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# ATTEST Tool: Ancillary Services Procurement Tool in the Day-Ahead Operation Planning of Active Distribution Systems

## Input Files

The developed tool is tested on the following set of active distribution systems, which are enriched with additional data coming from renewable energy resources, flexible loads, and electrical energy storages. The additional data is considered by the tool developer. However, the ATTEST project partner will provide the information about the new assets in near future. Once the new information is obtained, please update the corresponding input files.

The simulated active distribution systems are

1. UK\_DX\_01
2. PT\_DX\_01
3. ES\_DX\_03
4. HR\_DX\_01 (HR\_DX\_01 is further split into three sub-networks based upon its single line diagram. The three sub-networks are labelled as HR\_DX\_01\_green, HR\_DX\_01\_brwon and HR\_DX\_01\_red)

Furthermore, note that for each distribution system, there are two input files per network. These files are labelled as ‘network\_name.ods’ and ‘network\_name\_flex.ods’ where network\_name is replaced by the above-mentioned names (i.e., UK\_DX\_01, HR\_DX\_01\_green etc) for each respective network. The first file (network\_name.ods) contains the information which is provided in the matpower file of a particular network in T2.3, whereas the second/later file contains the data that is considered by the developer of the tool to validate it. This means that the information about renewable energy resources, flexible loads, electrical energy storages and on-load tap changing transformer can be found in various sheets of this file.

## Selection of Flexible Options

The available flexible options can be selected in the following manner

1. For electrical energy storage, go to ‘Storage\_Addt’ sheet of ‘network\_name\_flex.ods’ file and set ‘Status’ field equal to 1 for storage that you want to use as a flexible option. When ‘Status’ field is set to 0, the corresponding storage will not participate in provision of flexibility service.
2. For flexible load, go to ‘Loads\_Addt’ sheet of ‘network\_name\_flex.ods’ and set ‘Status’ field equal to 1 for a load to participate in the demand response. When ‘Status’ field is set to 0, no flexibility will be offered by the corresponding load.
3. For renewable energy resources, set ‘CurtStatus’ in the ‘Gens\_Addt’ sheet to activate the active power curtailment flexible option for the corresponding renewable resource.
4. For on-load tap changing transformer, set ‘status\_oltc\_flex’ in the ‘Lines\_Addt’ field equal to 1 for the transformer which can change its tap ratio.
5. For adaptive power factor, simply set the ‘flex\_adpf’ parameter in the ‘constants.jl’ file equal to 1 to allow the vary the reactive power output of the renewable energy resource.
6. Moreover, apart from setting these fields in the input excel sheet, one need to set ‘flex\_apc, flex\_oltc, oltc\_bin, flex\_fl, fl\_bin, flex\_str, str\_bin, and flex\_adpf’ parameters in the ‘constants.jl’ file either to 1 (to activate a particular flexibility) or 0 (to deactivate a particular fleixbility).

## Implementation in Julia

The developed tractable tool is implemented and programmed in Julia language with JuMP being used as a modelling layer, and CPLEX is used to solve it. In the following, a brief description is provided about successfully running this tool in Julia.

1. The stand-alone version (i.e., without integrating the tool in ICT platform which is being developed in WP6 of ATTEST project) consists of ‘**main\_sc\_milp.jl**’ file which calls different packages, custom functions, being written/programmed in the course of tool development, and input files (test network data and scenario generation data), as shown in Fig. 3, to successfully run this tool.
2. The installation of Julia and packages is explained in Appendix A.2 (Installation of Julia and relevant Packages), whereas the generation of scenario data, which is carried out through **Scenario Generation Tool**, is explained in Appendix A.3 (Scenario Generation Tool). The output of this tool i.e., RES uncertainty data, is saved in ‘**scenario\_gen.ods**’ file, as shown in Fig. 3, which is then called in ‘**main\_sc\_milp.jl**’ file.

