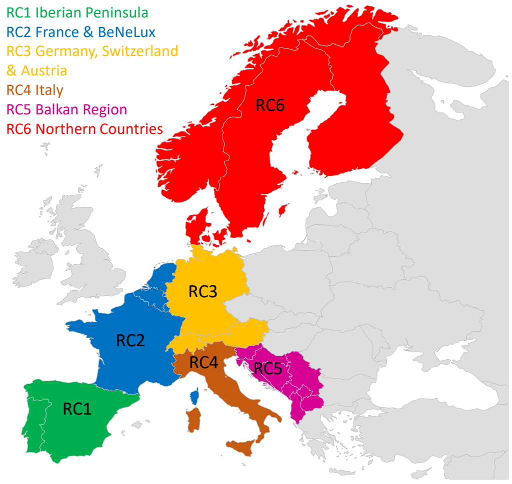

Fig. 2. The six regional cases

The six regional cases (cf. Fig. 2) are built using scenario data coming from the aforementioned pan-European scenarios, together with additional data sources integrating such data in order to create the comprehensive datasets which are then used to run the proposed planning tool. Grid topological data are mainly collected from ENTSO-E TYNDP 2018 Grid Model [10] together with additional data sources used in order to add geographic information and real characteristics of existing/planned power plants for each regional case.

Concerning distribution network, the collection of data is expected to be critical, especially considering the dimension (in terms of number of nodes and lines) of this infrastructure. For this reason, a procedure for the automatic development of synthetic (but realistic) distribution grid models will be adopted in order to evaluate the potential of low-power storage/resources for the optimal planning of both distribution and transmission systems. Taking advantage of the availability of the web-platform DiNeMo [12], realistic distribution networks can be built on the basis of the metrics collected from more than one-hundred European DSOs. The tool, in addition to return the model of the distribution network, it also provides realistic coordinates for the construction of a geo-referenced infrastructure. This is a valuable input for the planning tool developed by FlexPlan, since it can be used to create distribution network models

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784

also for countries in which DSOs are not directly participating to the consortium activities. The only drawback related to the use of DiNeMo consists of the software limitations and time effort required for the construction of a network model of whole countries. For this reason, at the expense of the geographic position of distribution nodes and lines, a simpler network synthesizer will be adopted [13]. This tool has the advantage of generating artificial distribution grids on the basis of few metrics/statistics which can be easily extracted from the analysis of real networks. The procedure for the creation of the distribution scenario will be based on the following steps:

1. DSOs involved within the FlexPlan consortium provide metrics on their actual network infrastructure for the countries in which they are operating.
2. For the remaining European countries, DiNeMo will be used in order to generate few artificial networks, to be used in order to deduce the necessary statistics provided by the DSOs.
3. Thanks to the collected metrics and the processing of the algorithm described in [13], the entire distribution system of the regional cases will be developed synthetically.

As anticipated above, the adopted algorithm is not capable of returning geographical coordinates for the generated network. However, having assumed a distribution planning approach which is not considering the development of new grid branches (but consider possible reinforcement of the existing ones), the geographical dimension is not a critical input of the FlexPlan tool.

VI. CONCLUSION

On the basis of the previous lines, it should be clear that the FlexPlan project comes in a moment of great expectation on the contributions storage and flexibility can provide in support to the planning process of transmission and distribution grids. Our expectance from the six detailed regional cases is to be able to build up a map of where and how storage and flexibility can be useful to prevent the deployment of new grid lines on the territory. In our opinion, the build-up of new lines in the future has to be attentively evaluated against possible alternatives (i.e. exploitation of storage and flexibility) for three important reasons:

1. the level of uncertainty on the development of generation and demand scenarios in the next years as compared with the big investments needed and the long amount of time till the new lines are finally put in service: a concrete risk subsists of generating stranded costs;
2. the increasing opposition of the public opinion to new grid investments, which entails longer time for the approval of new infrastructures;
3. the fact that RES variability, which generates intermittency in the grid flows, can be the cause for short-lasting congestion due to generation peaks, compensated by many hours in which the flows stay well below maximum grid capacities; in such cases new investments are hardly justified whereas exploiting local storage and flexibility can prove to be the ideal solution.

From the regulatory point of view, it is reasonable to foresee that investments in storage and flexibility will remain mostly in the hands of private investors. That means that depending on the results of the planning phase carried out by the System Operators, National Regulatory Authorities should translate the suitability of deploying new storage or flexibility in strategic network locations into opportune incentivization forms towards those who are possibly going to invest in that direction. This complicates a lot the scheme with respect to traditional planning modalities, where System Operators after carrying out their planning analyses were the only subject entitled to invest.

In this framework, FlexPlan is going on one side to provide a System Operators with a tool to allow including storage and flexibility into their grid planning analyses, on the other side to provide National Grid Authorities with a set of regulatory guidelines to allow optimal exploitation of the advantages storage and flexibility could provide to the system.

ACKNOWLEDGMENT

The research leading to this publication has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 863819

REFERENCES

[1] The European Commission, “A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy,” Nov. 2018

[2] The European Commission, “Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU,” June 2019

[3] CEDEC, EDSO, ENTSO-E, Eurelectric, GEODE, “TSO-DSO Report – An integrated approach to active system management,” Apr. 2019

[4] Eurelectric, “The Value of the Grid: Why Europe’s distribution grids matter in decarbonising the power system,” June 2019

[5] ENTSO-E, “The 3rd ENTSO-E Guideline for Cost Benefit Analysis of Grid Development Projects,” Oct. 2019

[6] H. Ergun, B. Rawn, R. Belmans, D. Van Hertem, “Optimization of Transmission Technology and Routes for Pan – European Electricity Highways Considering Spatial Aspects,” PowerTech 2015, June 2015

[7] Dave, J., Ergun, H., An, T., Lu, J., Van Hertem, D. (2019). TNEP of meshed HVDC grids: 'AC', 'DC' and convex formulations. *IET GENERATION TRANSMISSION & DISTRIBUTION*, *13* (24), 5523-5532. doi: 10.1049/iet-gtd.2019.0383

[8] J. Teuwsen, V. Liebenau, and C. Rehtanz, “Comparison of regionalization methods for network development planning,” 4th IEEE PES Innovative Smart Grid Technologies Europe, Oct. 2013

[9] C. Spieker, J. Teuwsen, V. Liebenau, S. C. Müller, C. Rehtanz, “European Electricity Market Simulation for Future Scenarios with High Renewable Energy Production,” PowerTech 2015, June 2015

[10] ENTSO-E, “Input grid datasets for the preparation of the TYNDP 2018”, available online.

[11] EUPHEMIA public description, https://www.europex.org/wp-content/uploads/2016/11/Euphemia-Public-Description.pdf

[12] M. Grzanic, M. G. Flammini, G. Prettico, “Distribution Network Model Platform: A First Case Study, ” Energies 2019, 12, 4079.

[13] G. Viganò, M. Rossi and D. Moneta, “Generation of artificial distribution networks for the evaluation of advanced control solutions, ” 2017 AEIT International Annual Conference, Cagliari, 2017, pp. 1-6

This is the accepted version of an article published in 2020 55th International Universities Power Engineering Conference - UPEC
http://dx.doi.org/10.1109/UPEC49904.2020.9209784