ATTEST

WP4

Tool for ancillary services activation in real-time operation of the distribution network

D4.3

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1.0	Mirna Gržanić, Tomislav Capuder, Karlo Šepetanc (ICENT)	31/08/2022	Description of T4.2

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Abbreviations and Acronyms

DA	Day-Ahead
DG	Distributed Generation
DER	Distributed Energy Resources
DSA	Dynamic Security Assessment
DSO	Distribution System Operator
EES	Electical Energy Storage
FL	Flexible Loads
LV	Low Voltage
MPC	Model Predictive Control
MV	Medium Voltage
NLP	Non-Linear Programming
OP	Operating Point
OPF	Optimal Power Flow
PV	Photo-Voltaic
SCOPF	Security Constrained OPF
RES	Renewable Energy Sources
RT	Real-time
TSO	Transmission System Operator

Executive Summary

This report describes the development of the tool "Tool for ancillary services activation in real-time operation of the distribution network", which constitutes the deliverable D4.3 in WP4 of ATTEST project, from functional/conceptional and technical point of view with detailed description of input and output data with connection between other tools. The goal of the tool is to activate flexibility sources connected to the distribution network in real-time operation according to the predefined day-ahead schedule and in coordination with transmission system operator to ensure secure and reliable distribution network operation and provide required services to the transmission system operator. The report describes the conceptual and technical framework of the tool with the detailed mathematical description of the model. Moreover, all variables and parameters used in the model are specified. The report provides a detailed insight in Model Predictive Control (MPC) algorithm which is used to consider possible future time steps in the current time period. Conceptual results are listed and explained together with computational complexity described with execution time, number of variables, etc.

1. Functional/conceptual description

1.1. Introduction

In order to limit the global temperature increase and harmful effects of climates changes, some crucial steps in reducing greenhouse gas emissions are necessary. Some of these changes are foreseen for energy sector which will contribute to the clean energy transition. Increasing energy efficiency and massive integration of renewable energy sources are some of the targets points declared in Green Energy Deal. Traditional power system operation and management is not suitable for these measures, so it is of the utmost importance to define innovative approaches in order to have secure system operation and reliable energy supply.

To ensure the goals set for low-caron transition, distribution and transmission network planning and operation are undergoing through the development phase which will enable to deal with increased uncertainty and variable nature of renewable energy sources. In low-carbon power system is necessary to ensure the adequate level of flexibility being provided not only from conventional power plants, but also distributed energy resources. The market participation of new entities from distribution level opens the door for diverse flexibility sources which also requires the coordination between transmission and distribution system operators.

In order to operate the network in safe and reliable way, both transmission and distribution system operators make decisions in day-ahead (DA) stage. However, these DA decisions are made based on the imperfect information due to uncertainty connected to RES production, load changes, or some contingencies in real-time (RT). The tool developed in this task is focused on corrections made in DA stage based on realistic measurement and precise information to ensure optimal system operation together with frequency stability.

1.2. Tool Functionalities

The main goal of the tool developed in task T4.2 is to activate distributed energy resources in order to provide flexibility services based on two parameters: i) the DSO's decision made in DA stage, and ii) request from the TSO. The tool cooperates with other tools developed in not only WP4, but also other work packages. The tool follows the decision made by the DSO in DA stage in order to satisfy limits in the distribution network and in the same provides ancillary services agreed with the TSO. The main objective is to minimize the deviations from the decision made in DA stage. When it comes to the service exchange between system operators, the TSO requires from the DSO to follow the predefined DA schedule of active (P^{DA}) and reactive (Q^{DA}) power exchange at each TSO/ DSO connection point (HV/MV substation) or to activate DERs reserved in DA stage (these active and reactive power request are in range from $[P^{DA} - P^{down}, P^{DA} + P^{up}]$ and $[Q^{DA} - Q^{down}, Q^{DA} + Q^{up}]$, where $P^{down}, P^{up}, Q^{down}, Q^{up}$ are reserved active and reactive power in DA for providing flexibility services to the TSO). The DSO receives these requests in a twofold manner:

i) one value for active power P^{req} and one value of reactive power Q^{res},
ii) two values for active power, either $P^{DA} - P^{act\_down}$ or $P^{DA} + P^{act\_up}$, where P^{act_down} can be in range from $[0, P^{down}]$ and P^{act_up} can be in range from $[0, P^{up}]$, and two values of reactive power, either $Q^{DA} - Q^{act\_down}$ or $Q^{DA} + Q^{act\_up}$, where Q^{act_down} can be in range from $[0, Q^{down}]$ and Q^{act_up} can be in range from $[0, Q^{up}]$.