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RD4RXhpZgAATU0AKgAAAAgABAE7AAIAAAAPAAAISodpAAQAAAABAAAIWpydAAEAAAAeAAAQ0uocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAE11aGFtbWFkIFVTTUFOAAAABZADAAIAAAAUAAAQqJAEAAIAAAAUAAAQvJKRAAIAAAADNzgAAJKSAAIAAAADNzgAAOocAAcAAAgMAAAInAAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Packages Calling

User-Defined Functions Compilation

Test Network File

Scenario Generation Data

Fig. 3: Tractable Tool main file showing packages, user-defined FUNCTIONS, and input files

1. The developed tool takes input data from two files for each network as explained in the previous section.
2. After the selection of input test case file (i.e., the network which needs to be simulated), the next point would be the selection of flexibility options that need to be considered in the network. Fig. 4 shows the flexible options that can be activated (set option = 1)/deactivated (set option = 0) in a network. The selection of a particular flexible option can be done in ‘constants.jl’ file. Please refer to ‘Selection of Flexible Option’ paragraph for further details.

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Description automatically 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Usage of Electrical Storages

Participation of Flexible Loads

Reactive Power from RES

OLTC Transformer

Active Power Curtailment

Fig. 4: Available Flexible Options

1. Once flexible options are set, press the Run All button as shown in Fig. 5. This starts the execution of S-MP-MILP model.

![A picture containing logo

Description automatically 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coKSo0NTY3ODk6Q0RFRkdISUpTVFVWV1hZWmNkZWZnaGlqc3R1dnd4eXqDhIWGh4iJipKTlJWWl5iZmqKjpKWmp6ipqrKztLW2t7i5usLDxMXGx8jJytLT1NXW19jZ2uHi4+Tl5ufo6erx8vP09fb3+Pn6/8QAHwEAAwEBAQEBAQEBAQAAAAAAAAECAwQFBgcICQoL/8QAtREAAgECBAQDBAcFBAQAAQJ3AAECAxEEBSExBhJBUQdhcRMiMoEIFEKRobHBCSMzUvAVYnLRChYkNOEl8RcYGRomJygpKjU2Nzg5OkNERUZHSElKU1RVVldYWVpjZGVmZ2hpanN0dXZ3eHl6goOEhYaHiImKkpOUlZaXmJmaoqOkpaanqKmqsrO0tba3uLm6wsPExcbHyMnK0tPU1dbX2Nna4uPk5ebn6Onq8vP09fb3+Pn6/9oADAMBAAIRAxEAPwDxWjHuaBS1oSJg/wB40m0/3j+lOopgJg/3jRj3paKAENTxf6lP90VAani/1Kf7ooQiAUtIKWkMKKKvaRpF1rWoLaWSZY8s54VF7sT2FMCjRUt0kUV3LHbyGWJWKq5GNwHf8aioAQ1PF/qU/wB0VAani/1Kf7ooQiAUtIKWkMv6No13ruopZ2Me525Zj91F9SfSvVp/DUuheDLjT/Dlubi+uFCSSllRmz1OSRgYzge9eU6Tdaml2lrpN3c28lw6piCVk3EnAzg+9ej+KfF48N6bHpGn3DXOpLGEkndt5j45JJ6sf0q1axLPM9R0260m8a1v0WOdRlkWRX2/XaTg+1VadJI8sjSSMXdjlmY5JPrTakoQ1PF/qU/3RUBqeL/Up/uihCIBS0gpaQy3puoS6Xd/arYDz1UiNzz5ZIxuA9cZxVV3aSRnkYs7HLMxySfWkopgFFFFACGp4v8AUp/uioDU8X+pT/dFCEQClpBS0hhRRRTAKKKKAEqeL/Up/uioKni/1Kf7ooEQClpBS0hna+DvCNl4m8P3jTO0N1HNtjmXnA2jgr3H61g694Z1Lw9cbL6HMTHCTpyj/j2Psa774T/8gS+/6+B/6CK7DV7nTrXTZX1l4VtSMOJgCG9sdz7Vpa6JvqfPVFaGtyaXLqsraHDNDaE/KsrZ/L0HsSaz6goSp4v9Sn+6KgqeL/Up/uigRAKWkFLSGdb4W8ZR+GdBu4Y4DPdzTbow3CKNoGT3P0rA1bWr/W7s3GpXDSt/CvRUHoB2qjRTuIKKKKBiVPF/qU/3RUFTxf6lP90UCIBS0gpaQwooopgFFFFACVPF/qU/3RUBqeL/AFKf7ooQiAUtIKWkMKK9I8MaTeXHhu1li0DRLpGDYmuf9Y3zHr8prFk8YWUUrxt4U0jcjFTiIdvwqrCucjRW1rev22rWscVvotjp7I+4yWyBS3GMHjpWLSGIani/1Kf7oqA1PF/qU/3RQhEApaQUtIZ6l4T1LxBB4WtIrDRYbm3AbZK12qFvmPY9KqWPh3ULe2KXnhKyvJS7MZnvFBOSTj8OlcpYaroNvYxxX3hz7ZOud8/26SPfz/dAwKsf234Y/wChR/8AKnL/AIVdyStr+p2V0v2W20O302aGUh3ikLE4yCOnrWJWtq2oaReW6Jpeh/2dIHy0n2t5dwx0ww4+tZNSMQ1PF/qU/wB0VAani/1Kf7ooQEApaQUtIYUUUUwCiiigBDU8X+pT/dFQVPF/qU/3RQhEFGfr+VApaQxNw9/yNJuHv+Rp1FMBNw9/yoz/AJxS0UAJU8X+pT/dFQVPF/qU/wB0UCIBS0UUhhRRRTAKKKKAEqeL/Up/uiiigR//2Q==)

