BTES_StandAloneTool_GUIv5

Stand-alone MATLAB-TRNSYS model

Table of Content

Model description 1

Structure, folders and files 2

How to use the tool 3

1. Install MATLAB Runtime (no license required) 3
2. Start the application 3

2.1 Set Default Parameters 4

2.2 Check Inputs 4

2.3 Design BTES System 4

2.4 Evaluate Performance 4

2.5 See Results 4

Additional notifications and messages 5

Ranges and limitations 6

Model description

This model simulates the behavior of a BTES system coupled to a combined heat and power plant. The system is shown in a simplified diagram, *Figure 1*. In it, there are two operational modes. During summer, the BTES system is charged, using hot water from the CHP plant's steam condenser outlet. During winter, the BTES system is discharged and the heat is used to preheat the inlet to the CHP plant's condenser. During the winter operation, a heat pump is used to help rise the water temperature. A detailed description of the variables and parameters used by the model is available in the user interface of the tool, section "1.Define Default Parameters" (more details are presented in section 2.1 of this document)

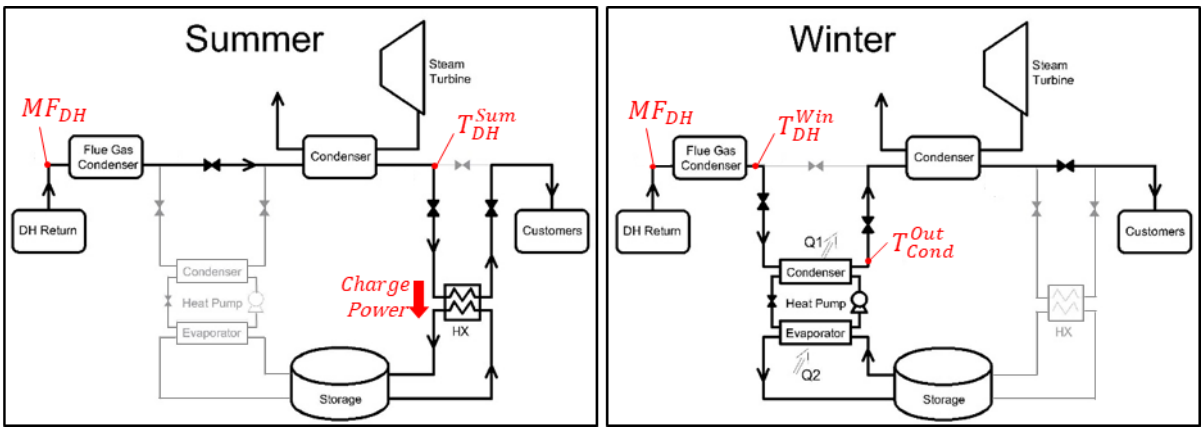


Figure 1. BTES system. Left, summer operation – Right, winter operation

Structure, folders and files

All the files have been gathered and organized in the main folder “BTES_StandAloneTool_GUIv5”. This main folder can be directly copied and pasted in any location of any PC, as long as the path does not contain any points “.” in it. For example, the path in Figure 2 is not valid because of the point character “.” in “WP3.1”. Any points in the path would cause the application to stop reading the path and the required files would not be found.

