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A discrete evolutionary PSO based approach to the multiyear transmission expansion planning problem considering demand uncertainties

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ABSTRACT

This paper presents a multiyear dynamic model to the Transmission Expansion Planning, TEP, problem to identify the most suitable set of projects as well as their scheduling along the planning horizon. The candidate plans are evaluated using a fitness function that incorporates operation and investment costs plus a set of penalty terms. These terms are associated with the level of losses, non-zero values for the power not supplied namely for the entire system and for $n-1$ contingencies, financial limits, maximum number of projects to implement in each year or all along the horizon and the capability to accommodate not only the expected demand, but also uncertainties affecting the demand forecasts. Given the discrete nature of the problem, we adopted an enhanced approach of the PSO algorithm to solve it. This includes an evolutionary adaptation of the PSO movement rule as well as several modifications to ensure that along the iterative process each candidate solution is technically feasible given its discrete nature. The paper also reports the results of a set of tests to evaluate several design decisions related with the development of the Discrete Evolutionary PSO, DEPSO, as well as to compare the results of its application to the TEP with results reported by other researchers.

1. Introduction

In the last 25 years power systems in several countries and geographic areas went through a restructuring process that involved the unbundling of traditional vertically integrated utilities in a number of activities covering the entire value chain from generation to consumption. These activities correspond to generation, transmission and distribution network operation, and retailing together with coordination activities, regarding the technical operation of the system, regulation and whole sale market functions. The unbundling of traditional utilities induced a large number of changes including the introduction of market mechanisms to link the generation and the demand, namely through Market Operators and Bilateral Contracts [1]. In general, this move also implied the development of regulatory mechanisms regarding transmission and distribution network activities (involving the expansion and network reinforcement, the operation and the maintenance) and the correct identification and assignment of all the costs along the value chain. This allows developing tariffs for each activity along the chain and then, using an additive principle, the creation of access tariffs and tariffs paid by final users that adequately reflect the costs each agent brings to the system.

Apart from the changes summarized above, for several years after the beginning of the restructuring process a large emphasis was put on shorter term activities, sometimes neglecting long term planning, in some cases with unpleasant consequences. However, long term studies both at the generation [2] and at the transmission [3] levels continue to be necessary as it is demonstrated by several recent publications, on one side, and by the plans to build a super transmission grid in Europe, on the other. In any case, there has been a change in the models as now generation and transmission agents correspond to different activities and entities. The first one is provided by several competing agents while the second one is typically assigned to a transmission provider or to a Transmission System Operator, TSO, that acts in terms of a regulated natural monopoly, regarding each geographic area. In the past, generation, transmission and distribution were included in the same utility so that long term forecasting and expansion planning activities were developed in a more integrated and centralized way. Now, each generation company develops its own expansion plan taking into account the possible reactions of its competitors and transmission companies should have estimates of the demand evolution and of the possible generation additions in order to prepare expansion and reinforcement plans.

As a result of this unbundling, the TEP problem gained a new complexity degree as the information at the generation and at the demand levels are more uncertain than in the past. In very general terms, a TEP problem aims at determining the timing, the type

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and the location of a set of new transmission facilities that should be added to an existing network along an extended planning horizon in order to ensure an adequate transmission capacity taking into account future generation options and load requirements. Regarding this definition, it is important to make a number of clarifications:

