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A novel efficient method for multiyear multiobjective dynamic transmission system planning

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ABSTRACT

The unbundling of the electricity sector in several activities, some of them provided in a regulated way and some others under competition, poses a number of challenging problems namely because in several areas there are conflicting objectives associated to different stakeholders. These different views and objectives paved the way to the development of new multiobjective tools able to represent this new paradigm. In this scope, this paper presents a multiobjective (MO) formulation for the Transmission Expansion Planning (TEP) problem using a new solution approach that combines concepts of evolutionary computation and multi agent population algorithms. The new proposed tool is termed as Multi-Population and Multiobjective Evolutionary Particle Swarm Optimization - MEPSO-II. The TEP problem is handled in a realistic way preserving the holistic view over the entire planning horizon and the true grid behavior because it considers the multi-stage nature of the problem and we use an AC Optimal Power Flow (AC-OPF) model to gain insight on the operation conditions of the network. The multi objective formulation considers the total system cost, on one side, and the Expected Power Not Supplied (EPNS), on the other. The total system cost comprises the investment cost in new equipment and the operation costs while the EPNS takes into account the uncertainties related to the non– ideal behavior of system components using a non-chronological Monte Carlo simulation. Numerical simulations are conducted using the IEEE 24 and the 118 Bus Test Systems in order to compare the proposed MO tool against other algorithms through performance evaluation indices. Although being a higher time-consuming tool, the MEPSO-II enables improving the Pareto-Front and therefore it gives more insight to transmission network planners when compared with other consolidated algorithms described in the literature.

1. Introduction

1.1. Motivation

Transmission grid expansion planning is becoming increasingly complex due to the unbundling and restructuring of the electricity sector as well as due to environmental concerns. The unbundling of the electricity business leads to multiple and conflicting objectives associated to different stakeholders and extra financial and physical uncertainties [1]. The growing environmental concerns widened the path to the large-scale use of renewable primary sources, several of them characterized by their intermittency, that have been gaining more and more space in the global energy matrix. A large amount of these units is connected to distribution networks or even at the end user installations contributing to modify the traditional generation-transmission-load patterns to be considered in transmission planning studies. The restructuring of the global power industry contributed to change long term established planning practices, since investors in generation are free to decide when and where to invest in new facilities and the presence of generation sources using volatile resources as wind and solar units introduced new types of uncertainties in planning problems. These changes turned less adequate traditional planning approaches only based on the identification of the lowest investment cost expansion strategies and plans.

As an answer to these changes, in recent years new multiobjective models and solution approaches as the ones in [2–4] were developed instead of considering just one objective as in classical optimization approaches. Nevertheless, TEP has some peculiarities that contribute to turn the development of new tools more difficult such as [5]:

- Non-convex search space, so that solution algorithms may converge to local optima.
- Integer nature leading to the phenomenon of combinatorial explosion of investment alternative plans. This characteristic usually requires a high computational effort to identify good quality plans.
- In some cases, there are isolated smaller systems that should be

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Nomenclature

Indices

b	index for bus
eq	index for equipment
i	index for individual
it	index for iteration
k	index for the weights for the MEPSO-II tool
p	index for period
st	index for system states
$*$	index for mutated parameter

Parameters

nb	number of buses
neq	number of equipment
d	discount rate
FOR	forced outage rate
np	number of periods
Nst	number of system states
OF	objective function
P	communication factor
T_{eq}^{com}	commissioning time
β	penalization factor for PNS

Variables

C_{inv}, C_{op}	investment and operation costs
D	distance between consecutive solutions
Dm	mean of all D
e, ER	error ratio parameter and Error Ratio
ed	Euclidian distance
$EPNS$	Expected Power Not Supplied
$gbest$	best solution found by the swarm
GD	general distance
K	coefficient of present-worth value.
npf	number of solutions in each Pareto-Front
n_{kj}	inserted equipment between bars k and j
$\overset{o}{n}_{kj}$	equipment on the base topology (between bars k and j)
N	diagonal matrix containing n_{kj}
$\overset{o}{N}$	diagonal matrix containing $\overset{o}{n}_{kj}$
$pbest$	best solution found until the current iteration
PF	Pareto-Front
PFR	Pareto-Front rate
P_D, Q_D	real and reactive power demand vectors
P_G, Q_G	real and reactive power generation vectors
PNS	Power Not Supplied
r	number of clones in the MEPSO-II tool
$rand()$	random number between 0 and 1
$round()$	rounding operator
S	apparent power
U	equipment availability
v	particle velocity
V	voltage magnitude vector
w	weights for the MEPSO-II tool
x	particle position
θ	bus angle
δ	equipment investment state
ε	uniformly distributed random number
α_b	variable used in the AC-OPF model to represent the load shedding in bus b

Sets

Ω	set of candidate equipment

connected to the main system and this can originate convergence problems.

Having in mind these difficulties and challenges, the research work reported in this paper describes a new efficient methodology capable of dealing with the mentioned drawbacks and considering the following characteristics:

- Multi-year nature that can accurately represents the multi-stage characteristics of investment decisions.
- True mathematical representation of the network using an AC formulation.
- Multiobjective formulation and solution approach.
- Uncertainties inherent to the long-term planning problems.

1.2. Literature review

The multiyear (or dynamic) nature of TEP problems requires considering in the same run several sub-periods over the planning horizon in order to identify a set of new equipment (transmission lines, cables or transformers) with the respective insertion times on the grid as described in [6,7]. This nature brings the benefit of preserving the holistic view over the planning horizon, but it also increases the computational burden of the problem in a way that it can become prohibitive. Up to now, dynamic TEP is performed just in small case studies that do not correspond to real systems [8]. Therefore, the TEP problem is often addressed in a simplified way also known as static approach as in [9–11]. In these cases, each period is treated separately and sequentially so that investments selected in one period will then be considered in operation in the next ones.

In order to further reduce the computational burden, the mathematical model of the TEP problem can also be relaxed using, for instance, the DC power flow model. This relaxation turns the TEP problem more manageable as suggested in [12]. Although this was a widely used approach both in academia and industry, this type of models does not guarantee that the optimum solution of the modified (relaxed) problem is feasible regarding the real problem. Furthermore, TEP DC and AC formulations were compared in [13,14] and the results indicate that the TEP using DC models often provide underestimates for the grid investment costs and additionally the associated expansion plans can produce violations of the true AC grid constraints. Differently from the DC based models, TEP AC models take into account the reactive power, the losses and the voltage limits on the bars, turning these models more adequate to reflect in a realistic way the operation conditions of the network [15].

The restructuring of the electricity sector brings additional challenges to transmission planers once TEP models should be able to meet the goals of different stakeholders as, for instance, improving the competition among electricity market agents, alleviating transmission congestion, minimizing the risk of investments, minimizing the investment and operation costs and maximizing system reliability [16]. Multi-objective (MO) approaches can provide information about the tradeoff between different conflicting objectives since MO problems do not have a single optimal solution, but they are typically associated to a set of non-dominated solutions – the Pareto-Front [17] among which the final decision should emerge. In this context, evolutionary