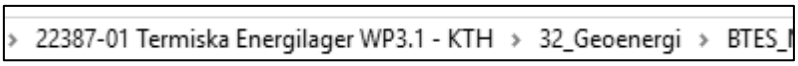


Figure 2. Invalid path for the folder BTES_StandAlone_v15

The main folder contains six items (see Figure 3). The folder **“DataFromUser”** contains text files with daily averaged information of relevant mass flows and temperatures values, used as inputs for the model if this feature is selected by the user when defining the default parameters in section “1.Define Default Parameters”. A description of this feature and files is provided in the file “About the input files.pdf”. The user can access this file by clicking on the button “About the input files” in the help section on the user interface (see Figure 4**Error! Reference source not found.**). The folders **“MATLABfiles”** and **“TRNSYSfiles”** contain the required files required for the model to work properly. **There is no need to open or edit any files within these two folders**. The folder **“Results”** contains the results of the simulations; these are summarized in one excel file, “BTES_simulation_results.xlsx”, and supported with additional plots and graphs of some of the key performance indicators. These results are available in this folder; however, they can also be accessed directly via the user interface, section “5. See Results” (see Figure 4). The other two files in the main folder are **“MyAppInstalle_web.exe”** for installing MATLAB runtime, and **“BTES_StandAloneTool_GUIv5.exe”** for starting the stand-alone tool user interface.

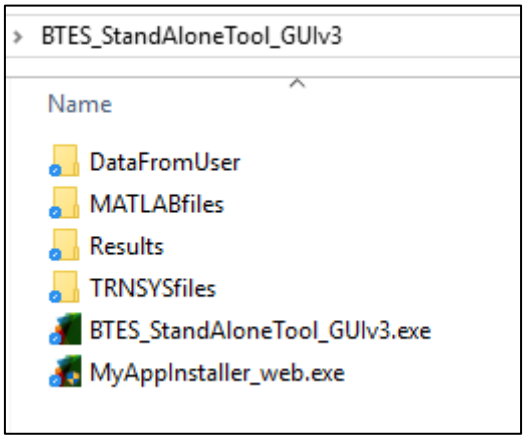


Figure 3. Main Folder

How to use the tool

1. Install MATLAB Runtime (no license required)

The MATLAB Runtime is a standalone set of shared libraries that enables the execution of compiled MATLAB applications or components without the need of MATLAB licenses. To install MATLAB Runtime, simply double click the file "MyAppInstalle_web.exe" (located in the main folder "BTES_StandAloneTool_GUIv5") and follow the instructions. This step (installing MATLAB runtime) is only required for the first time the application is used. Additional information is available in the file "MATLAB Runtime.txt", in the "MATLABfiles" folder.

2. Start the application

To start the application, double click on the file **"BTES_StandAloneTool_GUIv5.exe"**. The application might take a couple of seconds to start, especially when started for the first time.

The user interface is presented in Figure 4. It has seven sections. The sections 1 to 5 follow the simulation process (define inputs, check inputs, design the system, evaluate the performance, see the results). The two additional sections are "Help Section" and "Message Window". In the help section the user can find additional information about the parameters used in section "1. Define Default Parameters". The user can also access the files "BTES_StandAloneTool_GUIv5.pdf" and "About the input files". In the message window, the user can follow any warnings or results during the simulation process. Note that the full results are available in section "5. See Results".

