ATTEST

WP4

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

D4.6

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4.6	Mirna Gržanić, Tomislav Capuder, Karlo Šepetanc (ICENT)	29/12/2022	Final version completed

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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
EV	Electric vehicle
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
RES	Renewable Energy Sources
ROCOF	Rate of Change of Frequency
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 transmission network" 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 transmission network in real-time operation according to the predefined day-ahead schedule and in coordination with distribution system operator to ensure secure and reliable transmission network operation by using flexibility resources connected to the transmission network and distributed energy resources. 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. 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

To reduce the harmful effects of greenhouse gas emission and climate change, massive penetration of renewable energy sources (RES) changed the power system operation and control strategies. Their variable nature requires an increased level of flexibility in both transmission and distribution network management. This implies unlocking the flexibility potential from the non-traditional sources, namely distributed energy resources (DERs). To ensure the safe system operation, the Transmission System Operator (TSO) can procure ancillary services from the transmission connected resources and also DERs.

Due to incomplete information not only on their production, but also electric vehicle (EV) charging requirements and demand uncertainties, TSO predicts the required amount of ancillary services to be purchased in the day-ahead (DA) market. In order to operate the transmission network in the most reliable and secure way, the TSO activates the flexibility sources connected to transmission or distribution network in real-time to ensure the frequency stability, to mitigate unallowed voltage deviation and to remove congestion in the transmission network. The tool developed in this task is focused on corrections made in DA stage based on dynamic security assessment to ensure optimal system operation and frequency stability.

1.2. Tool Functionalities

The main goal of the tool developed in task T4.5 is frequency control, congestion management, and voltage control in real-time operation of the transmission network. In order to have adequate resources and volume of flexibility when necessary in real-time, the TSO reserves ancillary services based on the day-ahead decision from the resources connected to transmission network or from the resources connected to the distribution network. In order not to activate the counteracting services with the DSO, both DA procurement and RT activation of flexibility services are based on the coordination model between DSO and TSO developed in task T2.4. The tool is activated when dynamic security assessment detects an emergency (constraint violation) or an unexpected event (such as disconnection of more than one line due to different inconvenience, such as storm).

The TSO calculates the volume and cost of activated AS for each transmission level connected flexibility provider as well as activated ancillary service volume (active and reactive power values) at the interface with the DS0 as the result of transmission level model predictive control AC OPF (T-MPC-AC OPF). At the TSO/DSO interface the information exchange is required to ensure that DSO receives requested values of active and reactive power in each time step from the TSO. The problem is solved in stochastic linear model predictive control fashion considering if the flexibility service provider connected to the transmission network was activated in the previous time step t-1 and checks if the service is required from the same ancillary service provider in the next time step t+k. MPC rolls every 5/15-minutes and predicts the optimal operating points.

The tool receives network data in Matpower format, asset enrichment data for placing and sizing EV, storage and PV in the network, the reserved amount of flexibility for each ancillary service provider connected to the transmission grid from the DA stage from the tool developed in T4.4. and activation price of each flexibility provider from the tool developed in T2.6, and online dynamic security assessment developed in T4.6.

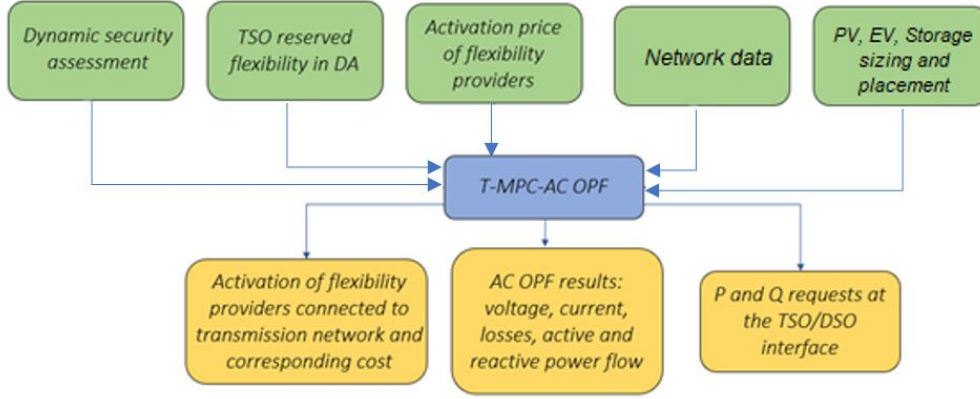A functional diagram of the tool is given in Figure 1:

2. Technical description

The tool developed in T4.5. activates the flexibility sources connected to the transmission or distribution network. Active and reactive power requests are sent to the DSO at each time step for each TSO/DSO interconnection point. The tool runs the AC OPF algorithm minimizing flexibility activation cost to satisfy transmission network constraints and to secure frequency stability taking into account dynamic security assessment.

