**FLEXXY INSTRUCTIONS**

*GENERAL*

Flexxy is a program for the hourly simulation of a small electrical system, as for example an electrical system of a small island or of a small autonomous community. The electrical system that can be simulated may be composed by a load (representing aggregated load), conventional generator units (typically diesel gensets), RES (Renewable Energy Sources) units, Flexible loads, and Storage system. Additionally a hybrid plant may be defined, consisting of RES units and Storage System, with a maximum limit for the power supplied to the grid. In this case only the RES units of the hybrid plant are utilized for the ‘charging’ of the Storage System.

The main rules of the operation of the system with this program are presented in the followings.

The program calculates the hourly operating values for each component of the system in order to cover the demand (Load unit operating value), if this is possible. It tries to utilize first the RES production (RES units connected at the AC side), then the Storage (operating value of Storage Interface), the flexible load and at last the conventional generating units (by committing the appropriate units), taking into account the various constraints for the operation of the system and for the various units. When there is a surplus of produced energy, typically the RES surplus energy is used for the charging of the storage system, then for the flexible load and if this is not adequate, RES energy is curtailed.

The calculations are conducted on an hourly basis, according to the hourly production and consumption values, and no schedule is performed.

For some type of units a priority value (1-10) may be defined, which concerns the priority among units of the same type. For conventional generator units a smaller priority value means that this unit has a higher priority for unit commitment. Units of the same priority are committed according to their cost. (Actually the ’cost’ for the commitment of a unit is multiplied by the priority value in the objective function of a minimization problem). For RES units a smaller priority value means that this unit has a higher priority when curtailments are required. RES units with larger priority value are curtailed first. For RES units of the same priority the energy to be curtailed is shared among the units proportional to their nominal value. Curtailments of RES units, connected at the AC side, may be required either due to a hybrid plant limitation or due to constraints from the operation of the system, for the production/consumption balance. Priority values affect only the curtailments caused by the system constraints. Curtailments due to hybrid plant limitation (i.e. maximum power to the grid) occur according to the order of the RES unit in the hybrid plant. Storage systems may be connected either directly at the AC bus of the electrical system, where they utilize all the energy sources (mainly RES units), or at a hybrid plant, where they utilize only the RES units of the hybrid plant. If storage systems are present at both locations, storage systems of the hybrid plant are used at first priority, when the operation mode is not the grid-connected mode. (If the grid-connected mode has been selected as operation mode, on the contrary, storage systems of hybrid plants have lower priority).

The hourly operating values (in kW) of some units depend on input read by the program from files. These files are typically files of a column of 8760 values (for each hour of a year). A header row is also allowed. If the file has more than one column (separated by semicolon), only the first column is read. The files should be located in the selected working directory.

*USER’S INSTRUCTIONS*

The main form of the Flexxy program when executed, provides an area for the graphical representation, as a block diagram, of the electrical system to be simulated. An AC bus with a Load unit connected to it is already available. An arrow on the line connecting a component indicates direction of power flow for positive operating values of the component. The user should add the components that compose the electrical system, and edit their parameters. This can be done with the Components menu, or by clicking the mouse right button on the area of the electrical system representation. If the mouse is clicked on a component the component is selected, if the mouse is clicked on the white area then none component is selected. The options edit/add/remove of the menu act on the selected component. If none component has been selected, edit/add act on system level. Components can be added up to a maximum allowable number, for each type of component.

Each component has a unique name. The parameters that can be edited for each type of component, in its corresponding user’s interface form, are described in the followings, together with relevant information.

*Load Unit*

File: A file should be selected, with a column of values (8760 rows for a period of one year) representing an hourly load in units of kW. If a file has been selected, the name of the file is displayed next to the file selection button.

Scale: A scale parameter is also available, with default value of 1.

The hourly load (operating value of the Load unit) is the product of the hourly values read from the input file and the scale parameter.

*RES Unit*

File: A file should be selected, with a column of values (8760 rows for a period of one year), representing the theoretic hourly output of the RES Unit, in Watts per installed kW (W/kW).

Nominal Power: The nominal power of the RES plant, in kW.

Priority: An integer value in the range 1-10.

Type: The type of a RES Unit may be selected among options Generic/PV/Wind.

