REVIEW OF TRANSMISSION AND DISTRIBUTION INVESTMENT DECISION MAKING PROCESSES UNDER INCREASING ENERGY SCENARIO UNCERTAINTY

Federico SILVESTRO
University of Genova
Italy
federico.silvestro@unige.it

Fabrizio PILO
University of Cagliari
Italy
pilo@diee.unica.it

Juan Carlos ARANEDA
Coordinador Eléctrico
Nacional Chile
juan.araneda@coordinador.cl

Martin BRAUN
Fraunhofer Institute
Germany
martin.braun@iee.fraunhofer.de

Jason TAYLOR
EPRI
USA
jtaylor@epri.com

Marie-Cecile ALVAREZ-HERAULT
University of Grenoble Alpes
France
marie-cecile.alvarez@g2elab.grenoble-inp.fr

Fabian HEYMANN
INESC TEC
University of Porto - Porto
fabian.heymann@fe.up.pt

ABSTRACT

This paper presents an overview of how transmission and distribution planning scenarios are consistently used to ensure holistic investment decision-making by TSOs and DSOs. The investigation is in the context of growing uncertainty in future energy scenarios due to increasing distributed energy resources (DER), electrification of transport, interconnection, consumer heating, global emissions targets, etc.. This paper aims at addressing the following issues: 1) describe current practices on considering and modelling uncertainties, and risk management in generation, transmission, distribution and demand sides; 2) review the investment decision making processes for transmission and distribution, 3) derive joint learnings and recommendations associated to optimal investment decisions under uncertainties – from distribution to transmission and vice versa. Research gaps are identified requiring further investigation. Finally, this contribution is ideal input to a worldwide potential survey on transmission and distribution planning under uncertainty.

INTRODUCTION

The significant increase in Distributed Energy Resources (DER) integration, interconnection with other grids, and utilization of Smart Grid technologies makes transmission and distribution system planning more challenging than in the past [1]. Particularly, it requires a stronger integration of TSOs and DSOs planning processes due to the stronger integration of both systems [2]. Indeed, the new structure of power system with increased generation and flexibility allocated at distribution level further narrows the boundary between transmission and distribution across both planning and operation [3].

Expansion plans that do not properly consider the mutual interactions between transmission and distribution systems might be far from techno-economic optimality, with possible negative consequences in terms of reliability, resiliency or operational costs. Nowadays users' measurements and data are available at both TSO and DSO level, including active power exchange measurements, load and generation data and interconnection capability data, which could be used to find robust plans with efficient resource allocation through an appropriate data exchange methodology and IT architecture [4], [5], [6].

Furthermore, transmission and distribution investment decisions resulting from a planning process require new approaches to deal with growing uncertainties on many parameters including new electricity market frameworks, penetration and availability of DER, demand growth and flexibility or climate change among others [7].

The paper reviews methodologies and practices applied by TSO and DSO in developed and developing countries, with particular attention to the proper consideration of uncertainties and the creation of joint or integrated expansion plans for transmission and distribution. In this contribution, we will especially focus on the synthesis of previous learnings from major, power system research-oriented institutions.

In the final section, preliminary outcomes from a survey performed by a Joint Working Group (JWG) of CIGRE C1.C6.37/B5/CIRED are presented. The survey participants include TSO and DSO across the globe and an overview of the survey tool is also provided here. The intent of this paper, and the working group, is to provide the international community a useful point-of-reference concerning the emerging discussion on uncertainty management in modern power system planning.

UNCERTAINTY IN TRANSMISSION AND DISTRIBUTION PLANNING

Key elements of transmission and distribution network planning are provided in this section. Uncertainty sources will be enumerated, and frequent model approaches present in the power industry addressed, see Figure 1 [8].