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):

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

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

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 T4.4 for DA operational planning of the transmission network. The tool considers DG units, storage units and flexible loads connected to the distribution and transmission network as service providers.

The problem is formulated as multi-temporal transmission level model predictive control AC OPF (T-MPC-AC OPF). The TSO runs RT OPF to determine the minimal cost of flexibility activation to solve congestion, voltage problems and to ensure frequency stabilization. The problem includes multi-temporal energy storage state of energy feature.

Following decision variables are considered in each time interval:

i)   active and reactive power flow on each line,
ii)   voltage magnitude and angle at each bus,
iii)   maximum apparent power of each line,
iv)   activated flexibility for each distributed service provider and total cost for activation.
v)   operating constraints violation variables.

The MPC rolls every 5/15-minutes and predicts the optimal reserve activation in order to solve transmission congestions 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.
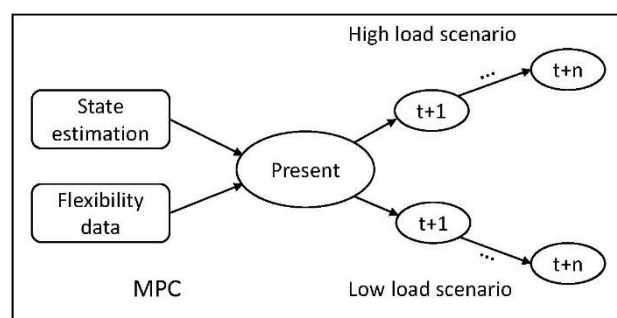

FIGURE 2 MPC OPTIMIZATION STRUCTURE

The tool loads neural network data for dynamic security assessment. The output of neural networks are nadir and RoCoF values. The optimization goal is to keep these values within safe limits. The input control variables are total synchronous machine active power production, total inertia, total wind production and possible additional entries, based on considered network.

3. Input and output requirements

3.1. Input data

The input data for this tool are following:

i)   Transmission test cases which are developed in T2.3 (Test cases) of WP2. 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 PV production profile,
iv) The expected states of ancillary services providers in T4.4 (Ancillary services procurement in day-ahead operational planning of the transmission network) for each flexibility service provider together with the number of activations,
v) Online dynamic security assessment,
vi) State estimation.
vii) Network data enrichment for PV, EV, and storage sizing and placement in the network for the upcoming years.

3.2. Output data

The outputs of the tool include flexibility devices activations to satisfy transmission system constraints:
i) Flexible generator active power curtailment,
ii) Flexible EV up and down active power,
iii) Storage up and down active and reactive power,
iv) Request for the DSO for flexibility service activation in real-time at the TSO-DSO interface.

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 Uk_Tx_2030 of 30 buses. 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 and uses the KNITRO solver.
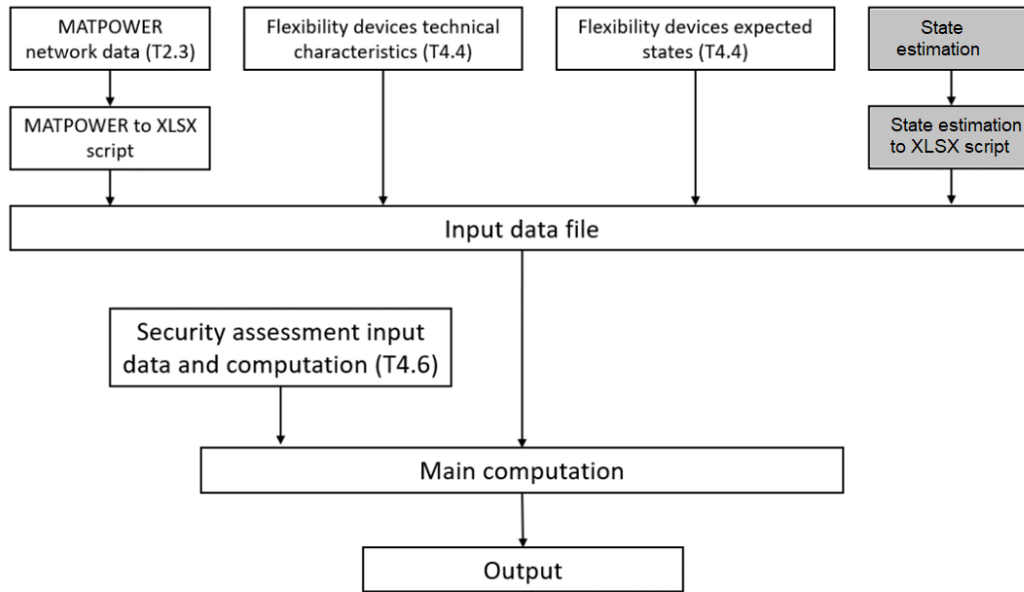
5. Data format connection between tools

FIGURE 3 INTERACTION OF TOOL 4.5 WITH OTHER ATTEST TOOLS

Figure 3**Error! Reference source not found.** shows the interaction between tool T4.5 and the other tools of ATTEST project. Tool 4.5. 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 T4.4,
iii) state estimation,
iv)   online dynamic security assessment developed in T4.6.
v)   network data enrichment for PV, EV, and storage for the upcoming years.

