A CASE STUDY TO ASSESS DATA MANAGEMENT AND PERFORMANCE OF OPTIMAL POWER FLOW ALGORITHM BASED TOOL IN A DSO DAY-AHEAD OPERATIONAL PLANNING PLATFORM

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ABSTRACT

Due to higher competitiveness of distributed energy resources, Distribution System Operators (DSO) are nowadays confronted with a rapid rise of renewable energy resources, leading to increasing grid congestion events into the distribution grid. In order to tackle these bottlenecks, DSOs are investigating several strategies including flexibility activation.

This paper looks at the performance evaluation of the Smart Operation tool in the context of flexibility activation with a focus on the day-ahead operational planning. The tool performance is evaluated based on its capability to: 1) effectively align with DSO's existing database 2) accommodate the various real-world needs like handling large network, specific time constraints to ensure proper coordination with the Transmission System Operator (e.g. sending signals before closure of market).

INTRODUCTION

The distributed energy resources (DERs) penetration into the distribution grid is rising, due to their decreasing capital cost and payback time, in addition to increasing environmental awareness. However, local clusters of DERs stress the distribution grid due to reverse flows and induced overvoltage [1]. In this context, DSOs are investigating several strategies for congestion mitigation, including DER flexibility activation. This calls for a deep understanding of the impact of DER flexibility in the operation of the distribution network. A software tool that helps plan the day-ahead operation of the distribution network comes handy in this context. The tool should model the DER flexibility along with the modelling of the distribution network. In this paper, Tractebel's proprietary tool, namely Smart Operation, is analysed from various perspectives in order to see how it fits as a day-ahead operational planning tool taking into account DER flexibility in optimizing the operation of the distribution network.

Smart Operation was developed and is being continuously adapted to include multiple capabilities, as a part of European R&D projects involving DSOs [2]-[6]. This tool performs a multi-period AC optimal power flow using second-order cone program optimization [7].The problem is tackled as a multi-period optimal power flow (OPF) problem. OPF problems are formulated to optimize power system related operational choices (i.e. decision variables). The flexibility of controllable resources, for example, decentralized generation, load, batteries and EVs are modelled in detail in Smart Operation. Smart Operation performs the grid operation optimisation taking the flexibility of controllable resources into account. In this paper, the modelling of generation curtailment of Smart Operation has been featured.

The OPF calculation core of Smart Operation handles both MV and LV studies. The mathematical methods used are valid, robust, and have sufficient numerical performance for simulation of radial networks of varying voltage levels, with combinations of cables and lines.

PROBLEM STATEMENT & METHODOLOGY

The optimal operational planning of distribution network including the flexibility of DERs requires detailed and accurate modelling of the distribution grid as well as the distributed energy resources. Some examples of DER flexibility includes generation curtailment, load shifting, shedding, etc. Additionally, batteries and Electric Vehicles are DERs that have potential for providing flexibility to the operation of the distribution network adhering to thermal and voltage constraint limits. The assessment of the impact of the DERs and their flexibility in the optimal operation of the distribution network is therefore of supreme importance.

In this context, Smart operation tool is to be analysed in the following aspects:

1. Data management and capability of the tool to effectively manage DSO database to simulate large network (topology/ prosumer mapping, voltage/current/power limits, generations/loads characteristics and profiles).
2. Power-system aspects: On one hand, Smart Operation should efficiently manage network losses. On the other hand, it should also minimize volume of flexibility needed to avoid congestion for a week/day-ahead operational planning, while meeting voltage and capacity limits in the MV grid.

3. The tool should also provide insights on the role of DER in wider DSO business operations.
4. Tool’s computational performance.

MATHEMATICAL ASPECTS OF SMART OPERATION

Goal of the Smart Operation tool is the optimal operation of the distribution network taking into account the flexibility of the DERs. The Objective function is therefore the minimization of the operation costs (grid losses, and flexibility activation costs) of the grid considering simultaneously all the flexible assets (PV / Load / Battery / EV / …) for the entire simulated period. Constraints include the load flow equations, the current constraints and the voltage constraints. The simulation time depends on several parameters including the number of nodes, number of flexible assets, time horizon under consideration and the time step resolution. Smart Operation uses a second order cone program (SOCP) relaxation of the branch flow model to solve the OPF problem [8]. The software is implemented in AMPL (version 20170914) with XPRESS solver (version 31.01) [9] using single core computation. The problems are solved with high accuracy (1e-06) in order to find the optimal objective function value within a precision of 0.1€.