In reality, due to the scarce amount of information at the distribution level, this tool receives data from the state estimation which provides topology together with active and reactive power on current injections and grid status.

The tool receives the reserved amount of flexibility for each ancillary service provider connected to the distribution grid from the DA stage from the tool developed in T4.1. and activation price of each flexibility provider from the tool developed in T2.6.

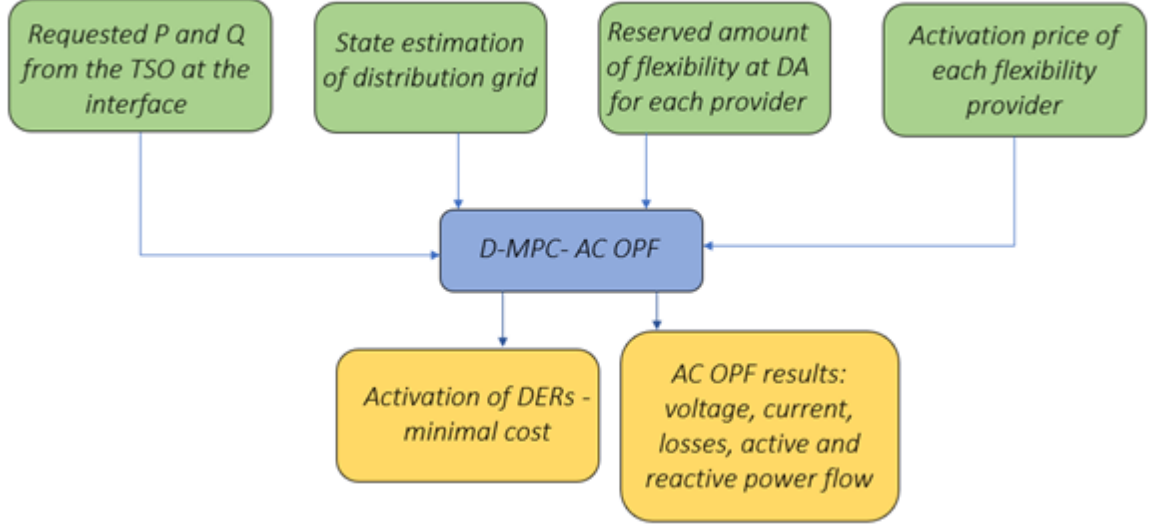A functional diagram of the tool is given in Figure 1:

FIGURE 1 HIGH LEVEL FUNCTIONAL DESCRIPTION OF TOOL 4.2

2. Technical description

The tool developed in T2.4. receives active and reactive power request in RT from the TSO for each time step at the TSO/DSO interface. The tool runs the AC OPF algorithm minimizing flexibility activation cost to satisfy the request sent by the TSO.

The objective function minimizes the cost of flexibility activation and penalties on operating constraints violations:

$$Min \sum_{t,dev,\frac{up}{dn}} c^{flex}{}_{activation} + \sum_{t,constr.} c^{pen} \tag{1}$$

$$c^{flex\_activation} = a \cdot \left(P^{up/dn}\right)^2 + b \cdot P^{up/dn} + c \tag{2}$$

$$c^{pen} = \pi^{pen1} \cdot (S \mid \underline{V} \mid \bar{V})^{pen1} + \pi^{pen2} \cdot (S \mid \underline{V} \mid \bar{V})^{pen2} \tag{3}$$

$P^{up/dn}$ is activated active power reserve and $(S \mid \underline{V} \mid \bar{V})^{pen1}$, $(S \mid \underline{V} \mid \bar{V})^{pen2}$ are apparent power and lower and upper voltage magnitude violation variables. Double penalty technique with different penalty values is used in this tool to allow for smaller operating constraint violations if that helps the system in the possible future scenarios, thus the $pen1$ and $pen2$ naming scheme.