– On the legal and regulatory side, the European Parliament and the European Council approved the Directive 2009/72/CE, establishing common rules for the internal electricity market [4]. TEP is clearly identified as a major responsibility of TSOs, given that they should ensure the long-term ability of the system to meet reasonable demands for the transmission of electricity. On the other hand, the EU Commission Regulation No. 838/2010 of September 23rd 2010, defined the guidelines to the inter-transmission system operator compensation mechanism associated with cross-border electricity flows, to be carried out by the Agency for the Co-operation of Energy Regulators. This ultimately means that transmission providers and TSO's should adequately develop their networks so that they are prepared to accommodate reasonable new generation and demand requirements.
– Secondly, given the complexity of the TEP problem, several researchers developed models that introduced simplifications at two levels as follows:
  • In the first place, an extended planning horizon was frequently addressed in a static way, that is, each year in the horizon was treated separated and in sequence, so that the final expansion plan was just a collection of partial plans. This type of approach eliminates the holistic view over the problem given that a particular expansion project justified to address a particular network bottleneck could very well be anticipated in order to address some other network problems given the meshed nature of transmission networks. This means that a multiyear expansion plan is not just the addition of partial plans identified in sequence. The expansion plan should be built using an holistic model that treats the entire planning horizon at a time.
  • On the other hand, several researchers simplified the problem using continuous variables to represent the transmission capacity between a pair of nodes. Although computationally more efficient, these continuous versions of TEP will lead to solutions that are not implementable from a technical point of view, given the available conductor sections and voltage levels. This ultimately means that at the end a rounding process was typically used eventually turning the final rounded solution far away from the optimum of the true discrete TEP problem.
– Thirdly and perhaps more than in the past, long term expansion activities are subjected to uncertainties that can now be considered as key elements of any planning process [5]. An expansion plan should be good not only for a reference scenario regarding both the evolution of generation and demand but should also be robust if some changes on this reference evolution happen in the future. This means for instance that the demand can be subjected to uncertainties and that an increasing part of generation is now connected to distribution networks and it is powered by volatile primary resources. In this way, transmission networks should be prepared to accommodate the connection of new generators, uncertain demand as the current economic crisis is showing and the injection of electricity by distribution networks in case the connected distributed generation is larger than the demand of these networks.

As a result of all these concerns, this paper details a multiyear dynamic mathematical model to the TEP problem. The problem is formulated as a single objective discrete optimization problem and it represents all the years or stages in which the planning horizon is discretized. The adopted objective function aims at minimizing the operation plus investment costs along the planning horizon subjected to a number of constraints having technical and financial natures. Given its mixed integer nature, we developed a set of adaptations to the Evolutionary PSO algorithm, in order to turn it more adequate to treat discrete problems. On the other hand, the demand can be subjected to uncertainties modeled by triangular Fuzzy Numbers [6]. This framework is used to evaluate each candidate plan characterizing the risk of eventually not being able to supply the demand subjected to uncertainty. This information is then integrated in the fitness function of the Discrete Evolutionary PSO, DEPSO. According to these ideas, this paper is structured as follows. After this initial section, Section 2 reviews the literature addressing the TEP problem, Section 3 addresses load modeling using Fuzzy Sets, Section 4 details the PSO and the EPSO algorithms and the adaptations in terms of the DEPSO, Section 5 presents the mathematical formulation of the TEP problem and the developed solution algorithm and Section 6 presents results of two Case Studies to illustrate the approach and to compare the obtained results with the ones reported by other researchers for the same networks. Finally, Section 7 presents the most relevant conclusions.

2. Review of transmission expansion planning models

Traditionally the expansion planning of transmission networks was addressed in an integrated way with generation expansion planning as detailed in [7]. More recently, integrated generation/transmission expansion planning approaches continue to be reported in the literature, namely considering geographical areas in which the unbundling of the sector was not implemented [8,9]. Under this more traditional and integrated view, it is important to consider that there were approaches that could be used to build expansion plans considering an extended amount of data and forecasts into the future, as well as several software packages designed to evaluate pre-built plans namely computing reliability, transient behavior or stability indices. Typically, these packages were developed by utilities or in research centers closely related with them.

With the advent of the unbundling of the power sector, transmission companies or entities responsible for the preparation of reference transmission expansion plans started to use external information namely related with the construction of new generation stations, the development of distribution networks as demand increases, the increased number of dispersed generation namely connected to distribution networks including recently to LV networks, and the variability of several primary generation resources as wind and solar radiation. In view of these changes, the TEP problem gained new dimensions and it can now be defined as the selection of a set of new transmission equipments (both lines and transformers) and the scheduling of their commissioning along an extended planning horizon. This selection is driven by a criterium or by a set of criteria in case of multi objective approaches [10,11] while enforcing a number of constraints. With the restructuring of power systems, the TEP problem that was already a complex mixed integer optimization problem has to meet new challenges given that:

– More than one entity owns generation assets and the capacity of transmission lines can determine the degree to which generators in different locations can compete.