AN INTEGRATED PLANNING APPROACH FOR THE SCHEDULING OF GRID ACTIVITIES REQUIRING OUTAGES

Maxime Hanot[1]*, Prateeba Ruggoo*[1]*, Julien Le Baut*[1*]

[1]*N-SIDE, Boulevard Baudouin 1er, 25, B-1348 Louvain-la-Neuve, Belgium*
**jlb@n-side.com*

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Abstract

The further integration of renewable energies in the power grid, the ageing of certain network components and cost pressure, lead to an increasing complexity to maintain and operate the grid. Outage planning is becoming more and more challenging to perform in some countries due to the high wind feed, which leads to short-term rescheduling. As a consequence, finding a feasible planning of outages is a difficult task for planning engineers without an appropriate decision-support tool.

The proposed approach considers the problem of outage planning as a scheduling problem, which is solved using constraint programming techniques. Multiple constraints and business objectives are taken into account, which enable the system operators to embrace a fully integrated approach and reach the optimality.

The tool has been tested on historical data and led to significant improvements of several key metrics, such as reduction of the number of outages, the reduction of the workload or the increase of planned grid activities.

1. Introduction

1.1. Trends and Challenges in Outage Planning

With the energy landscape in full transition, outage planning is becoming a key challenging and impacting activity for the system operators in order to keep guaranteeing the security of supply for their millions of consumers.

On the one side, the aging of the network assets increases the need for preventive maintenance interventions and the investments made to develop the grid and integrate distributed energy resources increase the number of infrastructure projects to realize each year. All these interventions often required to disconnect some parts of the grid (planned outages) for safety reasons, having a non-negligeable impact on the security of supply.

One the other side, the acceleration of the penetration of intermittent and decentralized renewable energy sources as well as the emergence of storage technologies and decentralized flexibility make peak loads and generation capabilities much less predictable. This situation has the consequence of reducing the number of opportune moments to plan outages (the so called “outage windows”) and increasing the need for short-term outage replanning due to unpredictable changes in the operating conditions.

1.2. Current ways to perform Outage Planning

The current approach followed by most of the System Operators is to apply a decentralized and sequential process to perform the planification of their grid interventions and associated required outages. The process is applied independently for each geographical zone and voltage level. It is usually organized in three main steps:

1. For each intervention, the project leader or the planning manager creates a tentative experience-based planification of the activities and required outages.
2. An assessment of the feasibility of the global planning with regards to the security of supply is realized for each day by the network analysts. If needed, arbitration and adaptations of the planning are performed.
3. When a feasible planning is achieved with regard to the network constraints, a resource feasibility assessment and nominative allocation of the works is performed. Arbitration and adaptations are once again performed if required.

This sequential approach lacks of coordination on three main dimensions. First, this planning process is applied independently for each operational team, resulting in a lack of grouping of the interventions requiring planned outages on the same network assets. Secondly, resource and network constraints are considered in a sequential way, requiring many back and forth between the work planning and outage planning teams. Finally, every change in the expected operational conditions implies a long and cumbersome procedure to update the planning. All-in-all, this results in an inefficient and suboptimal planning.

1.3. Gaps and approach

The current context described in section 1.1 has the consequence to subsequentially increase the complexity faced by operational planning teams as well as the number of factors they have to consider simultaneously. At the same time, manual processes used to create the planning of grid interventions as described in section 1.2 prevent these teams to reach the level of agility and integration required to overcome this new complexity. Altogether, it is now extremely difficult to solve the outage planning problem efficiently without a decision-support tool. It therefore forces the operational planning teams to reinvent their processes.

The proposed approach consists in modelling the outage planning problem as a large-scale optimization problem. The resulting solution is a decision-support optimization software able to find an optimal planning for one year with up to 10.000 grid activities and linked outages. The tool can be used with a time horizon going from year-ahead planning to day-ahead updates, allowing a more agile planning of activities when possible but also more stable when necessary. The approach is detailed in section 2 of this document.

2. The Outage Planning Optimization

2.1. Objectives of the tool

The goal of the solution developed is to improve the planning of grid-related interventions in a more agile way, both for operational and strategic needs, as well as to realize the necessary maintenance works and infrastructure projects in a more integrated way. The tool provides an optimized intervention and outage planning along with an interesting warning scheme which consists of generating explanations concerning specific interventions that could not be scheduled by the solver.