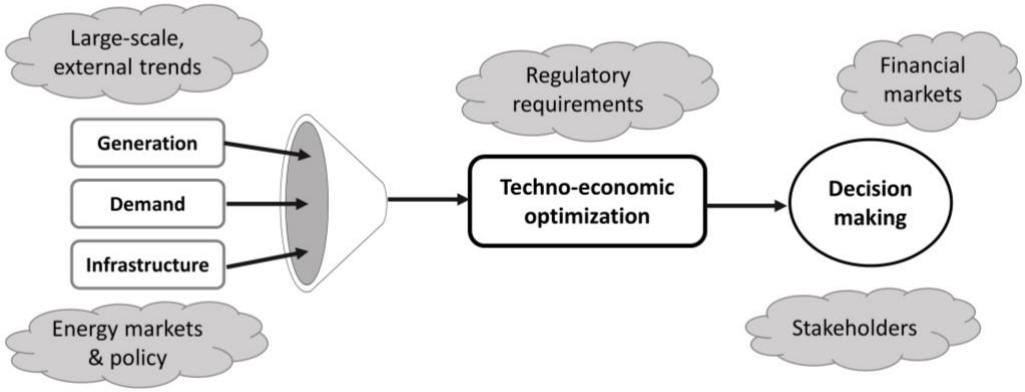

Figure 1-Uncertainty sources in T/D planning and investment decisions

Planning Practices

Transmission system expansion planning usually adds new transmission lines or reinforces old connections and substations at lowest possible cost. Under deregulated market frameworks, transmission planners are deemed to facilitate wholesale market access and promptly connect supply to loads. Investments are carefully weighted as components are capital intensive and may be in use over 40 years and more. Upfront negotiation and licensing periods of up to 10 years are typical. In regulated markets, the transmission expansion problem (TEP) consists of minimizing investment costs while assuring to meet demand and reliability constraints.

Traditional distribution system planning, on the other hand, prioritizes system reliability and safety for all consumers, providing service under reasonable cost. Capital investments focus on serving additional load growth (both green space as well as per capita) as well as system upgrades intended to improve system reliability.

Planners and operators use a wide array of tools. Such tools might include load and generation forecasts, fuel, credit and CO_2 cost forecast, and circuit-based tools – such as power flow analysis, fault analysis, power quality analysis, dynamic behavior analysis, and advanced optimization among others. In many cases, these tools were developed to support planning studies that tended to be deterministic in nature. However, this may change as the degree and nature of uncertainties continue to increase.

While commonalities exist between transmission and distribution planning, uncertainties can influence each different given inherent characteristics of each system. Some of these characteristics is summarized in Table 1. In general, transmission planning is concerned with fewer components when compared to distribution planning.

Additionally, distribution level assets tend to serve

relatively fewer customers meaning some types of uncertainty may be higher when planning at this level. Still, transmission system planners need to perform planning studies for much longer planning horizons, given the lead-times associated with transmission system upgrades, which also acts to increase uncertainty when comparing planning across the two levels of the system.

Table 1. General system characteristics influencing planning under uncertainty

	Transmission grid	Distribution grid
Primary drivers of system expansion	• Non-discriminatory access provision • Reliability • Reduce congestion • System stability constraints	• Non-discriminatory access • Reliability • Thermal and voltage constraints
Forecast horizon	15-20 years	10-15 years
Spatial forecast granularity	5 – 10 km²	0.25 – 2.5 km²
Typical number of customers served by primary assets	Billions to hundreds of thousands	Tens of thousands to single loads
Load flow	Balanced three-phase	European inspired : balanced in MV and unbalanced in LV and north American inspired unbalanced
Investment cost per component	Relatively high	Relatively high
Commissioning process	Single projects with public hearings, env. impact assesses. and regulatory approval	Aggregated asset evaluation or indirect rate case evaluation by regulatory authority

Differences between the cost of individual projects, along with the number of assets to be examined, also drives

differences in overall planning practices, project selection, and commissioning process that may or may not be influenced by changing uncertainties. In any case, the reconciliation or coordination of planning studies and decisions across both levels might reduce uncertainties in both.
Within the restructuring of power systems (unbundling & decentralization) in many countries and a dynamic uptake of renewable, sometimes mainly dispersed, power generation, several new uncertainty sources appeared. According to [9], such can be grouped into:

- Fossil fuel price uncertainty
- Environmental regulation & energy policy uncertainty
- Load forecast uncertainty
- Renewable power generation forecast uncertainty
- Cost evolution of power system components
- Distributed generation and storage business model evolution uncertainty

Alongside such developments, risks have shift from fuel price risks to market price risks for most system planners. Furthermore, customer behaviour is also introducing new forms of uncertainty – especially at the distribution levels – such as the level of future adoption of DER and other technologies as well as participation in incentive programs or third-party aggregators.