The theoretic output of the RES Unit for each hour is the product of the hourly values read from the input file and the nominal power, multiplied by 10-3 to convert to kW. The input file may be the outcome of another program that calculates the output power of a RES plant based on resources’ data (e.g. weather data), or may be based on real measurements. The actual output of the RES unit is calculated during simulation based on the theoretic output taking into account any required curtailments.

*Hybrid plant*

Maximum value: The maximum of the hourly value of power supplied to the grid by the hybrid plant.

When the production of the RES Units of the hybrid plant is higher than this value, the excess energy is used to charge the battery of the hybrid plant, and if this is not possible, it is curtailed.

A minimum value of default value 0 is also used for the hourly value supplied to the grid, implying that RES units which are not part of the hybrid plant are not utilized to charge the battery.

*Conventional Generator Unit*

Maximum value: The nominal power of the generator, in kW.

Minimum value: Technical minimum limit of the generator when operating (ON), in kW.

Priority: An integer value in the range 1-10.

File ON: A file with binary values (0/1). Hourly Value of 1 means that the Unit must be operating (ON state) that hour.

File OFF: A file with binary values (0/1). Hourly Value of 1 means that the Unit must be shut down (OFF state) that hour.

Minimum ON Time: The minimum time in hours, that the unit must stay ON after it starts operation.

Minimum OFF Time: The minimum time in hours, that the unit must stay OFF after it shuts down.

a, b, c: Coefficients a, b, c of a second order polynomial function a·P2+b·P+c, expressing the hourly fuel consumption, in Kgr/h, as a function of the operating power P, in kW. Coefficient a should be a non-negative value. There is an option also to estimate these coefficients from the values of the specific consumption of the unit (in kgr/MWh) at three power levels (in kW).

Fuel cost: Cost of fuel, in €/kgr. It is used for the commitment of the most cost effective units among conventional generators, in order to cover the hourly load.

Number of linear segments: An integer value in the range 1-10. Number of linear segments for the linearization of the second order polynomial function of fuel consumption.

The Starting or Shutting Down cost of the Unit is not taken into account, as for this type of generators used in small electrical systems (usually diesel gensets), is almost negligible.

*Storage Interface*

Type: The type of the Storage Interface may be selected among Converter/Generic. Option Generic allows the setting of a non-zero minimum value for the Storage Interface Unit.

Maximum value in positive direction: The maximum value, in kW, in positive direction, e.g. in ‘discharging’ operation. This is the nominal value of the unit, at the AC side.

Maximum value in negative direction: The maximum value, in kW, in negative direction, e.g. in ‘charging’ operation. The maximum value in the negative direction should be entered as a negative value, prefixed by the minus sign (-). For the case of a bi-directional converter a value equal to the maximum value in positive direction divided by the ‘charge’ efficiency (i.e. in negative direction) is recommended.

Minimum value in positive direction: The minimum value, in kW, in positive direction, i.e. in ‘discharging’ operation. This option is available if Storage Interface is of type Generic.

Minimum value in negative direction: The minimum value, in kW, in negative direction, i.e. in ‘charging’ operation. The minimum value in the negative direction should be entered as a negative value, prefixed by the minus sign (-). This option is available if Storage Interface is of type Generic.

Efficiency in positive direction: The efficiency of the Storage Interface Unit for energy conversion in the positive direction, i.e. in ‘discharging’ operation. A positive value smaller or equal to 1 should be entered.

Efficiency in negative direction: The efficiency of the Storage Interface Unit for energy conversion in the negative direction, i.e. in ‘charging’ operation. A positive value smaller or equal to 1 should be entered.

The Storage Interface unit is the interface unit between the storage unit (e.g. battery) and the AC bus, where the rest electrical units are connected. Typically for a battery this would be a power electronics device, a power converter. A constant value for the efficiency of the Storage Interface is used, in charge or discharge operation, expressing an average value for the various operating conditions. For power converters, which usually have an almost constant efficiency for a large range of operating conditions, this is a reasonable approximation.

*Battery Unit*

Nominal capacity Qnom: The nominal capacity of the Battery, in Ah.

Voltage: The voltage of the battery bank, in Volts. A positive value of the battery bank voltage should be entered, though the exact value does not affect the results.