Figure 1 below gives the high-level outline of the optimization model along with its input and its output. The following sections give an overview of the core of optimization model.

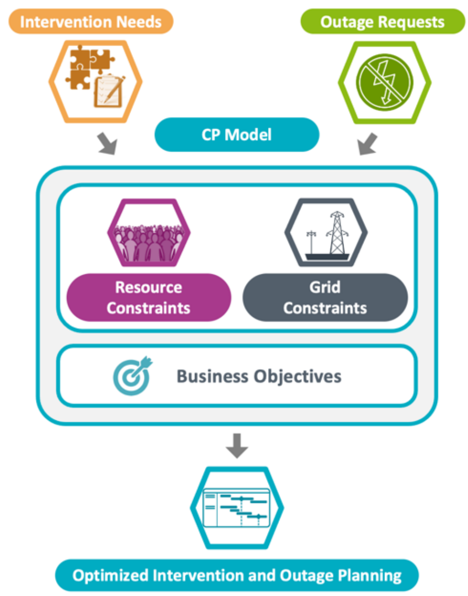

Figure 1: High-level outline of the optimization model.

2.2. Constraint Programming Model

To solve the Outage Planning Optimization problem, a constraint programming model is built with the consideration of the underlying resource and network constraints. Constraint Programming (CP) has been identified as a strategic direction and dominant form for the industrial application of production planning and scheduling [1, 2]. It has been proved to be effective in dealing with combinatorial optimization problems because of its broad representational scope and generally applicable solving algorithm [3]. In our case, the problem is a combined scheduling and assignment problem. The core of the model can be defined using the classical definition of a Constraint Satisfaction Problem (CSP) consisting of a triple $\mathrm{M} = (\mathrm{X}, \mathrm{D}, \mathrm{C})$ where X is an n-tuple of variables $\mathrm{X} = (\mathrm{x}_1, \mathrm{x}_2, \cdots, \mathrm{x}_\mathrm{n})$, D is a corresponding n-tuple of domains $\mathrm{D} = (\mathrm{D}_1, \mathrm{D}_2, \cdots, \mathrm{D}_\mathrm{n})$ s.t $\mathrm{x}_\mathrm{i} \in \mathrm{D}_\mathrm{i}$, and C is a t-tuple of constraints $\mathrm{C} = (\mathrm{C}_1, \mathrm{C}_2, \cdots, \mathrm{C}_\mathrm{t})$. An objective function is added to the CSP problem making it a Constraint Optimization Problem (COP) reflecting the real-life scenario where instead of being satisfied with a feasible solution, an optimal solution with a definite objective is desired. The definitions of some objective functions as well as a sample of the constraints present in the model are explained and illustrated in the following sections.

2.3. Constraints

Constraints are used in order to define what is a feasible planning of grid interventions. Out of all categories of constraints implemented in the scheduling tool, a sample of the four most important of them are described in this section.

2.3.1. Time constraints

The first category of constraints applied in the model are time constraints. This category covers both the consideration of working days (WD) and non-working days (ND) to plan the different intervention-days (ID) of the activities as well as the requested execution periods (minimal start and maximal end). These constraints are illustrated on Figure 2.

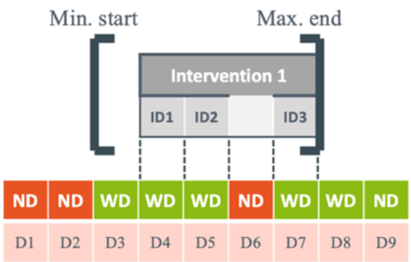

Figure 2: time constraints.

2.3.2. Dependency constraints

The second category of constraints considered in the optimization model are dependency constraints. This group of constraints models the interactions between two or more grid interventions: precedence, incompatibility and delay constraints. Precedence constraints are illustrated on Figure 3.

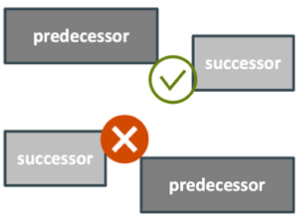

Figure 3: precedence constraints.