The tool uses the AC model of the OPF problem in rectangular coordinates as described with (4) and (5):

$$P_{ij} = e_i^2 G_{ij} + f_i^2 G_{ij} - e_i e_j G_{ij} + e_i f_j B_{ij} - f_i e_j B_{ij} - f_i f_j G_{ij} \qquad (4)$$

$$Q_{ij} = -e_i^2 B_{ij} - f_j^2 B_{ij} + e_i e_j B_{ij} + e_i f_j G_{ij} - f_i e_j G_{ij} + f_i f_j B_{ij} \qquad (5)$$

where P_{ij} and Q_{ij} represent active and reactive power flows on the line ij, e_i and f_i are real and imaginary part of voltage at the bus i, while B_{ij} and G_{ij} are susceptance and conductance of the line ij. The same network data (B_{ij} and G_{ij}) are used in T4.1 for DA operational planning of the distribution network. The tool considers DG units connected to the distribution network, storage units and flexible loads as service providers.

The problem is formulated as multi-temporal distribution level model predictive control AC OPF (D-MPC-AC OPF). The DSO runs RT OPF to determine the minimal cost of flexibility activation to satisfy the request from the TSO and in the same to solve local congestion and voltage problems if state estimator detects the violation of distribution network constraints. In the case without distribution constraints violation and no request from the TSO for flexibility activation. The problem includes multi-temporal energy storage state of energy feature.

Following decision variables are considered in each time interval:

i)   Distributed generator down active power,
ii) Flexible loads up and down active power,
iii) Storage up and down active and reactive power.

The MPC rolls every 5/15-minutes and predicts the optimal reserve activation in order to solve local congestion and voltage problems. The MPC makes decision for the present time step considering future scenarios to potentially save available reserve resources for even more unfavorable near future. Future time periods are generated with one increased and one decreased load scenario. Visualization of MPC is shown in Figure 2.
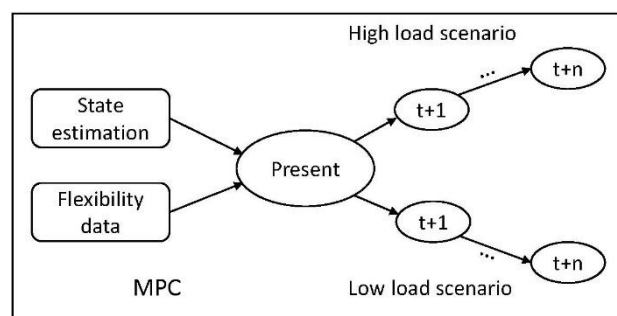

FIGURE 2 MPC OPTIMIZATION STRUCTURE

3. Input and output requirements

3.1. Input data

The input data for this tool are following:

i) Test cases which are developed in T2.3 (Test cases) of WP2 and datasets from Croatian DSO (HEP ODS) which are provided in WP7. The test cases provide the necessary network data such as information related to network buses (network topology), lines (susceptance and conductance of the line, thermal capacity of lines), transformer characteristics, active and reactive values of load and generation units,

ii) Technical constraints of the flexibility service providers (maximum charging and discharging power of battery, battery capacity, etc.),

iii) The expected states of ancillary services providers in T4.1 (Ancillary services procurement in day-ahead operational planning of the distribution network) for each flexibility service provider together with the number of activations,

iv) State estimation of distribution network from T4.3.,

v) Active and reactive power at the interface requested by the TSO in RT, specified in T4.5 (active and reactive power flow from the upstream grid)