Modelling Uncertainty and Other Challenges

In transmission and distribution planning, uncertainty has been traditionally captured two-fold [9]:

1) Through scenarios (that may represent different load & generation portfolios)
2) Through sensitivities (that analyse changes in the key variables and the effect on final outcomes)

Many network planning units consider both dimensions in a two-staged process. While first, network expansion requirements are estimated using renewable/ conventional generation capacity extensions, operational aspects and cost analysis is conducted in the simulation part of the second stage. Sometimes, sensitivities are modelled relying on computational-heavy tools such as Monte-Carlo simulations that allow to compare a high number of scenarios with probability theory.

In a recent study [7], the Electric Power Research Institute (EPRI) presents a list of 10 most pressing large-scale challenges to electric power system planners. Such are listed below:

1. Incorporating operational detail
2. Increasing modeling granularity.
3. Integrating generation, transmission, and distribution planning
4. Expanding analysis boundaries and interfaces.
5. Addressing uncertainty and managing risk
6. Improve forecasting
7. Improving modeling of customer behavior and interaction
8. Incorporating new planning objectives and constraints
9. Integrating wholesale power markets
10. Supporting expanded stakeholder engagement

Interestingly, many of the aspect above relate directly (Point 5) and indirectly (Point 1, 2, 4, 6, 8, 9 and 10) to the representation and modelling of uncertainty and their impact on decision making and investment risk.

In the survey that is presented in the following sections of this paper, an attempt to further differentiate uncertainty sources (e.g. along technologies and time horizons) will be presented.

PRELIMINARY OUTCOMES OF A GLOBAL SURVEY ON RISK MODELING IN T/D

A Joint Working Group (JWG) of CIGRE C1.C6.37/B5/CIRED has been organized in order to work on the regulatory and market mechanisms that need to be in place to facilitate a common planning approach and, hence, effective interactions between TSOs and DSOs.
In particular the WG has created and disseminated a survey to gather information regarding TSOs and DSOs around the world to know the current state-of-the-art in planning procedures at TSO/DSO interface.

The survey is part of the working program that includes the following areas:

- Review of previous CIGRE/CIRED WG and JWG and Regulatory framework for investments in transmission and distribution
- Survey on transmission and distribution methodologies for planning under uncertainty
- Transmission and distribution methodologies for planning under uncertainty
- Transmission and distribution investment decision-making processes and how coordination among them is done

This section gives an overview of the methodology used to gather information on the actual policy and future plans among TSOs and DSOs for the planning activities. The survey results have been analyzed, feeding into the other areas for further analysis. The results of the questionnaire

act as a benchmark against which the transition towards active distribution systems may be assessed.

Survey Instrument and Topics

The WG developed a questionnaire to make inquiries about current planning methods and tools of transmission and distribution networks. The next step is to collate the answers of the energy companies into national reports. The survey has investigated the current planning studies that are performed by the operators through 44 questions. The main topics concern:

- Statistical information about the company,
- Planning scope (horizon and responsibility),
- Scenarios, uncertainties and decisions,
- Regulatory regime of network investment remuneration,
- Scenario and decisions,
- Barriers/tools for the exchange of information between TSO and DSO planning.

Overview of questionnaire results

To date, 37 survey responses have been received (60% of DSOs and 40% of TSOs/ISOs), representing a number of different energy companies in the geographical regions of Oceania (4), North America (4), South America (5), Western Europe (16) and Asia (8). A binary analysis has been used to evaluate the questionnaire responses and to determine the extent to which probabilistic studies are carried out, at present, in the electrical industry.