Run Button

Fig. 5: Run button of Juno IDE

1. During the course of execution, several user-defined functions are called which read the input test case data, simulate the AC power flow and execute the proposed tractable methodology. In the following, a list of functions and/or files is shown to specify the role of each user-defined function and/or file being called in ‘**main\_sc\_milp.jl**’ file.

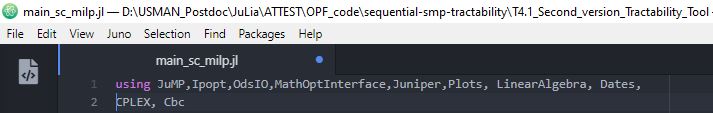
|  |  |
| --- | --- |
| Functions/File | Brief Description |
| interface\_excel (file) | Read the input test case data from .ods file |
| interface\_scenarios (file) | Read the RES uncertainty data from ‘**scenario\_gen.ods**’ file |
| Constants (file) | Contains input parameters that are to be set by the end-user of the tool |
| constants\_pf\_opf (file) | Parameters that are based on the input data as well as those defined in the ‘constants’ file and do not need to be updated/changed by the end-user |
| data\_lines (function) | Takes the network lines information as an input and calculates line admittances |
| data\_nodes (function) | Takes the nodes/buses information as an input and restructure the data into ‘**node\_data**’ structure |
| data\_load (function) | Takes the load data as an input and defines increment/decrement flexibility cost parameters along with the index information of FLs |
| data\_gen (function) | Take the generation, both conventional and renewable, sources and define index information of non-curtailable (conventional) and curtailable (RES) generation sources |
| ac\_power\_flow\_model\_check (function) | Newton Raphson based AC power flow module |
| recovery\_branch\_current\_pf (function) | Calculates the branch current once AC power flow is solved |
| constraint\_violation\_pf (function) | Calculates the nodes voltages and branch current violations after solving AC power flow |
| sql\_loop (function) | Function which contains several sub-functions to implement the proposed tractable methodology M1 |
| sql\_opf\_model (sub-function of sql\_loop) | Function which implements the S-MP-MILP OPF model |
| opf\_model\_initialization (sub-function of sql\_opf\_model) | Function which initializes the decision and control variables of model M1 |
| opf\_model\_objective (sub-function of sql\_opf\_model) | Function which defines the objective function of model M1 |
| opf\_model\_power\_balance\_cons (sub-function of sql\_opf\_model) | Function which defines the linear active and reactive power balance, and nodes voltage constraint (2)-(8) of model M1 |
| network\_constraints\_no\_function\_new\_milp (sub-function of sql\_opf\_model) | Function which defines the constraints (9)-(27) of model M1 |
| opf\_model\_solve (sub-function of sql\_opf\_model) | Function which calls the CPLEX solver and solves the model M1 |
| opf\_model\_solution (sub-function of sql\_opf\_model) | Function which retrieves the values of decision and control variables after model M1 is solved |
| s\_inj\_power\_max\_power (sub-function of sql\_opf\_model) | Function which implements the trustable approximation loop criterion |

## Appendix A.2 (Installation of Julia and relevant Packages)

Appendix A.2 provides the necessary information needed to install Julia and corresponding packages needed to run the proposed tractable tool.

