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The new challenges to transmission expansion planning. Survey of recent practice and literature review

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ABSTRACT

Transmission Expansion Planning (TEP), the problem of deciding the new transmission lines that should be added to an existing transmission network in order to satisfy system objectives efficiently, is one of the main strategic decisions in power systems and has a deep, long-lasting impact on the operation of the system. Relatively recent developments in power systems, such as renewable integration or regional planning, have increased considerably the complexity and relevance of this problem. This is particularly true in the case of the European Union. These issues have motivated the appearance of a vast array of projects that propose specific development plans for the required transmission, together with academic literature that deals with the different theoretical aspects of the problem. It seems, therefore, pertinent to review these recent works and put them into context.

This paper performs a critical review on TEP focusing on its most recent developments. It analyzes the current challenges to transmission planning and illustrates them with some instances of TEP in a European context. Then, it proposes a taxonomy of modeling decisions and solution methods for this problem, linking them to some of their main representative works in the literature with an emphasis on the most recent advances. These alternatives are critically compared, providing with insights that can guide researchers or practitioners when undertaking this kind of studies.

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1. Introduction

Electric power transmission is the long-distance transfer of electricity from generation plants to substations. From these substations, electricity is subsequently delivered to consumers through the distribution network. The transmission grid is therefore the basic infrastructure that enables the large physical power flows that make the power system possible. It imposes physical constraints to the power flows that traverse it (Kirchhoff's Laws) and therefore to generation and demand. The main consequence of this is that not all dispatch solutions are feasible. Consequently, Transmission Expansion Planning (TEP), that is, "deciding which new lines will enable the system to satisfy forthcoming loads with the required degree of reliability" [1], is one of the key strategic decisions in power systems. Table 1 provides some context on the decisions that concern the transmission network, with TEP being one of the most important, highest-impact problems .

Transmission investments are very capital intensive and have extremely long useful lives (of up to 40 years), so transmission investment decisions have a long-standing impact on the power system as a whole. This is reflected on the relatively large sums dedicated to this purpose: for instance, ENTSO-e members have a joint budget over EUR 100 bln for their 2012–2022 investments [2].

This long-term impact on the power system is particularly relevant for the integration of new generation. In some cases, it is only necessary to connect a new power plant to a nearby node, which is relatively inexpensive compared to the long-distance connections and wide-range reinforcements that are required when generation is located in remote areas. The later case is increasingly relevant given that renewable generation largely determines its location based on the availability of the resource, particularly wind and solar, which often abound in remote areas far away from the main demand centers.

In addition, the European Union has set very aggressive emission reduction targets, establishing a 20% reduction in greenhouse gases with respect to 1990 levels by 2020 and endorsing an objective of 80% reductions and 100% clean electricity by 2050 [3,4]. Although considerable amounts of renewable power have been installed in the past couple of decades, most of the member countries are still far from meeting these targets [5]. Therefore, vast amounts of new generation are expected to be built in the medium-term future. These ambitious projects depend critically on the transmission network to integrate the new generation. The necessary expansion can emerge in the form of isolated reinforcements, an extensive HVDC overlay to the existing network or an entirely new grid. The latter case, known as *greenfield expansion*, applies to the particularly interesting case of offshore grid design, where no existing network can be used as the starting point for the developments.

The design of large-scale network expansions poses considerable challenges that have been addressed in a vast array of both projects and academic literature. Existing reviews on this topic can be found in references [6,7]. However, the current context of the problem, together with the extension of the recent works, makes it interesting to review it again. This paper contributes to the literature with the following:

- A high-level perspective of the present conditions for practical TEP problems and the challenges they face. Given its special interest, we will focus on a European context. However, most of the issues have a more general scope of application.
- A review of some of the most interesting instances of TEP carried out in the recent past, highlighting the scope of each study and its main features.
- A taxonomy of modeling decisions and solution methods for this problem, linked to some of their main representative works in the literature, with an emphasis on the most recent works.
- A critical evaluation of these modeling decisions and solution methods. These alternatives are compared in the light of the type of problem under consideration.

This article, therefore, has the final aim of providing the reader with an overview of the problem and its current circumstances, together with comments that have the aim of serving as a guide to select appropriate modeling features and solution methods.

This paper is structured as follows. First, Section 2. discusses the current challenges to TEP, which are illustrated with recent project examples in Section 3. Then, Sections 4 and 5. describe the main modeling choices and solution approaches. Finally, Section 6. extracts conclusions.

2. The new challenges of transmission expansion planning

Having such a deep impact on the power system as a whole, it is not surprising that TEP has been studied in an academic context for decades. In addition, it has long been recognized that the uncertainties present in the problem, together with its combinatorial nature, constitute a considerable burden to its resolution [8]. However, relatively recent changes have substantially increased this complexity. This is particularly true in the case of the European Union, as will be explained below. Because of this, this paper takes a predominantly European focus, but it should be stressed