3.2. Output data

The outputs of the tool include flexibility devices activations to satisfy distribution system constraints and to fulfil transmission system activated reserve:

i) Distributed generator down active power,

ii) Flexible loads up and down active power,

iii) Storage up and down active and reactive power

4. Results

Results contain reserve activation decisions of procured flexibility sources to eliminate or reduce real time operating constraints violations, i.e. voltage magnitude and line capacity limits. Example case study is done on a test network of 30 buses. The problem consists of 3627 variables and 2682 constraints. The output consists of 46 variables. The execution time is 0.1 seconds. For solving small size AC OPF problem, 8 GB memory is enough. However, for large-scale power systems, memory requirements increase to 16 GB. The developed tool is programmed in AMPL as an NLP problem and is solved using the state of the art KNITRO solver.
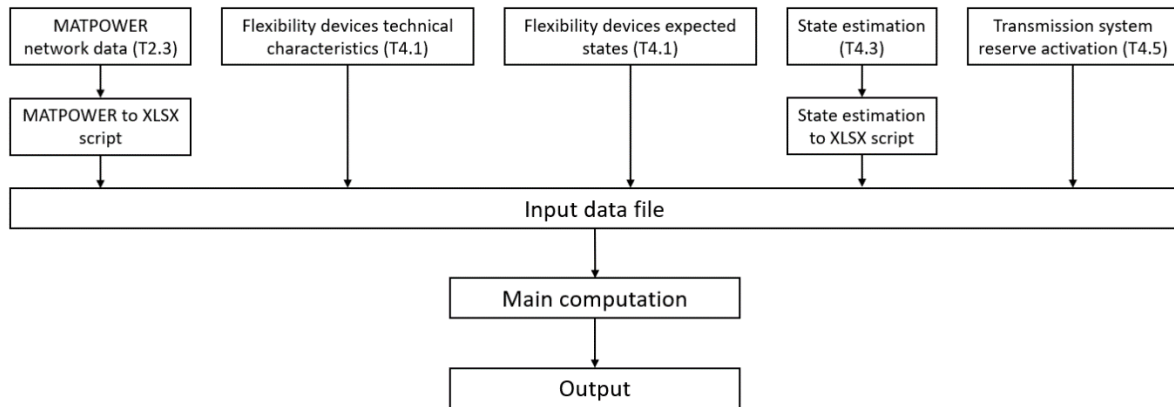
5. Data format connection between tools

Figure 3**Error! Reference source not found.** shows the interaction between tool T4.2 and the other tools of ATTEST project. Tool 4.2 receives data from:

i)   test cases developed in T2.3,

ii)   upper and lower bound of reserved flexibility in DA for both active and reactive power for each flexibility service provider from T4.1,

iii)   reserve devices expected state provided by T4.1,

iv)   estimated load profile and network topology from T4.3. which serve as required input for AC OPF analysis due to insufficient data for the distribution level,

v)   active and reactive power requests from the TSO at the interface (these values can be in the range from $[P^{DA} - P^{down}, P^{DA} + P^{up}]$ and $[Q^{DA} - Q^{down}, Q^{DA} + Q^{up}]$) from T4.5.

6. User manual

To run the tool, the following steps need to be executed based on the workflow displayed in Figure 3:

1.   Acquire data inputs from T2.3, T4.1, T4.3 and T4.5 tools (Figure 4):
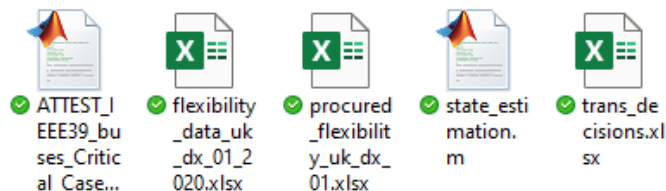

FIGURE 4 INPUT DATA FROM OTHER TOOLS

2.   Use MATPOWER to XLSX Julia script to transform network data into AMPL loadable format (Figure 5 and Figure 6):
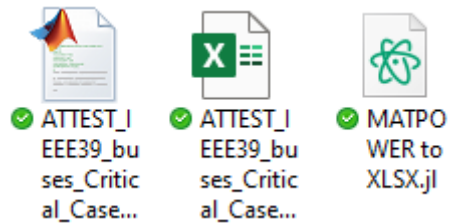
```
clearconsole()
using PowerModels, DataFrames, XLSX

source_files="C:\\Users\\karlo\\OneDrive - fer.hr\\Optimization\\OPF\\ATTEST\\data\\new\\ATTEST_IEEE39_buses_Critical_Case.m"
destination_files="C:\\Users\\karlo\\OneDrive - fer.hr\\Optimization\\OPF\\ATTEST\\data\\new\\ATTEST_IEEE39_buses_Critical_Case.xlsx"
```

