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Improved cost–benefit analysis for market-based transmission planning, a European perspective

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HIGHLIGHTS

- Consideration of environmental policy in the decision of transmission expansion plans.
- Semi-dynamic heuristic approach including societal, economic and availability standards.
- Market-based approach using nodal pricing.
- The amount of reduced unserved load is not equal to the amount of capacity increase of a line.
- Less environmental costs lead usually to higher congestion costs due to overly power trading.

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ABSTRACT

This paper addresses the problem of transmission planning in interconnected power systems under the uncertainty of future generation parks and fast varying marginal production costs. The decision maker has to consider many different aspects during the definition of different transmission planning strategies that sometimes might even be contradicting. Major contributions are the incorporation of energy policy measurements in the evaluation process of candidate transmission plans and the inclusion of short- and long-term uncertainties. The proposed methodology, so-called C-TRAP, is based on a semi-dynamic heuristic approach that solves the social welfare maximization problem for several discrete steps considering different preferences for energy policy and transmission network reinforcements. The flexibility provided through the heuristic analysis is very important for decision makers in the new uncertain environment in power systems.

1. Introduction

In the present fast evolving changing power systems environment many uncertainties appear. Thus, the transmission planning becomes more and more an exercise where many aspects have to be considered. On the way to a sustainable future power system the combination of environmental requirements, market structures, future generation and demand and network transmission capability is of vital importance.

So far, the transmission network planning process has been identified as multi-criteria, multi-objective, multi-stage process (Alseddiqui and Thomas, 2006; Escobar et al., 2004), while no environmental aspects have been considered and only few information is given specifically for the European interconnected system and its characteristics as a whole. In previous work (Papaemmanouil et al., 2010) generation and transmission models have been combined in a cost–benefit analysis in order to evaluate potential transmission expansion plans in the European interconnected system. Short-term indicators, i.e. avoided environmental costs (AECs) and avoided congestion costs (ACCs) due to additional transmission capacity had been compared to transmission lines investment costs. However, in this work long-term aspects, a detailed description of the identification of proposed candidate lines and an indicator for system adequacy analysis were missing. This paper comes to fill this gap, proposing an integrated

Abbreviation: ACCs, Avoided Congestion Costs; AECs, Avoided Environmental Costs; AULCs, Avoided Unserved Load Costs; CBA, Cost–Benefit Analysis; C-TRAP, Coordinated Transmission Planning; DC-OPF, Direct Current Optimal Power Flow; ENTSO-E, European Network of Transmission System Operators for Electricity; HVDC, High Voltage Direct Current; IC, Investment Costs; ISO, Independent System Operator; MPCs, Marginal Production Costs; MW, Megawatt; NTC, Net Transfer Capacity; OPF, Optimal Power Flow; TC, Transmission Capacity; TSO, Transmission System Operator

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Nomenclature

n	total number of power plants
i,j	node number indicators
pp_i	power plant on node i
k	investment plan consisting of groups of transmission lines
a	additional transmission capacity factor
SW	Social Welfare
SW_{env}	Social Welfare including environmental policy, e.g. internalization of external costs
w	additional marginal production costs factor
C_i	marginal production costs for a node i (€/MWh)
P_i	injected power at node i (MW)
Π_i	marginal price at node i for a specific level of injected power (€/MWh)
Pf_{ij}	power flow from node i to node j (MW)
TC_k	transmission capacity of candidate lines k (MW)
TC_m	transmission capacity of all other lines m (MW)
θ_i	voltage angle of node i (degrees)
$Q_{pp,i}$	quantity produced from a power plant pp on node i (MW)
L_i	load level on node i (MW)
Z	the whole evaluation period (years)

methodology for coordinated transmission planning, called C-TRAP (Fig. 1).

1.1. Challenges of future power systems

The challenges of future power systems are mainly arising from the increasing share of intermittent power generation in the power system and interregional market integration. One large example of the intermittent power development is the wind power in the North Sea. Great potential of wind power in the North Sea has been identified and envisioned by the ENTSO-E. These wind power projects if realized will demand large investments in the off-shore grid in the North Sea as well as network reinforcements in the involved countries (ENTSO-E, 2011). In combination with bulk power trading using HVDC lines from the North or the South of Europe, increased power flows throughout Europe and higher levels of variability and uncertainty in power grid operation are expected. The need for power balancing requires flexible generation as well as flexible and reliable transmission systems. Power system availability and adequacy has regained more importance since the recent large-scale power system blackouts in the USA and Europe 2003–2006 (Andersson et al., 2005; Merlin and Desbrosses, 2007). To ensure secure and reliable energy supply in future, it is necessary to reinforce the existing transmission grids taking into account modern availability indicators.

1.2. Major contributions of C-TRAP

- Consideration of environmental policy in the decision of transmission expansion plans, either by implementation of carbon tax or by internalization of the imposed external cost in the marginal cost curves.
- Combination of static and dynamic approach into a multi-criteria cost–benefit analysis that provide multi-criteria information to decision makers regarding the energy policy strategy and the optimal additional transmission capacity enabling the best investment strategy to be identified.
- Consideration of long-term reliability aspects in the form of availability of the reinforced transmission network.
- Combination of generation mix development, emissions reduction targets, transmission network reinforcement and market price signals.

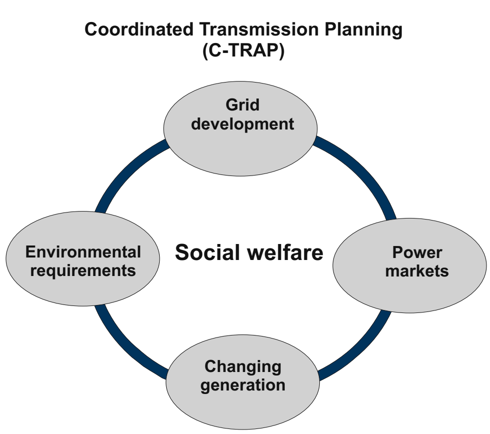

Fig. 1. Framework of the coordinated transmission planning (C-TRAP).

2. Transmission planning process

The C-TRAP is a semi-dynamic heuristic approach that solves the social welfare maximization problem for several discrete steps considering different preferences for environmental policy implementation and transmission network changes. With semi-dynamic is meant, that although the problem is solved for a certain time period of several years, the discrete steps refer to a static representation of the system. In case that the time steps correspond to years, only one snapshot of a year is considered in each step. The heuristic part refers to topology or transmission capacity changes for many marginal production cost cases. The methodology consists of two parts, one part includes the multi-criteria analysis and provides short-term information to the decision maker and the second part includes a cost–benefit analysis that accommodates the decision maker with long-term information of economic profitability. The combination of both parts, the so-called integrated multi-criteria cost–benefit analysis, leads to the optimal additional transmission capacity in case that marginal production costs are provided.

During the planning process the inputs such as generation, consumption data and marginal production costs are the most uncertain (Roh et al., 2009). Other inputs, e.g. transmission lines data and environmental costs are considered as known. The variability of the inputs influences strongly the selection of transmission investment scenarios, the output indicators and therefore the final decision. Hence, a sensitivity analysis is needed in order to characterize the system. The criteria used are indicators that provide information on the impact of the selected scenarios on societal, environmental, economic and availability factors. Societal or economic indicators are for instance change in social welfare, in nodal prices, in congestion costs and in operational costs. Environmental indicators show the change in production of conventional power plants or the increase of green power production due to the additional