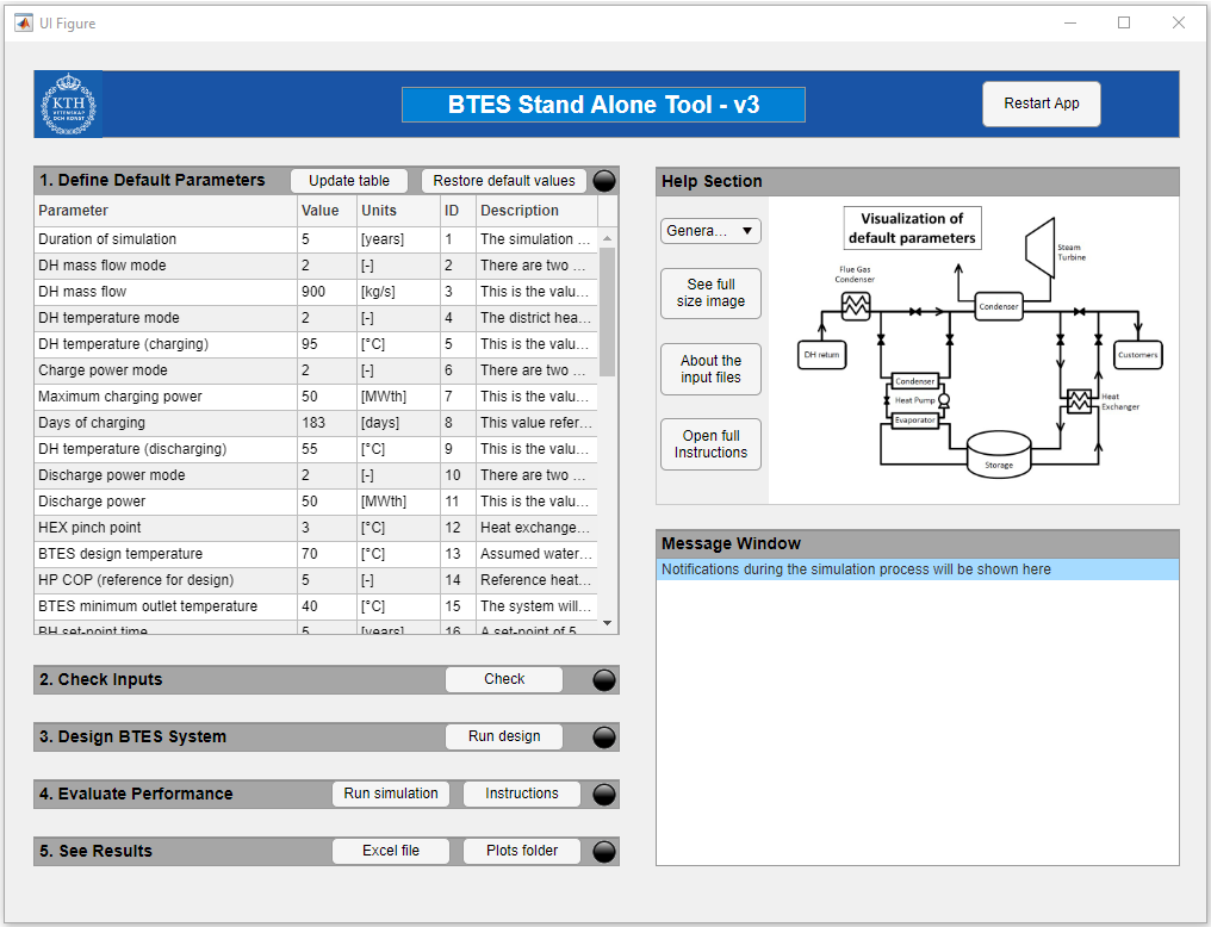


Figure 4. User Interface

2.1 Set Default Parameters

Before running a simulation, the user can edit the values in the column "Value" of the section "1. Define Default Parameters". Notice that each parameter has an identification number for easier referencing (column "ID"), as well as a description (displayed fully when hoovering the cursor over the description). The user can only edit the fields in the column "value" (i.e. not the units). Once the desired values are entered, click on the button "Update table". The indicator (black circle on the right hand side of the section heading) will turn green if the inputs have been input correctly. **For additional information about the ranges and limitations of this simulation tool, please refer to the section "Ranges and limitations" at the end of this document.**

2.2 Check Inputs

This section is to make sure the inputs defined are valid without having to run the full simulation. Click on the button "Check". If the inputs are valid, the indicator will turn green and a message will appear in the message window. If there is a problem with the inputs, you will receive a message with more information about the error.

2.3 Design BTES System

This section will find a feasible design that satisfies the parameters defined in the first section. To start it, click on the button "Run Design". During the design process, the indicator should turn amber, indicating that the tool is busy sizing the components. Once finished, the indicator turns green, indicating that a design has been found. The preliminary results of the design process are shown in the message window when finished. If there is an error in this stage, the simulation will stop and the error message will appear on the message window.

2.4 Evaluate Performance

To evaluate the performance of the system designed, click on the button "Run simulation". This will launch the TRNEdit application, which starts the simulation in the dynamic model developed in TRNSYS. Detailed information about how to navigate on the TRNEdit environment can be found in the file "TRNEdit instructions". You can access this file by clicking on the button "Instructions" in the heading of section "4. Evaluate Performance".