The important parameter is the available storage energy, i.e. the product of the nominal capacity and the voltage.

Round-trip efficiency: The efficiency of the energy conversion during a complete charge-discharge cycle of the battery, under typical operating conditions. A positive value smaller or equal to 1 should be entered, expressing an average round-trip efficiency under typical operating conditions.

Maximum SOC: The maximum value of State of Charge (SOC) of the battery during operation.

Minimum SOC: The minimum value of State of Charge (SOC) of the battery during operation.

SOC values are entered as real numbers in the range 0-1. Value 1 (100%) corresponds to full battery, value 0 (0%) corresponds to empty battery. The allowable maximum and minimum values of SOC are related to the battery technology which is used.

Ratio Qmax/Qnom, fraction c, flowrate k: These are the parameters of the battery according to the kinetic battery model which is used for the modelling of the battery in the program. This models the battery as two conducting tanks, as presented in [1]. Ratio Qmax/Qnom defines the maximum capacity Qmax of the battery in relation to Qnom. This maximum capacity is meant as the capacity of the battery at a very slow rate of discharge. Fraction c is a ratio defining the sizes of the two tanks and flowrate k is the rate of flow between the two tanks, in units hrs-1. These parameters can be extracted from manufacturers’ data, as described in reference [1], for a specific manufacturer’s model. Some typical values are available for each technology of the options of the Type parameter of the Battery Unit.

Type: The type of the Battery Unit may be selected among Lead\_bat (Lead acid battery technology) /Li\_bat (Lithium battery technology)/Generic. For each option selected, some default values of the parameters of the kinetic battery model are available, which can be used by the user as typical values. For all the types the same kinetic battery model is used. The default values of the Generic option diminish the two-tank model to one tank.

*Flexible Load*

Maximum value in positive direction: The maximum value, in kW, in positive direction, i,e. the maximum power of the extra flexible load.

Maximum value in negative direction: The maximum value, in kW, in negative direction. The maximum value in the negative direction should be entered as a negative value, prefixed by the minus sign (-).

Minimum value in positive direction: The minimum value, in kW, in positive direction.

Minimum value in negative direction: The minimum value, in kW, in negative direction. The minimum value in the negative direction should be entered as a negative value, prefixed by the minus sign (-).

File of ON-positive direction: A file with binary values (0/1). Hourly Value of 1 means that the Unit must be operating (ON) that hour. In this case the operating value of the unit in the positive direction is equal to the minimum value at least.

File of OFF-positive direction: A file with binary values (0/1). Hourly Value of 1 means that the unit cannot be used as extra load, in the positive direction, that hour.

This unit is a flexible load, positive operating values are added to the load of the system (as indicated by the direction of the arrow on the line connected to the symbol of the flexible load). It represents an extra flexible load which can be switched on whenever there is surplus of energy, in the case of power flow in the positive direction. Negative values (power flow in negative direction) represent rejection of load. This may occur whenever there is an energy shortage.

*System operation settings*

Minimum conventional generation value: The minimum value of the percentage of the hourly value of load which should be covered by conventional generation. A value in the range 0-100. If the option ‘Conventional plus storage’ is selected, then this percentage of load may be covered by both conventional generators and the available energy from storage systems.

This limit is usually set for reasons of dynamic stability of the electrical system.

Reserves: There are three options for the setting of the operational reserves.

No check: No check is performed for the required capacity of the operating conventional generators.

Percentage increase: In this option, the capacity of the operating conventional generators for each hour should be higher than the value of the net load (load minus RES) plus a percentage of the load, the wind generation, the PV generation or the annual peak of the load. All these percentages of the selected values are added to the net load value. If the option ‘Include storage for reserves fulfillment’ is selected, then this requirement may be covered by both conventional generators and the available energy from storage systems.

N-1 of conventional generators: In this option the capacity of the operating conventional generators should be able to cover the load in case of failure of the largest conventional generator.

If the required capacity cannot be met then a nonzero Error Code is recorded for that hour, which can be viewed after exporting the results.

Operation Mode: There are three options for the operation mode.

Use storage as possible. This is the main operation mode, where the storage is used as much as possible, in order to cover efficiently the load, complying to the various constraints which may have been set.

