Extended Abstract for: Scheduling the Equipment Maintenance of an Electric Power Transmission Network using Constraint Programming

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1 Introduction

The main objective of every electric power system is to transport electricity from the generating units to the load centers in a secure manner. To do so, one of the main tasks of the *network control center* (NCC) is to use a contingency approach to ensure that maintenance activities do not lead to interrupted power supply [4].

The transmission maintenance scheduling (TMS) problem consists on finding an annual maintenance plan for electric power transportation equipment while maintaining the stability of the network and ensuring a continuous power flow for customers. The maintenance plan must satisfy withdrawal rules and transit-power constraints. Transit-power constraints are based on complex constrained differential power-flow equations and cannot be easily integrated in a mathematical model.

To the best of our knowledge, there are no related works that solve TMS problems on a complete transmission grid with various electrical equipment and transit-power constraints.

The main contributions of the full paper[1,2] are: (1) an approach based on constraint programming (CP) for solving a TMS problem on a transmission grid with power-transit constraints; (2) the use of a black box simulator to validate the satisfaction of the transit-power constraints; and (3) experimental results on five strategic points of a real infrastructure.

By doing so, we aim to provide planners with insight in order to help them in their planning decisions, which are currently done manually based on their field expertise.

2 Modeling the Transmission Maintenance Scheduling Problem

Given a set of requests to withdraw a set of equipment temporarily (withdrawal request) and their respective duration, the goal is to schedule the withdrawal requests while satisfying a set of constraints. A withdrawal request has a list of equipment to withdraw and a duration. Each piece of equipment can be associated to one or several withdrawal requests indicating

[1] Popovic is the main student author, Cappart is advisor, Côté, Gaha and Nguewouo are industrial partners

[2] The full paper was accepted at the CP 2022 Conference

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that it must be withdrawn when the request is fulfilled. We model this problem using the formalism proposed by Laborie et al. [2, 3][3].

Four constraints are involed in our model, two of them are based on the *alwaysIn* constraint [3] and the other two are based on the *noOverlap* constraint. The first constraint states that a maximum of h pieces of equipment from a set of equipment A can be withdrawn together between the days d_s and d_e. The second constraint states that the sum of the charges of the withdrawn equipment from a set of equipment B must always be below θ. The third constraint states that for a given set (Λ) of sets of equipment (C_k), only equipment coming from the same set or having the same identifier can be withdrawn together. The fourth constraint states that equipment from a given set (S) cannot be removed together.

A solution is feasible if all the withdrawal requests have been scheduled while satisfying the four constraints presented above. However it does not guarantee the satisfaction of the transit-power constraints. Based on heuristic rules used by field specialists, we propose to integrate two objective functions with a lexicographic importance in order to increase the chances of satisfying the transit-power constraints.

The first objective function tries to spread as much as possible the withdrawal requests inside the planning horizon using the balance constraint introduced by Bessiere et al. [1]. The second objective function tries to schedule maintenance activities related to the same equipment together.

3 Solving the Transmission Maintenance Scheduling Problem

Although the transit-power constraints cannot be integrated inside the model, their satisfaction can be easily checked thanks to a simulator based on complex differential power-flow equations. We propose to leverage this simulator as a black-box tool. It consists of two black-box functions: one that computes the transit-power generated by the solution for a specific day (ψ_1) and one that computes a lower bound on the transit-power that must be satisfied for the obtained schedule, also for a specific day (ψ_2). A solution on the power grid is feasible if ψ_1 is greater or equal to ψ_2 during the planning horizon. Because the black-box only determine if a solution satisfy the transit-power constraints, no feedback can be provided to the CP solver.

The idea of the solution process is to generate diverse solutions and to filter them using the simulator. We resort to three mechanisms to ensure the diversity of solutions: (1) integrating domain knowledge as objective function, (2) adding constraints dynamically when a solution has been found, and (3) directing the search by a *multi-point* strategy. Solutions that are compliant with the simulator are feasible and can be used in practice. This process is illustrated in Figure 1.

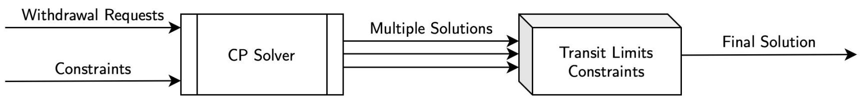

Figure 1 Illustration of the solving pipeline.

[3] A visualisation and more details on the decision variables are presented in the full paper

4 Experimental Results

The goal of the experiments is to show the adequacy of the approach to generate maintenance plan that can be used in practice for the geographic area considered. To do so, the maintenance plan designed by field specialists for the year 2020 is considered and compared with the plan obtained by our approach. The maintenance plan has an impact on five strategic points of the transmission power grid infrastructure, also referred to as *interface*. Each interface has its own transit-power constraints and a piece of equipment can impact more than one interface. The model generates a maintenance plan within an execution time of a few minutes.

For four interfaces, the transit-power constraints were respected. For one interface, the transit-power constraints were violated only a few times[4]. It was confirmed with field specialists that ensuring the satisfaction of transit-power constraints at this interface is challenging even in practice and they must sometimes allow certain constraints to be violated.

References

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2 Philippe Laborie and Jerome Rogerie. Reasoning with conditional time-intervals. In *FLAIRS conference*, pages 555–560, 2008.

3 Philippe Laborie, Jérôme Rogerie, Paul Shaw, and Petr Vilím. IBM ILOG CP Optimizer for scheduling. *Constraints*, 23(2):210–250, 2018.

4 Gilles Trudel, Jean-Pierre Gingras, and Jean-Robert Pierre. Designing a reliable power system: Hydro-quebec's integrated approach. *Proceedings of the IEEE*, 93(5):907–917, 2005.

[4] Detailed solutions for the five interfaces are presented in the full paper