CASE STUDY

In line with the methodology described above, four test cases were carried out as detailed below:

- Test Case 1: The aim of this test case is to show the generation curtailment modelling capability of Smart Operation. This in turn has two sub test cases as follows:
  - Test case 1a: modelling simple generation curtailment capability.
  - Test case 1b: modelling firm and flex access generation curtailment capability. The firm access is defined as that part of the wind production which when curtailed will have to be reimbursed (financially compensated) by the DSO. The flex access is defined as that part of the wind production which when curtailed will not be reimbursed by the DSO.
- Test Case 2: The aim of this case study is to assess the performance of Smart Operation in function of number of curtailable assets.
- Test Case 3: The aim of this case study is to assess the performance of Smart Operation in function of number of days.
- Test Case 4: The aim of this case study is to assess the performance of Smart Operation in function of network size.

The test cases #1 to #3 were carried out in the network shown in Figure 1. Test case #4 which aims to assess the performance of Smart Operation in function of the network size is carried out in the larger network shown in Figure 2.

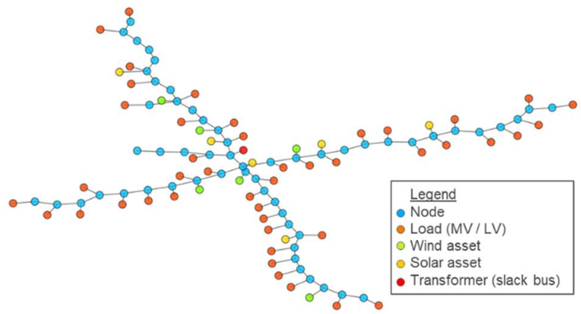

Figure 1:Analysed limited MV network (57 nodes).

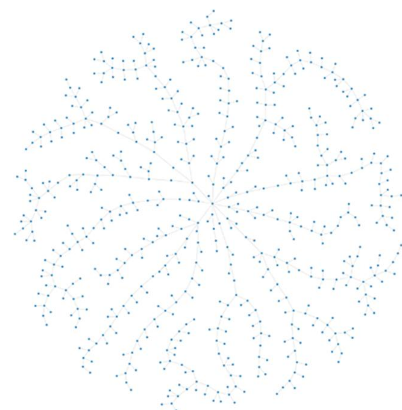

Figure 2: Analysed larger MV network (291 nodes).

Table 1 describes the characteristics of the two networks.

Table 1: Overview of main characteristics of the two simulated networks (i.e. limited and larger).

	Limited Network	Larger Network
# nodes	57	291
# MV clients	33	72
# LV cabins	11	165
# wind assets	8	9
# solar assets	6	103

Smart Operation tool used in the case study was hosted in the cloud with the following Cloud server characteristics:

- Server: m5.4xlarge instance on Amazon Linux Web Server
- m5 family is hosted by Intel Xeon 2.5GHz processor
- 16 VCPUs (i.e. Each VCPU is a processor thread)
- 64 GB of RAM
- 2.2 Gbps network

RESULTS

This section discusses the results of the four test cases described above. The first and foremost step was to assess the data management capability of Smart Operation, that is, the assessment of the effort of converting the available data with regard to network topology and DERs into Smart Operation compatible format. A tailored Python script was written to automate the data handling process. This resulted in time of transfer of less than 2 minutes to handle the DSO data for the network shown in Figure 2 and use it in a Smart Operation compatible format. The sanity check of the data handled was achieved using visual checks of the radial network and Smart Operation's built-in validation checks.

Test Case 1

Figure 3 shows the aggregated load and generation profiles of the network over 6 days in April where the aggregated generation exceeds the aggregated load enabling the demonstration of generation curtailment.

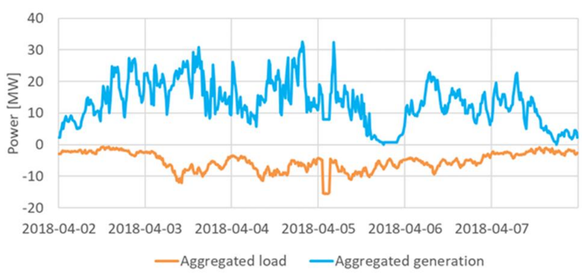

Figure 3: Aggregated load (LV/MV) & generation (Wind & Solar assets) profiles of the limited MV network over 6 days in April.