2.3.3. Resource constraints

Resource constraints is the third type of constraints considered in the model and can be applied both for field workers and for control room operators. This type of constraints states that the number of hours of work planned on each day for each team of workers cannot exceed the capacity of the team. This team capacity can differ from day to day and therefore can be adapted taking into account the real availabilities of the teams. These constraints are illustrated in Figure 4.

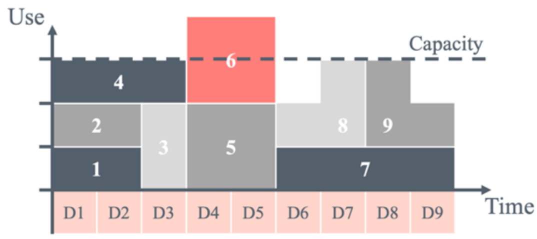

Figure 4: resource constraints.

2.3.4. Grid constraints

The last main category of constraints considered in the model are grid constraints. These constraints are used to avoid that several interventions are planned simultaneously on some assets which cannot be isolated from the grid at the same time. These constraints are modelled using so called "cardinality exclusions" meaning that, during a defined period of time, out of a group of *N* network assets, maximum *k* of them can be put in outage at the same time. This is illustrated on Figure 5.

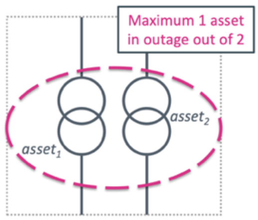

Figure 5: cardinality exclusions.

2.4. Objective function

In order to arbitrate what is the best solution out of all feasible solutions (respecting all constraints), an objective function is defined. This section formally describes some of the sub-objective functions implemented in the model to give the general outline of the optimization problem defined as a minimization problem. The objective function remains however fully customizable. The following notations are used for the modelling purpose:

Sets.

I	Set of grid interventions
A	Set of network assets
D	Set of calendar days

Parameters.

$weight_i \in \mathbb{Z}$	Weight associated to intervention $i \in I$
$cost_a \in \mathbb{Z}$	Cost associated to asset $a \in A$

Variables.

$$x_{i,d} \in \begin{cases} 1, & \text{If intervention } i \in I \text{ starts on day } d \in D \\ 0, & \text{Otherwise} \end{cases}$$
$$y_{a,d} \in \begin{cases} 1, & \text{If an outage on asset } a \in A \text{ starts on day } d \in D \\ 0, & \text{Otherwise} \end{cases}$$
$$z_{a,d} \in \begin{cases} 1, & \text{If asset } a \in A \text{ is in outage on day } d \in D \\ 0, & \text{Otherwise} \end{cases}$$

The global objective function f is the weighted sum of the different sub-objective functions defined in the following sub-sections, each targeting either the activity needs or the outage requests.

2.4.1. Maximization of the number of planned grid interventions

The first sub-objective considered is the maximization of the number of interventions planned on all days. The goal of this objective is to realize as many interventions as possible during the planning period.

$$f_1(x) = -\sum_{d\in D}\sum_{i\in I} weight_i \,.\, x_{i,d}$$

2.4.2. Minimization of the peak number of outages

The second sub-objective is the minimization of the maximum number of outages planned on a single day. The contribution of each outage is multiplied by the cost of the linked asset. The purpose of this objective is to spread the planned outages over the completed planning period.

$$f_2(y) = max_{d\in D} \sum_{a\in A} cost_a \,.\, y_{a,d}$$

2.4.3. Minimization of the number of planned outages

The third sub-objective is the minimization of the number of days of outages planned on the complete planning period. The purpose of this objective is to incentivize the grouping of interventions requiring the same outages at the same time.

$$f_3(z) = \sum_{d\in D}\sum_{a\in A} cost_a \,.\, z_{a,d}$$

2.4.4. Minimization of the number of changes

The fourth sub-objective is in fact a penalty scheme that "penalise" whenever an intervention is moved or removed by the solver compared to the already existing planning. There are two different types of penalty cost: a fixed cost which corresponds to a penalty for moving or removing an intervention, and a variable cost corresponding to the number of days each intervention is moved by the solver. Thus, the fourth objective aims to minimize the number of changes between the initial planning and final planning.