Planning principles and integration of uncertainties

Preliminary results coming from the on-going survey are showing that DSOs across the world are conducting probabilistic studies using a scenario-based approach with very few scenarios as depicted by Figure 2. About 60% of the companies are using less than three scenarios which mainly rely on self-generated statistics.

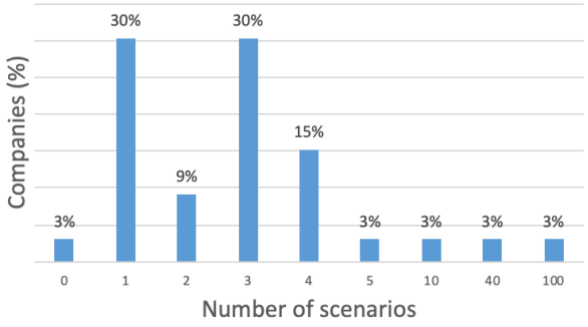

Figure 2 -Scenarios for planning studies adopted

These ones take into account the economic development of the country, the weather and natural hazards, socio-demographic indicators and regulatory or policy changes over a planning period of 10 years (for about 46% of the companies). 20% of them consider a planning period over 15 years and 15% lower than five years. These master plans are update almost every year.

Among the new technologies and new ways of managing the network, the key features that are more important for DSOs are the impact of demand response (i.e. active network management), electric vehicles, and electrification of heating systems as reported in Figure 3. Regarding the penetration of renewable energy resources (RES), about 70% of the companies already integrate the forecasted share of RES to peak load and their location in the system.

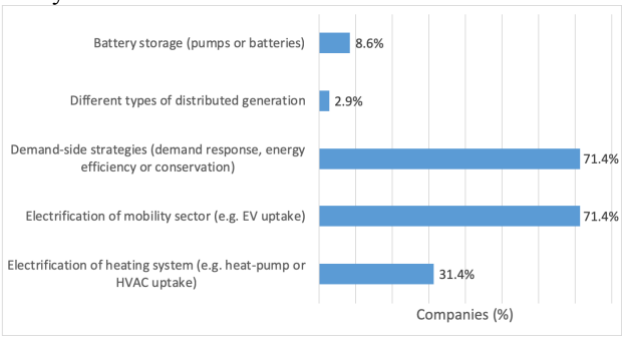

Figure 3 – The Technologies for planning studies

Further it is evident the main significant assumption is still load growth as reported in Figure 4 because it was historically the main variable which impacts grids expansions

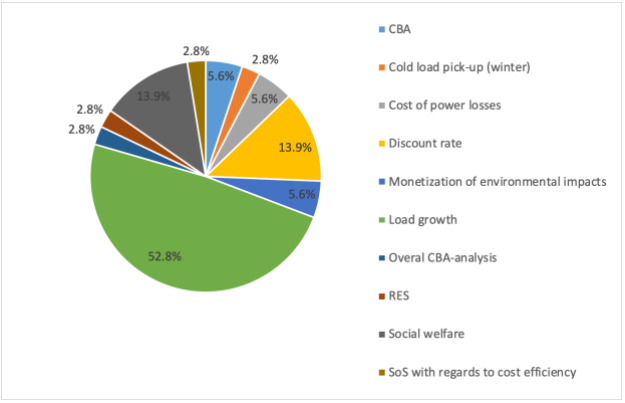

Figure 4 - Decision making drivers

DSOs, TSOs and ISOs planning interaction

A majority of the TSOs and DSOs report the use of combined studies between TSOs and DSOs – more than 80%. Across this majority, an equal number of participants plan both the transmission and distribution or just one or the other. Thus, the preliminary number due not provide a conclusive result on whether combined studies are more likely for vertically integrated utilities or not.

In any case, the current practices among operators that is evident from the preliminary information coming from the survey is that there is still a lack of transparency and standards to exchange information which are based on informal meetings or reports. Figure 5 shows that the main information exchanged are for 80% of the companies load

scenarios, for 50% production scenarios and for 20% methodology and costs.