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, T4.4, state estimation and T4.6 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):
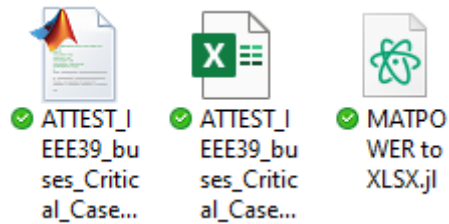
```
clearconsole()
using PowerModels, DataFrames, XLSX

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):
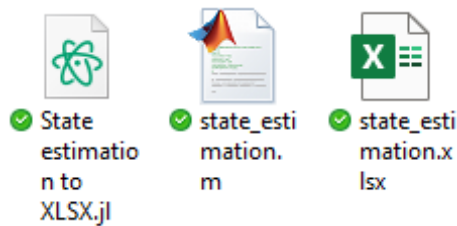

FIGURE 7 STATE ESTIMATION FILES AND CONVERSION SCRIPT

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

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

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

#Flexibility data - output of T4.1 tool
param flexibity_devices_tech_char_file symbolic = "data\UK_Dx_01_2030.xlsx";
param PV_profile_file symbolic = "data\PV_production_diagram.xlsx";
param flexibity_devices_expected_states_file symbolic = "data\procured_flexibility_uk_dx_01.xlsx";

#Transmission activated reserve file - define output of this 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.   Define the dynamic security assessment input file in securaity_assesment.run

```
###### Input file - user input ######
#NN data file
param NN_data_file symbolic = "data\template nn _ 4 var_Python_Script_Keras_Model_Validation.xlsx";
```

FIGURE 9 DEFINE SECURITY ASSESSMENT NEURAL NETWORK DATA INPUT FILE
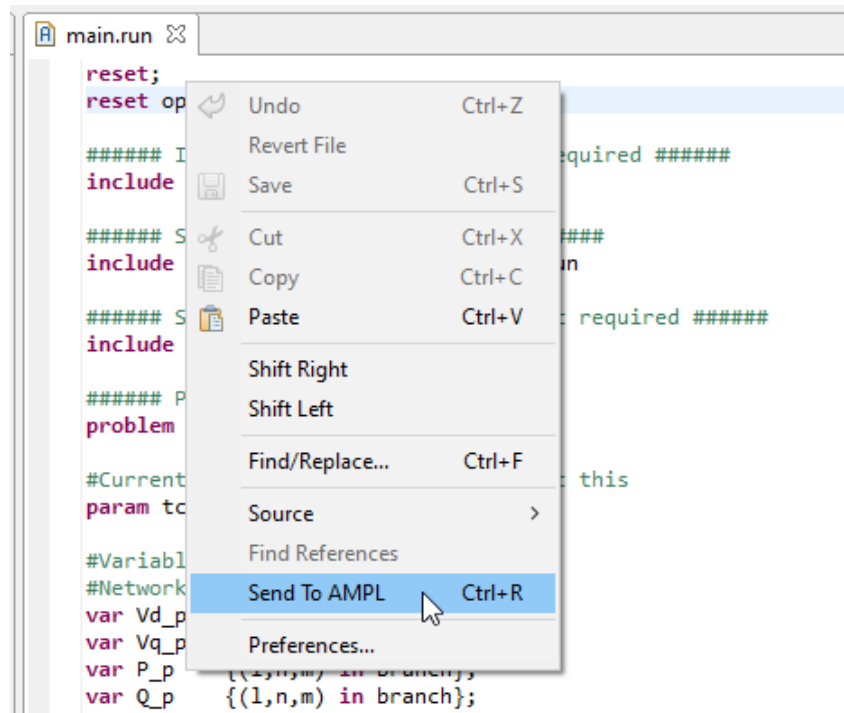
6.   Run the main program (Figure 10):

FIGURE 10 RUNNING THE OPTIMIZATION IN AMPL (RIGHT CLICK AND SEND TO AMPL OR CTRL+R)

7.   Results are saved automatically in output Excel file (Figure 11):

FIGURE 11 OUTPUT FILE