1. Download and install **Julia** from the following link for Windows/Mac <https://julialang.org/downloads/> or download Julia for Visual Studio Code from <https://code.visualstudio.com/docs/languages/julia> which is a free editor for Julia language.
2. There are two available versions of Julia 1. “**Current stable release**” 2. “**Release with long term support**”. Download the “Current stable release” which right now is v1.7.3. The provided codes are developed using v1.4.2 but running it on the latest version is possible and user will not face any problem as the developers have claimed.
3. After the installation of Julia, the next step involves installing all the packages that are being used in the code. The packages that are being used in the code are defined at the start of ‘**main\_sc\_milp.jl**’ file (followed by the word “using”) as shown in the below figure.

**Packages**



1. The instructions for the installation of packages can be found at <https://docs.julialang.org/en/v1/stdlib/Pkg/> and are briefly explained below.
   1. Let’s say, one needs to install JuMP package. On Julia REPL, press **]** and one will enter Pkg REPL (Read Execution Print Loop).
   2. Write “add JuMP” and press enter. This will start downloading and installing the package.
   3. Once the package is installed (assuming no problem occurs), press *backspace* to go back to Julia REPL and executes the instructions mentioned in step 5.
2. Once the package is installed, it needs to be compiled before being used in the code. There are two ways of doing this.
   1. One is to use the “using” command as shown in the above figure. Write “using JuMP” in Julia REPL and the package will start compiling.
   2. The other way (very rarely, it can happen that “using” command does not compile the package successfully) is to use “Pkg.build(“xxx”)” command where “xxx” is the name of package.
3. Once all the packages are installed and compiled, the codes can be executed by pressing the “Run all” button on Julia command bar.

## Appendix A.3 (Scenario Generation Tool)

1. The scenario generation tool generates the scenarios of PV and wind RES which become the input of SLA-based S-MP OPF tool. The main file of this tool is “**scenario\_gen\_tool.jl**” which calls Julia and Python packages as well as other Julia files. Note that this tool needs to be run before running the proposed tractable tool.
2. This tool calls several functions from Python using “PyCall” package which is an interface between Julia and Python. The ‘PyCall’ package uses *Conda.jl* Julia package and installs a minimal Python distribution via Miniconda that is private to Julia.
   1. With this package installed, one can use “pyimport(xxx)” command to call the python function and use it in Julia. Let’s say, one wants to use the **ARIMA** function which is available in the submodule (“**arima\_model**”) of Python package (“**statsmodels**”). One can simply call it in Julia by first importing the “arima\_model”
      1. arima\_py = Pyimport(“statsmodels.tsa.arima\_model”)

and subsequently, calls the ARIMA function using

* + 1. arima\_py.ARIMA()

1. The input file of this code is “**data\_scenarios.ods**” which takes the wind speed and solar power data and generates RES scenarios.
2. The output file of this code is “**scenario\_gen.ods**” which contains the wind and solar RES uncertainty scenarios as well the joint probability of these scenarios. This file is then used in the ‘**main\_sc\_milp.jl**’ file as shown in Fig. 3

## Appendix A.4

Appendix A.4 presents the scenarios of wind and solar power which are generated using scenario generation tool. Figs. 8 and 9 show the wind and solar power data, respectively. In both figures, for the sake of simplicity, only 10 scenarios are shown and for each scenario, the values corresponding to a horizon of 10 hours are reported.

Calendar

Description automatically generated

Fig. 10: Wind power scenarios

Calendar

Description automatically generated

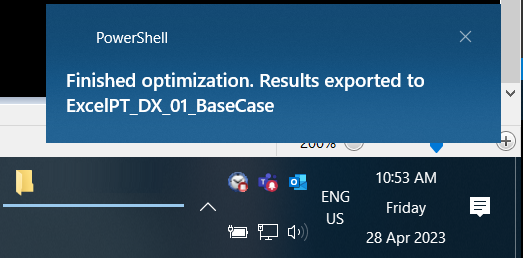
Fig. 11: Solar power scenarios

# Addendum:

After departure of the initial developer, small improvements were conducted on the tool. The modifications concern representation of results, and making the tool more user-friendly. The modifications on the code do not change the core process, and should not cause changes to the results of a test case.