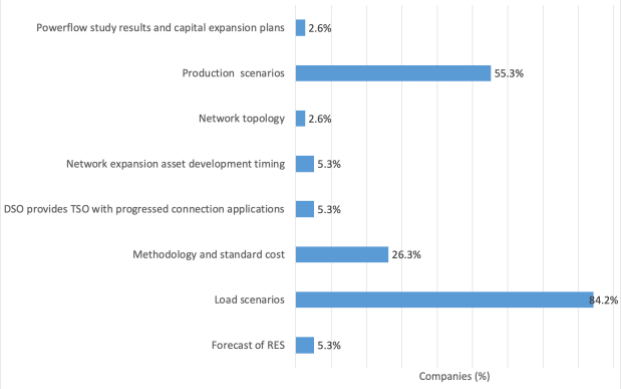

Figure 5 - Information exchange among TSOs and DSOs

In some countries, these interactions can be complicated when the ISO/TSO interface with a high number of DSOs. The DSOs/TSOs consider that reliability, RES penetration, cost and losses are relevant drivers at their interface.

SUMMARY AND NEXT STEP

This work is part of the Joint Working Group (JWG) of CIGRE C1.C6.37/B5/CIRED. Its team is currently working towards a technical brochure, which will draw together the international perspectives and experiences when dealing with the planning for electricity distribution networks of the future.

Preliminary results coming from the on-going survey is showing that TSOs and DSOs among the world are conducting different probabilistic approach to manage the growing uncertainties and the new capabilities that current and future automation allow to build and design more active electricity networks.

The WG will explore the current methodologies that are applied from TSOs and DSOs to deal with the growing uncertainties. In particular the focus will be on the ability to integrate RES uncertainties in a global approach for TSO/DSO exchange. Further it is investigating the evolving requirements of operators for a clearer and robust decision-making procedure. In fact, transmission and distribution investment decisions resulting from a planning process require new approaches to deal with growing uncertainties on many parameters including new electricity market frameworks, penetration and availability of DER, demand growth and flexibility, climate change, etc.

CONCLUSION

This paper has presented an overview the methodologies and current challenges that relate to planning and optimization of electrical distribution and transmission systems. The following issues have been addressed: 1) current practices on considering and modelling uncertainties, and risk management in generation, transmission, distribution and demand sides; 2) transmission and distribution planning under uncertainty and distributors' evaluation of recommendations on planning under uncertainty; 3) review of investment decision making processes, for transmission and distribution, in different jurisdictions and how coordination among them is done; 4) The extraction of research gaps that can are consecutively fed into an online survey. That way, this article built the foundation to foster joint learnings and recommendations associated to optimal investment decisions under uncertainties – from distribution to transmission and vice versa.

REFERENCES

[1] K. Bell, "Methods and Tools for Planning the Future Power System: Issues and Priorities," Model. Requir. GB Power Syst. Resil. Dur. Transit. to Low Carbon Energy, no. Paper 5, pp. 1–35, 2015.

[2] ICF, "Integrated Distribution Planning," 2016.

[3] JWG C1.29 "Planning criteria for future transmission networks in the presence of a greater variability of power exchange with distribution systems" (Brochure 681, March 2017)

[4] Working Group C6.19, "Planning and Optimization Methods for Active Distribution Systems". August 2014.

[5] Li R, Wang W, Chen Z, Jiang J, Zhang W. A Review of Optimal Planning Active Distribution System: Models, Methods, and Future Researches. Energies. 2017; 10(11):1715.

[6] THEMA Consulting Group, "Data Exchange in Electric Power Systems: European State of Play and Perspectives," Oslo, 2017.

[7] EPRI, "Developing a Framework for Integrated Energy Network Planning (IEN-P)," Palo Alto, California, 2018.

[8] F. Heymann, J. Melo, P. D. Martínez, F. Soares, and V. Miranda, "On the Emerging Role of Spatial Load Forecasting in Transmission / Distribution Grid Planning," in *11th Mediterranean Conference on Power Generation, Transmission, Distribution and Energy Conversion*, 2018.

[9] F. Kahrl et al., "The Future of Electricity Resource Planning," Report n. 6, Lawrence Berkeley National Laboratory, 2016.