Test Case 1a: Congestion management with curtailment

The above shown load and generation profile when applied to the network in Figure 1 results in network congestion, namely the power to be exchanged through cable #9790-9641 reaches its limit. Figure 4 shows the generation profile of the wind farm #11431 whose curtailment solves the grid congestion. Figure 4 also shows apparent power of the cable #9790-9641 where congestion takes place. Additionally, it is interesting to note that Smart Operation suggests to curtail the wind farm #11431 instead of wind farm #9790. Intuitively, one would have curtailed the wind farm located at node #9790 to directly limit the injected power at that node and therefore circumvent the network congestion. However, curtailing the wind farm #11431 demonstrates several advantages:

- Curtailment of wind farm #11431 solves capacity constraints on cable #9790-9641 (see orange dotted lines between the upper and lower graphs in Figure 4).
- Curtailment of wind farm #11431 is more interesting from an economic point of view than curtailment of wind farm #9790:
  - It reduces reached capacities on several cables.
  - It results in total lower grid losses and associated costs. For example, lower operation costs (i.e. 84,646 €/yr) are reached when curtailing wind farm #11431 instead of curtailing wind farm #9790 (i.e. which results in operational costs of 85,103 €/yr).

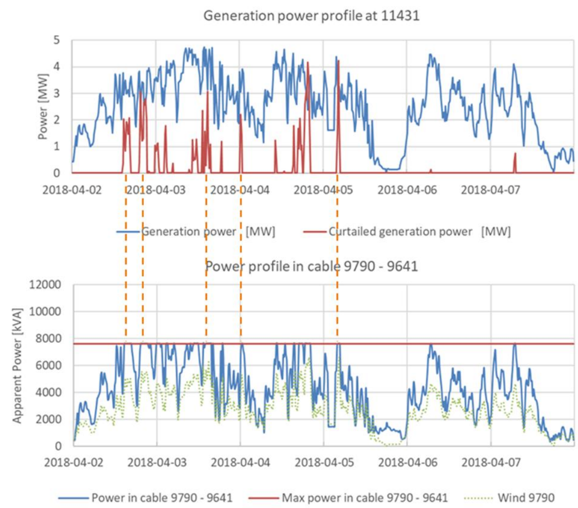

Figure 4: Example of grid congestion management (i.e. power capacity limit) through optimal flexibility activation: wind farm curtailment to respect power capacity limit in the MV cable #9790-9641.

Test Case 1b: Congestion management with firm/flex curtailment

This test case is similar to test case 1a except that all the curtailable assets are assumed to be 70-30 firm/flex. That is, first 70% of their production capacity is considered as firm access (that is, reimbursable) and the last 30% of their production capacity is considered as flexible access (that is, non-reimbursable). Figure 5 shows the generation profiles of the wind turbines under this test case.

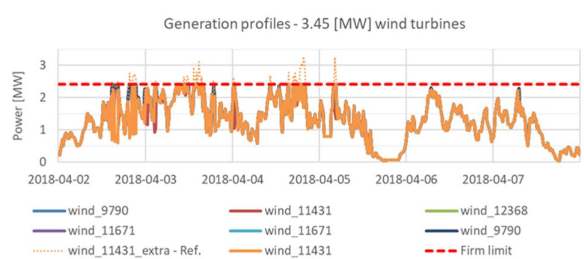

Figure 5: Obtained wind turbines generation profiles after imposing firm limit (i.e. 70% of 3.45 MW installed capacity) vs. reference generation profile (i.e. orange dotted line).

Table 2 compares the results of test cases 1a and 1b. The results show that the impact of flex and firm access results in reduced costs of operation. However, increased amount of generation is curtailed due to the zero cost of curtailing flex access generation.

Table 2: Comparison of test cases 1a and 1b: impact of flex/firm curtailment on congestion management optimal solution.

	Case 1a	Case 1b
Voltage/ Power constraints	respected	respected
Costs - Operation [€/yr]	84,646	55,364
Costs - Grid losses [€/yr]	32,873	31,694
Losses [MWh/yr]	548	528
Curtailment [MWh]	1,513	2,986
Max. power from grid [MW]	7.7	7.7
Max. power to grid [MW]	28.9	25.7

Test Case 2: Performance in function of number of curtailable assets

In this test case, for the same number of representative days (6 days), for the same time step (1/4 hour), for the same number of nodes (57 nodes) and for the same number of assets (100% penetration), the number of curtailable assets were varied from 25% to 100% of the original curtailable assets (i.e. 8 wind farms). Figure 6 shows the computation time as a function of number of curtailable assets. A total of 127 simulations were investigated, resulting from the combinations obtained by taking respectively 2, 4, 6 and 8 curtailable assets out of the larger set of 8 (i.e. C(8,2), C(8,4), C(8,6) and C(8,8)). Out of the 127 investigated simulations, 39 proved to be physically unsolvable (i.e. complete curtailment of the corresponding assets cannot solve the observed congestions). The remaining 88 solvable simulations were successively handled by Smart Operation. For the considered case and solvable simulations, performances are independent of the number of curtailable assets. This is explained by the fact that curtailment is a linear and continuous variable to handle in an OPF problem.