3. Results

3.1. Scope of the study

Between September and December 2020, a study was conducted by N-SIDE on a real network to analyse the impact of using the newly developed algorithm. The purpose of this study was to compare a planning of interventions which was created manually by operational planning experts with the planning that could have been executed if the planning was created by using the Outage Planning Optimization tool developed by N-SIDE. Only interventions requiring outages were considered in this analysis.

3.2. Results on the planning

The analysis has been performed on two different use-cases. In the first one, only the interventions that were manually planned by the operational teams were considered. The purpose was to analyse the ability of the tool to plan the same number of interventions with less grid impact. In the second use-case, interventions that operational teams were not able to plan were also considered. The goal of this second use-case was to analyse the ability of the tool to plan more interventions with the same resource constraints and with a similar grid impact. A qualitative comparison of the outage planning generated manually by the planning team and generated by the optimization tool is illustrated on Figure 6.

Figure 6: comparison between the manual and the optimized planning.

3.2.1. Case 1: identical planned interventions

The goal of this first simulation was to assess whether an optimal planning of grid activities could have been achieved with the same planned interventions and the same resources and network constraints. The results of this first simulation are depicted in table 1.

Table 1: Results of use-case 1.

Key Performance Indicator (KPI)	Manual Planning	Optimized Planning
Number of interventions	705	705
Number of outages	455	**369**
Number of days of outage	2062	**1843**
Number of interventions per outage	1.55	**1.91**

This first use-case shows that for the same number of planned interventions, the number of outages drops from 455 to 369, meaning a decrease of outages by 19%. The consequence of this decrease is a reduction of the workload for the switching operators and for the control room operators. In addition, the duration of the outages (number of days of outage) also considerably decreases, going from 2062 to 1886, meaning a decrease of 8.5% and therefore an electrical grid which is less under stress. Overall, the number of interventions per outage increases from 1.55 to 1.91 (23%), meaning that a better use of the outages is achieved.

3.2.2. Case 2: more planned interventions

With the ambition to assess the ability of the tool to increase the number of planned interventions with equivalent constraints, a second simulation was performed considering not only the interventions manually planned but also all the interventions that the operational planning teams were not able to schedule. The results of this use-case are shown in table 2.

Table 2: Results of use-case 2.

Key Performance Indicator (KPI)	Manual Planning	Optimized Planning
Number of interventions	705	**1009**
Number of outages	**455**	551
Number of days of outage	**2062**	2218
Number of interventions per outage	1.55	**1.83**

In this second use-case the number of planned interventions is no more constant between the manual and the optimized planning. Indeed, this number increases from 705 to 1009, meaning that with equivalent constraints, the number of planned interventions increases by 43%. At the same time, the number of planned outages only increases by 21% and the number of days of outage increases by only 7.5%. All-in-all, it results in an increase from 1.55 interventions per outage to 1.83, meaning an increase by 18% and showing, once again a better use of the planned outages on the grid.

4. Conclusion and outlook

Due to the changes in the energy landscape, traditional operational planning procedures are reaching their limitations. Fortunately, Advanced Analytics, and in particular, Constraint Programming, offer new perspectives for system operators to tackle the increasing complexity coming along with the energy transition.

The innovative modelling presented in this document allows operational planning teams to become more agile by re-optimizing frequently the planning, in order to adapt to changes in the expected operational conditions. It also allows to perform an integrated planning with the full picture of the process considered in a single tool. Most importantly, it allows the planning teams not to satisfy themselves with a feasible solution but to go the optimal way, with a better use of the planned outages on the grid and more interventions realized with the same resource and network constraints.

Furthermore, this unique approach brings the opportunity not only to increase the efficiency of the operational planning but also to support strategic decisions. Indeed, key decision makers can use the solution to perform what-if scenario analysis and support their decisions with an explicit arbitrage tool. Sensitivity analysis could indeed be done by adapting the configuration of the tool, such as updating the weights in the objective function or adapting resource or network constraints and then analysing the impact on the planning and its associated Key Performance Indicators.

5. References

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