## Additional packages:

* **Statistics**: used to calculate max, min, average and standard deviation of certain values. Before disabling this package, disable the commands: {minimum, maximum, mean, sum} wherever they appear in the code. These commands appear when exporting data to excel, inside the subfunction: “AppendStats”.
* **Printf**: pretty print data during simulations. Before disabling this package, disable the command “@printf(…)” wherever it appears in the code.
* **Alert**: display a notification on the taskbar in Windows 10 (outside VS code window), once a simulation is finished (for users multi-tasking). Before disabling this package, disable the command “alert” wherever it appears in the code.



* **Infiltrator**: An alternative to the debugger of Visual-Studio code. Before disabling this package, disable the command “@infiltrate” wherever it appears in the code.

## Choosing your case:

Previously, the input and output files had to be named explicitly. For example:

|  |
| --- |
| # filename\_mat = "input\_data/uk\_dx\_01\_2020.ods"  # filename\_addt = "input\_data/uk\_dx\_01\_2020\_flex.ods"  ⋮  # file\_op = "output\_data/uk\_output.xlsx" |

When several test-cases exist, specifying input file names is not user-friendly. The user would need to change the filenames manually for each case, or deactivate or reactivate particular lines from a long list of filenames.

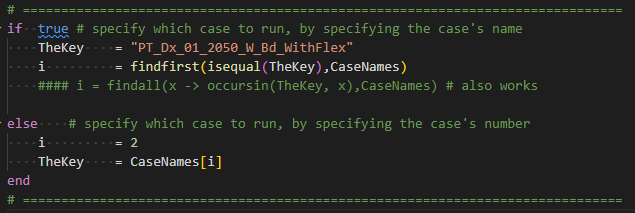
Text

Description automatically generated

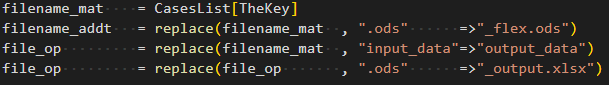
Alternatively, we create a dictionary of all case names, and the path to the case’s main input file. The user needs NOT to comment out or reactivate any lines. The user only needs to specify the case’s name, or the case’s number, using the block of code depicted below.

In the figure below, the test case is specified by its name (dictionary key). The “if-else” condition is set to “true”, and the code will always proceed to define the variable “TheKey”. The ID of the case will be determined by the case name (TheKey).

If, alternatively, the user intends to run all cases in an order, regardless of the case name, the user can change the “if-else” condition to “false”. The code will proceed to define the variable “i", and the name of the case (TheKey) will be automatically extracted from the dictionary.



Specifying the path to the file with flexibility-assets data, and the name of the output file, is not necessary. The file names are automatically generated by the code:



## Log file:

The modified code also keeps a log of the success/failure of each simulation. This information is appended to the same universal log file, such that the user can observe the outcome from all test cases in one sheet. The universal log file is located at:

|  |
| --- |
| OutLog = "output\_data/March2023\_LoadDataFromAttestCloud/EditedInputFiles/OutLog.xlsx" |

The first few columns just identify the case:

* Case name
* Path to the input file (relative to my computer)
* Path to the output file (relative to my computer)
* The time I started the simulation.

the next columns report how far through did the simulation go:

1. **Init\_PF**: if the initial PF finished successfully, this will be TRUE. Otherwise, the initial PF started and failed.
2. **N\_violations**: how many violations of the system limits where found in the initial PF. If there are no violations at all, this column will have a value of FALSE. At the same time, it is pointless and unnecessary to optimize any flexibility assets, and the next columns are going to be FALSE.
3. **Opt\_Started**: if there are violations, the program should proceed to optimize flexibility assets. This should be “1” (TRUE) as long as N\_violations > 0
4. **Opt**\_**Found**: optimum dispatch of flexibility assets to solve the system violations was found. Optimization was successful.

## Results Output Files

### Initial OPF:

The program solves an initial OPF, for the purpose of identifying violations of the grid codes (e.g. voltage limits, line flow / thermal limits). The modified code exports the results of this initial OPF.