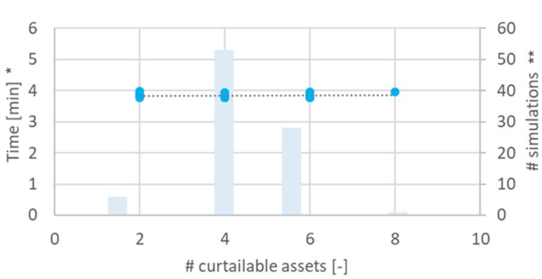

*Figure 6: Performance in function of number of curtailable assets (*Left-hand y-axis: Simulation time → dots, **Right-hand y-axis: number of simulations → bar diagrams).*

Test Case 3: Performance in function of number of days simulated

In this test case, for the same time step (1/4 hour), for the same number of nodes (57 nodes) and for the same number of assets (100% penetration), the number of simulated days were varied from 1 day to 6 days, resulting in 21 simulations. Figure 7 shows the results of the simulations. The longer the time horizon, the longer the simulation time: a close to linear increase can be observed (i.e. factor 1.4). Additionally, for the considered days, performances are almost independent of the day selected. For instance, for the case with 1 day, a total of 6 simulations were performed and they were all achieved in between 28 and 30 seconds. However, it is to be noted that the impact of the number of days on the simulation time will depend on several elements. Load shifting and batteries create dependency between the timesteps which complexifies the optimization and hence the computation time.

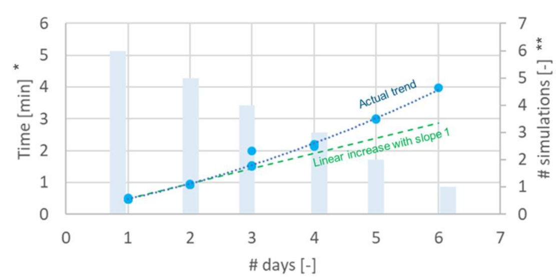

*Figure 7: Performance in function of number of days simulated (*Left-hand y-axis: Simulation time → dots, **Right-hand y-axis: number of simulations → bar diagrams).*

Test Case 4: Performance in function of number of network size

In this test case, the performance of Smart Operation in function of the number of network nodes is assessed, by performing simulations respectively on the Limited and Larger MV networks, separately for the 6 days of available data. Figure 8 shows the result of the test case. Simulation time increases linearly with the number of nodes (factor 2). Simulation time of less than 5 minutes was achieved for a day-ahead simulation with 291 nodes and all curtailable assets activated.

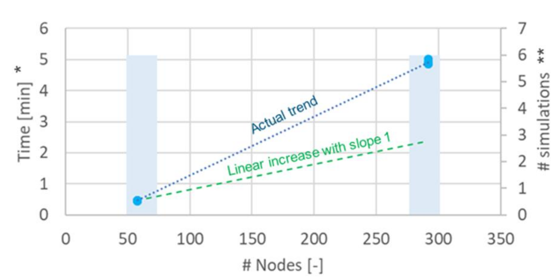

*Figure 8: Performance in function of number of nodes simulated (*Left-hand y-axis: Simulation time → dots, **Right-hand y-axis: number of simulations → bar diagrams).*

CONCLUSIONS

This paper demonstrates Smart Operation tool's capabilities to optimize grid operation making use of DER flexibility. Automation of the interface of the DSO database with the Smart Operation tool has been successfully demonstrated. The typical outputs relevant for day-ahead operational planning are shown. High performance, that is, computational time of less than 5 minutes is achievable for day-ahead operational planning simulation over a complete MV network (291 nodes) with 15 minutes timestep. For the considered network and for the type of flexibility assessed (that is, generation curtailment), the computation time is independent of the number of curtailable assets and linearly depending on the number of days and nodes. However, it is to be noted that load shifting and batteries create dependency between the timesteps which complexifies the optimization and hence the computation time.

NOMENCLATURE

AC	Alternating Current
DER	Distributed Energy Resource
DSO	Distribution System Operator
EV	Electric Vehicle
LV	Low Voltage
MV	Medium Voltage
OPF	Optimal Power Flow
PV	Photovoltaics (solar panels)
R&D	Research & Development
SOCP	Second Order Cone Program
TSO	Transmission System Operator
VCPU	Virtual Central Processing Unit

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