2.5 See Results

Once the dynamic simulation is finished, the information is post-processed (this might take a few seconds, the indicator should turn amber (busy calculating) and relevant information about the status of the process will be displayed in the message window. After post-processing, the results will be available. You can access to these files directly through the buttons in section 5, or going to the folder "Results" in the Windows environment.

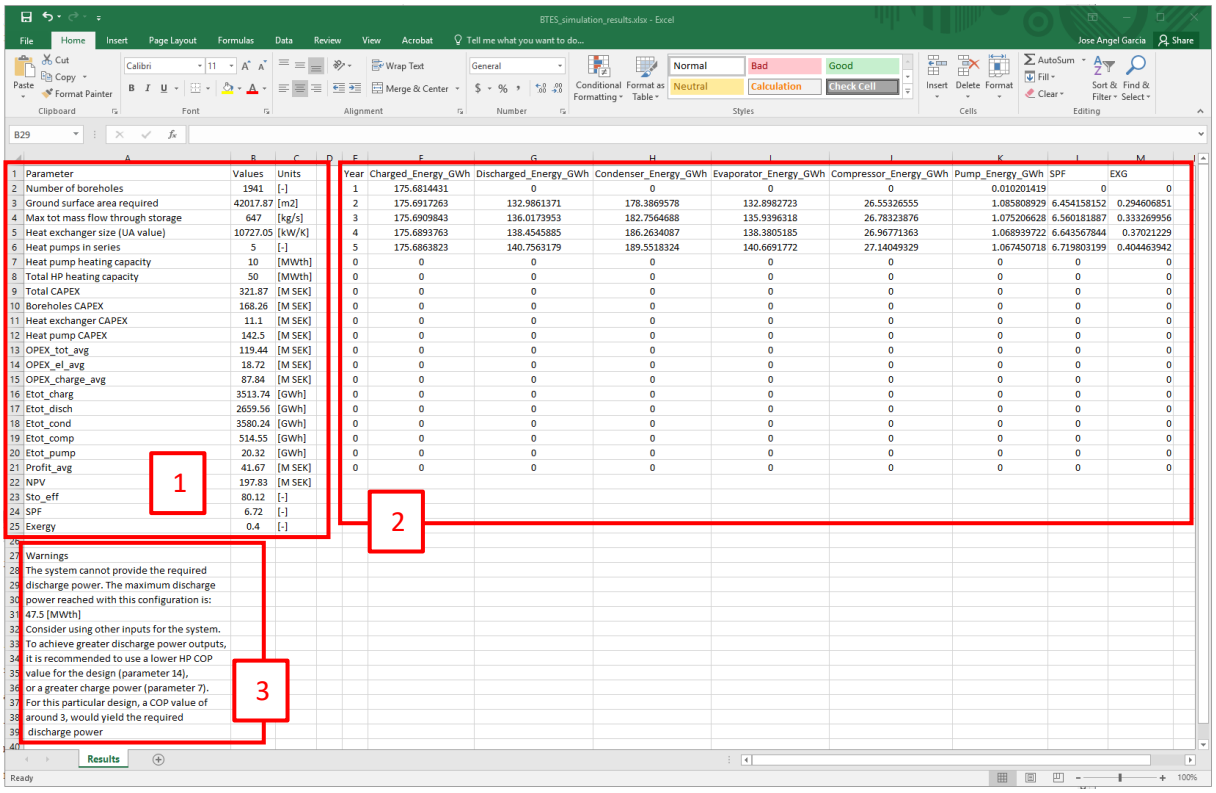
The excel file "BTES_simulation_results" has two sheets. In the first sheet, "Summary", there are three sections (see Figure 5).