As long as the OPF could be solved, with or without violations, the output excel file will always contain the following sheets: {"VOLT", "Crnt\_PU", "Crnt\_SI", "P\_load", "Q\_load", "Pg\_max", "Qg\_max"}. Furthermore, if violations of the voltage limits exist, the sheet “Vlt\_Viol” will be created. Similarly, a sheet named “Crnt\_Viol” will only exist if there are violations of the lines’ thermal limits.

The contents of each sheet are explained in Table 1 below.

|  |
| --- |
| **Note:** If the initial OPF does not reveal any violations of any type, the results of the OPF will be exported anyway. However, this means that flexibility is not needed, and it is pointless to proceed to optimization of flexibility assets. Therefore, the code will stop after exporting the results. The code will throw an error: |

### Flexibility Assets Optimization

If any grid codes are violated, the tool will proceed to acquiring flexibility by optimum utilization of flexibility assets. If the optimization fails, the excel file stays as is (with the results of the initial\_OPF).

Alternatively, if the optimization is successful, the following sheets are added to the excel file: {"APC\_MW", "EES\_CH\_MW", "EES\_DCH\_MW", "FL\_OD\_MW", "FL\_UD\_MW", "COST"}. The contents of each sheet are explained in Table 1 below.

**Table 1.** Explanation of output excel file

|  |  |  |  |
| --- | --- | --- | --- |
| Group | Sheet name | Specific description of the sheet contents | Remarks |
| Results of the initial PF (before optimizing flexibility assets). | **VOLT** | Voltage magnitude on each bus for each weather scenario. | This data has 3 dimensions (weather scenario, bus#, value of interest), we had to unfold it such that the first column represents Scenario, and second column is bus ID).  Each row represents one the value\_of\_interest for a particular (scenario, ID) combination.  Each row represents one time period. |
| **Crnt\_PU** | Current flow on each line, in PU |
| **Crnt\_SI** | Current flow on each line, in SI units (Amperes) |
| Load and RES data from the input files, for cross checking against input data | **P\_load** | Active/Real power component of load |
| **Q\_load** | Reactive/Imaginary component of load |
| **Pg\_max** | Active/Real power component of RES generation |
| **Qg\_max** | Reactive/Imaginary component of RES generation |
| Violations detected in the PF result (before attempting to optimize flexibility assets). If NEITHER of these 2 sheets exist, then there were no violations at all, and there is no need for optimizing flexibility assets. | **Vlt\_Viol** | List of violations of the voltage limit. If this sheet does not exist, it means there are no such violations. | Each violation is represented by 1 column.  **First** column (e.g. x1) is the ID# of the violation  **Second** column (e.g. Itr:1) is the iteration of PF where this violation was identified  **Third** column (e.g. viol\_num: 1) is violation ID (same as first column)  **Fourth** column: Weather scenario where this occurs.  **Fifth** column: The time period (t) where this violation occurs.  **Sixth** column: the bus/node where this violation occurs.  **Seventh** column: voltage value  **Eighth** column: violation size = Voltage value – limit |
| **Crnt\_Viol** | Violations of the lines thermal limits (i.e. high current flow)  If this sheet does not exist, it means there are no such violations. | Each violation is represented by 1 column. (Column A is one violation. Column B is the second violation)  **First** column (e.g. x1) is the ID# of the violation  **Second** column (e.g. Itr:1) is the iteration of PF where this violation was identified  **Third** column (e.g. viol\_num: 1): violation ID (same as first column)  **Fourth** column: Weather scenario where this occurs.  **Fifth** column: The time period (t) where this violation occurs  **Sixth** column: “From\_Bus” side of the concerned line  **Seventh** column: “To\_Bus” side of the concerned line  **Eighth** column: Actual current flowing on this line  **Ninth** column: Flow limit on this line  **Tenth** column: Violation size = Actual flow – flow limit |
| Results of flexibility optimization. If these sheets were not found, then the optimization failed. | **APC\_MW** | Active power curtailment | Each row represents one asset  Each column represents one time period  The last 4 rows represent: “Min”, “Max”, “Average”, and “Sum” of all actions in this time period. |
| **EES\_CH\_MW** | Energy storage charging events |
| **EES\_DCH\_MW** | Energy storage discharging events |
| **FL\_OD\_MW** | Flexible load events of over-demand (increasing consumption) |
| **FL\_UD\_MW** | Flexible load events of under-demand (decreasing consumption) |
| **COST** | Total cost of flexibility deployment |  |