FIGURE 6 DEFINE NETWORK INPUT AND OUTPUT FILE IN THE CONVERSION SCRIPT

3. Use State estimation to XLSX Julia script to transform network data into AMPL loadable format (Figure 7):
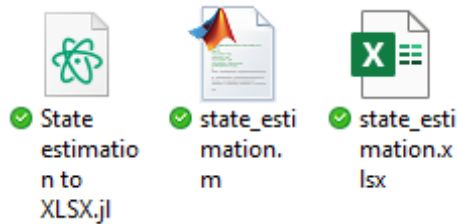

FIGURE 7 STATE ESTIMATION FILES AND CONVERSION SCRIPT

4. Define addresses of input files in AMPL input_file.run (Figure 8):

```
input_data.run ☒

    reset;

    ###### Input files - user input ######

    #Network file
    param network_data_file symbolic = "data\new\uk_dx_01_2020.xlsx";

    #Flexibility data - output of T4.1 tool
    param flexibity_devices_tech_char_file symbolic = "data\new\flexibility_data_uk_dx_01_2020.xlsx";
    param flexibity_devices_expected_states_file symbolic = "data\new\procured_flexibility_uk_dx_01.xlsx";

    #Transmission activated reserve file - output of T4.5 tool
    param trans_activated_reserve_file symbolic = "trans_decisions.xlsx";

    #State estimation file - output of T4.3 tool
    param state_estimation_file symbolic = "state_estimation.xlsx";
```

FIGURE 8 DEFINE INPUT DATA SOURCES IN AMPL FILE

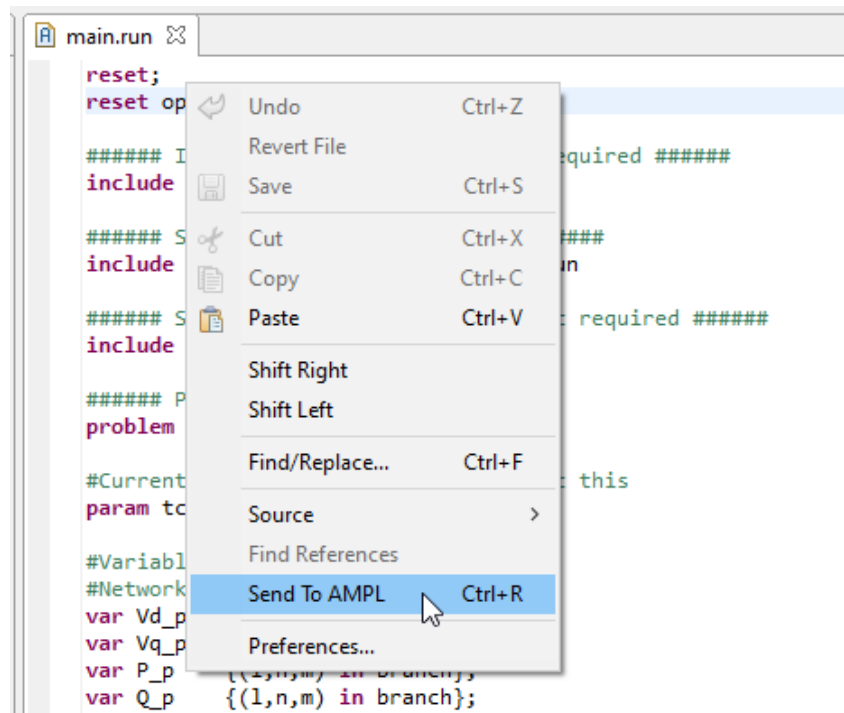5.   Run the main program (Figure 9):

FIGURE 9 RUNNING THE OPTIMIZATION IN AMPL (RIGHT CLICK AND SEND TO AMPL OR CTRL+R)

6.   Results are saved automatically in output Excel file (Figure 10):

FIGURE 10 OUTPUT FILE