Section 1 provides a summary of the results including design results (e.g. number of boreholes, ground area required, etc.) and performance results (e.g. energy used for charging, energy delivered, OPEX, NPV, etc.). Since the performance of the system changes from year to year, the OPEX value reported in this section is the average yearly OPEX (averaged considering the lifetime of the system, parameter 43). The energies and profits reported in this section also account for the total lifetime of the system (these are not averaged but totalized). For the NPV calculations, it is assumed that the years after the last simulated year (in this case, years 6 to 20) have the same performance as the last year simulated (year 5). Finally, the las three results reported in this section, efficiency, SPF and exergy, are the results of the last year of the dynamic simulation (year 5).

Section 2 provides with annual values of energies. Only the simulated years are shown (years 1 to 5). As mentioned before, for the techno economic KPIs (e.g. NPV) this values are assumed constant throughout the lifetime of the system (in this case, years 6 to 20).

Section 3 shows warnings (if any). In the example below it is shown how the model could not find a design able to provide the required discharge power. Instead, it found the maximum discharge power such system could provide. It also shows what would be a tentative COP value to reach the required original discharge power (this condition is further explained in the next section of this document).

The second sheet of the file, "Hourly results", has daily averaged values of relevant variables such as temperatures in and out of the components, mass flows, powers, etc.



	Parameter	Values	Units
2	Number of boreholes	1941	[-]
3	Ground surface area required	42017.87	[m2]
4	Max tot mass flow through storage	647	[kg/s]
5	Heat exchanger size (UA value)	10727.05	[kW/K]
6	Heat pumps in series	5	[-]
7	Heat pump heating capacity	10	[MWth]
8	Total HP heating capacity	50	[MWth]
9	Total CAPEX	321.87	[M SEK]
10	Boreholes CAPEX	168.26	[M SEK]
11	Heat exchanger CAPEX	11.1	[M SEK]
12	Heat pump CAPEX	142.5	[M SEK]
13	OPEX_tot_avg	119.44	[M SEK]
14	OPEX_el_avg	18.72	[M SEK]
15	OPEX_charge_avg	87.84	[M SEK]
16	Etot_charg	3513.74	[GWh]
17	Etot_disch	2659.56	[GWh]
18	Etot_cond	3580.24	[GWh]
19	Etot_comp	514.55	[GWh]
20	Etot_pump	20.32	[GWh]
21	Profit_avg	41.67	[M SEK]
22	NPV	197.83	[M SEK]
23	Sto_eff	80.12	[-]
24	SPF	6.72	[-]
25	Exergy	0.4	[-]

Year	Charged_Energy_GWh	Discharged_Energy_GWh	Condenser_Energy_GWh	Evaporator_Energy_GWh	Compressor_Energy_GWh	Pump_Energy_GWh	SPF	EXG
1	175.6814431	0	0	0	0	0.010201419	0	0
2	175.6917263	132.9861371	178.3869578	132.8982723	26.55326555	1.085808929	6.454158152	0.294606851
3	175.6909843	136.0173953	182.7564688	135.9396318	26.78323876	1.075206628	6.560181887	0.333269956
4	175.6893763	138.4545885	186.2634087	138.3805185	26.96771363	1.068939722	6.643567844	0.37021229
5	175.6863823	140.7563179	189.5518324	140.6691772	27.14049329	1.067450718	6.719803199	0.404463942
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

Warnings
The system cannot provide the required discharge power. The maximum discharge power reached with this configuration is:
47.5 [MWth]
Consider using other inputs for the system.
To achieve greater discharge power outputs, it is recommended to use a lower HP COP value for the design (parameter 14), or a greater charge power (parameter 7).
For this particular design, a COP value of around 3, would yield the required discharge power

Figure 5. BTES_simulation_results

Additional notifications and messages

It is possible that the model does not find a solution for the input parameters set by the user. For example, if the charging power (provided by the CHP during summer for charging the BTES) is too low for the discharging power required (provided by the BTES during winter), the model might not find a solution because there will not be enough heat stored in the BTES for covering the demand.