Use storage as required. In this mode some different procedures are used for some calculations. In most cases however the results are similar to the previous option. The charging of the storage systems is utilized in order to avoid curtailments of the RES units (this may affect mostly the shares of curtailments among individual RES units). Also, by default in this mode, the commitment of the conventional generators is based on the hourly value of the net load, without taking into account the available discharge energy of the storage units.

Grid connected mode. In this mode the system under consideration is supposed to be connected to a larger system. Any local imbalance energy is supposed to be exchanged (imported or exported) with the larger system. In this mode conventional generators typically are not utilized. Storage systems also behave differently depending if they are part of a hybrid plant or not. In particular, storage that is not part of hybrid plants is charged by the surplus of energy in the local system, storage of hybrid plants is charged only by the RES energy of the hybrid plant that is higher than the maximum limit value of the hybrid plant. In this operation mode the local load is supplied by energy produced by RES units, then by storage and if required by energy imported by the grid (storage which is not part of hybrid plants is utilized first, and then storage of hybrid plants). If there is a local surplus of energy by the RES units, the surplus is utilized by storage that is not part of hybrid plants and then by flexible load, and if this is not adequate the surplus is exported (instead of being curtailed, as in the other modes). If there is a hybrid plant in the system, then the storage system of the plant is charged only by the part of the production of the RES units of the hybrid plant which is higher than the maximum limit of the hybrid plant. The part of the RES production which is higher than the maximum limit of the hybrid plant and cannot be accepted by the storage system, is curtailed.

The calculations are performed hour by hour, and no schedule for any time horizon is performed. If the demand/supply balance cannot be met by complying to all constraints, then the hourly imbalance energy is calculated and recorded. For the two first operation modes this concerns unmet or excess energy of the electrical system and of course this should not occur in a real application.

Besides the Components menu option, the following menu options are available.

File menu option. With this menu option the user can select an existing working directory (for opening and saving files), start a new project, exit program, save a project or open an already saved project (file with extension prj). A saved project stores the system components and their parameters (no results are saved).

Run menu option. With this menu option the simulation of the operation of the system is performed, for a specified number of hours (with a maximum number of hours equal to 8760).

Results menu option. With this menu option the user can view or export the results of the simulation. A table with the main operation data of the components for each hour is shown on the Results window, together with aggregated values for each type of component. A descriptive name of the data of each column is available on each column header. With the button ‘Summary’ accumulated key results over the simulated hours are presented. The button ‘View’ is used for a quick view of the results, after selection of columns or a row of the table. A column or a row may be selected by clicking on the column or row header. Multiple columns may be selected by clicking on the column header with the Ctrl key pressed. A plot of the values of the selected columns is available on the evolving window. Zooming can be accomplished by selecting an area with the left button of the mouse, moving to the right and bottom of the screen. Un-zooming is accomplished by moving the mouse in the opposite direction. The button ‘Export’ is used for exporting the data in an ASCII file, for further processing and visualization by more specialized software tools. The user can select the data to be exported from the various components (multiple selection is possible by pressing the Ctrl key). The file with the exported columns includes a header row with a descriptive name of each column. Aggregated data of the system can be exported also, including a column with an error code of the hourly simulation, with discrete values of the following meaning:

0: OK ; 1: Energy unmet ; 2:Capacity unmet ; 4:Energy excess ; 8: Minimum conventional generation limit unmet ; 16: Unexpected error, wrong results.

*DISTRIBUTION FILES*

The program is provided with the following files:

1.Flexxy.exe

2.Lpsolve55.dll

3.Binary\_Template.csv : Example for using as input file of binary values (0 or 1 values)

4.Template\_Load.csv: Example for using as input file for load values (example of the load of a typical small Mediterranean island)

5.Template\_PV.csv: Example for using as input file for a RES unit (example of hourly values of the output of a PV plant in Mediterranean area, generated by simulation)

6.Flexxy instructions.docx: Instructions on using the program

The first two files are required in order to run the program.

Note: Flexxy is a free Windows program developed with the Lazarus IDE, and uses the LPsolve linear programming system ( <https://sourceforge.net/projects/lpsolve/> ).

References

[1] J. Manwell, J. McGowan ‘Lead acid battery storage model for hybrid energy systems’, Solar Energy Vol.50, No 5, pp399-405, 1993