There are plenty of variables and parameters the user can change for the model to find a solution. The main three parameters are the "Charge power" (parameter ID 7), the "Discharge power" (parameter ID 11) and the "HP COP" (parameter ID 14). By increasing the charging power or decreasing the discharging power, the model will be able to find a solution, i.e. would find a design that satisfies the

requirements. In a similar way, by lowering the HP COP (defined as HP heating capacity to electric power ratio), the model will converge to a solution since this parameter effectively changes the ratio of heat output from the HP to heat input to the HP, Q1 and Q2 in Figure 1, right-hand side. In such case (lowering the COP) the boreholes would need to store less energy and the HP's compressor would consume more electricity to cover the required demand.

If the model cannot find a solution for the parameters set by the user, it will automatically try to find a recommended COP value. This condition will be notified in the message window. Then, with the original COP defined by the user, the tool will determine what is the maximum discharge power possible for the system and continue the simulation for this new discharging power.

Additional messages include:

- Additional message number 1: Occurs when the difference between the temperature of the DH water used for charging the storage (temperature of water entering the hot side of the heat exchanger, parameter ID 5) and the BTES design temperature (temperature of water leaving the BTES and entering the cold side of the heat exchanger at the design point, parameter ID 13) is less than the heat exchanger pinch point temperature (parameter ID 3).

- Additional message number 2: Occurs when the model did not find a solution for the requirements defined by the user, then tried to find a recommended COP value or a maximum discharge power possible but did not succeed.

- Additional message number 3: Occurs when the charging power (parameter ID 7) is less than 50% of the discharging power (parameter ID 11). In this case, the model will not even look for a recommended COP value nor will it find the maximum discharge power achievable. The recommended action is either to lower the discharge power requirement or to increase the charging power available.

Ranges and limitations

This simulation tool was developed starting from a reference BTES system design. This reference system has a capacity of 50 MW; i.e., the components are sized for a maximum charging power of 50 MW and a maximum discharge power of 50 MW. The heat pump model used in these simulations was developed for this particular configuration and consists on mathematical correlations derived from data provided by a heat pump manufacturer. This heat pump model can be used for configurations with maximum discharge powers between 10 and 90 MW (heat injected into the district heating network). The charging and discharging power (heat exchange) in thermal systems can be scaled up/down by changing either the temperature levels or changing the mass flows to be handled. It is assumed that temperatures in this application (BTES←→DH) are relatively similar for different installations (DH supply temperature is normally 55°C, boreholes outlet temperature is around 40-60 °C, charging temperature 95 °C, etc.). Therefore, it is recommended to use similar temperatures to those set by default in the user interface and scale up/down the system by changing the mass flow it handles. It is possible, however, to run simulations with different temperature levels.

One problem encountered within the design stage of process is that, under certain conditions, the code does not find a solution (a number of boreholes) such that the design conditions defined are met. In general, this problem occurs when the discharge power (heat injected in the DHN) is larger than the

charge power (heat injected in the BTES). It is true that there is a HP consuming electricity and adding up heat to the heat delivered by the boreholes. In this case, the HP is compensating for factors such as the charging power not being constant (when the BTES is “hot”, it cannot absorb as much heat as when it is “cold”), and that there is a gradient of temperature across the storage (the heat is not evenly extracted from the storage volume). The approach adopted to work around this problem is to use the discharging power as an “aiming target”. The design process will start as usual but if the code does not find a number of boreholes such that the required condition is met, the discharging power will be “relaxed”. Then, the discharge power will be re-written to a fraction of its original value (e.g. 97% of its original value), and the process will start again. Eventually the code will find a solution and report this situation in the final results, explaining that under the conditions defined (charging and discharging powers, temperatures, mass flows, etc.) the required discharge power was not met, and the maximum power achieved by the system was 97% of its original value (or whatever that final value is). It is also shown in the results what would be a tentative COP value for the system to reach the required discharging power.

It is worth noting that a choosing a different COP value will not change the HP itself, but will change the ratio of heating/cooling capacity the HP is going to be operating on the dynamic model. Lower COP values will result in lower required heating outputs from the BTES (higher HP contribution during operation).