THERMAL AND POWER GRID LIBRARY DEVELOPMENT + USER MANUAL

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INTRODUCTION

This package of the library is to simulate thermal and power grids including single buildings to larger power and district-heating systems. The purpose of this library is to provide modularity and flexibility to facilitate reusability of the models with ease. The simplicity of the current models enable clarity in the modelling hence enabling further modifications.

The sub packages of this model contain the components and sub-components required for small to large scenario simulations. This version facilitates the annual simulation of scenarios and hence the complexity of the component models equations is kept moderate.

OBJECTIVE

The objective of this project is to model and simulate Energy and Grid models of low to medium complexity. The Power grid scenarios are to have power sources like Solar PV, wind energy, etc and consumptions like car charging, domestic consumption, etc. Similarly, the thermal energy models are to have sources like solar CSP, biomass boiler with consumption such as domestic space heating, industrial consumption. It is also to have large thermal storage to store excess energy and to utilize in times of deficit energy supply.

Note: The library Energy and Grid Modelica models to run with Open Modelica has been developed for Linköping University, Sweden.

1. THE POWER GRID LIBRARY

1.1. LIBRARY STRUCTURE

Figure 1, shows the structure of the library. The main sections of the libraries are *“Interfaces”*, *“Utilities”*, *“Components”* and *“Grid Scenarios”*.

- **Interfaces:** This sub package contains the port used in the library.
- **Utilities:** This sub package contains the system parameters and data import related modules.
- **Components:** This sub package contains the grid component modules like power generation, system management, storage, load modules and etc.
- **Grid Scenarios:** This sub package contains the inbuilt grid scenario examples.

There are four library examples in the grid scenarios sub package. Scenario-1 to 4 representing single house, group of houses, city and country grid scenarios. Each scenario can be run directly and corresponding parameters for the simulation are already incorporated with default values in the system parameters of the corresponding scenario.

All the data files related to the library are kept in the resource folder of the package.

Assumptions:

- The library has simplified equations in each of the models.
- The example scenarios and the sample data are close to real scenarios but does not include the actual or physical data (For scenario 1 to 3).
- The model like “Charging station” is a hypothetical model in the current version of the library.

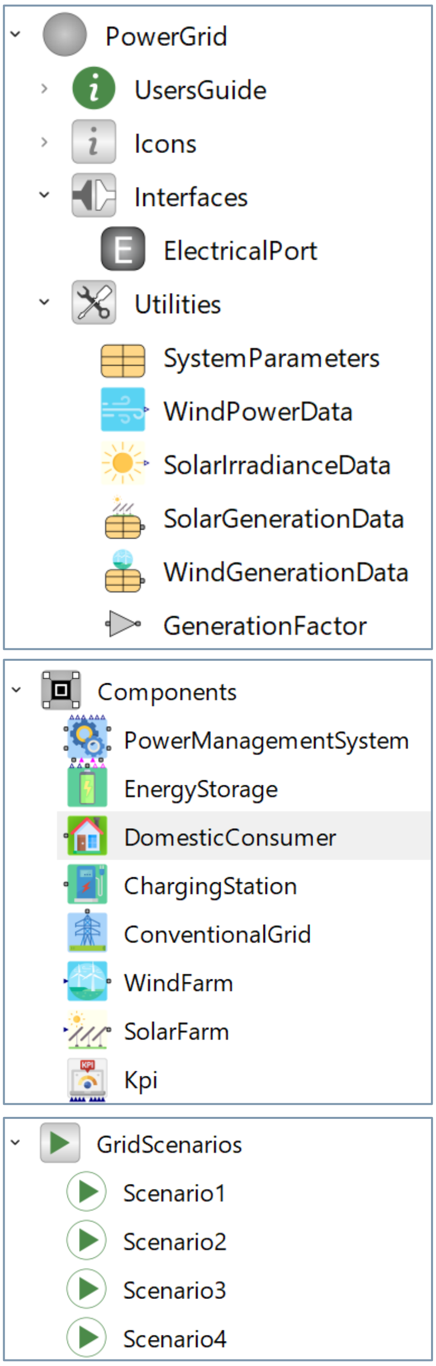


Figure-1: Power grid package

1.2. LIBRARY SECTION DETAILS

1.2.1. INTERFACES

The library uses mainly one dedicated interface port called as *"Electrical Port"*. The port has two variables *"Power"* and *"Voltage"*. Where power variable is flow type & voltage variable is potential type. At present version the voltage variable is kept as dummy.

1.2.2. UTILITIES

The library system parameters and data files related modules are kept under this sub package. There are three main modules namely *"System Parameters"*, *"Wind Power Data"* and *"Solare Power Data"*. The sample data for solar irradiance, wind speed and domestic power demand are obtained from the data sources as explained below,

The raw solar irradiance hourly data for the library is taken from the "Swedish SMHI (weather institute)" for the Norrköping location (As shown in Figure 2). The raw data is interpreted using a python script to segregate "direct irradiance data" and "global irradiance data" (for the thermal grid package). The segregated data file is shown in Figure 3.

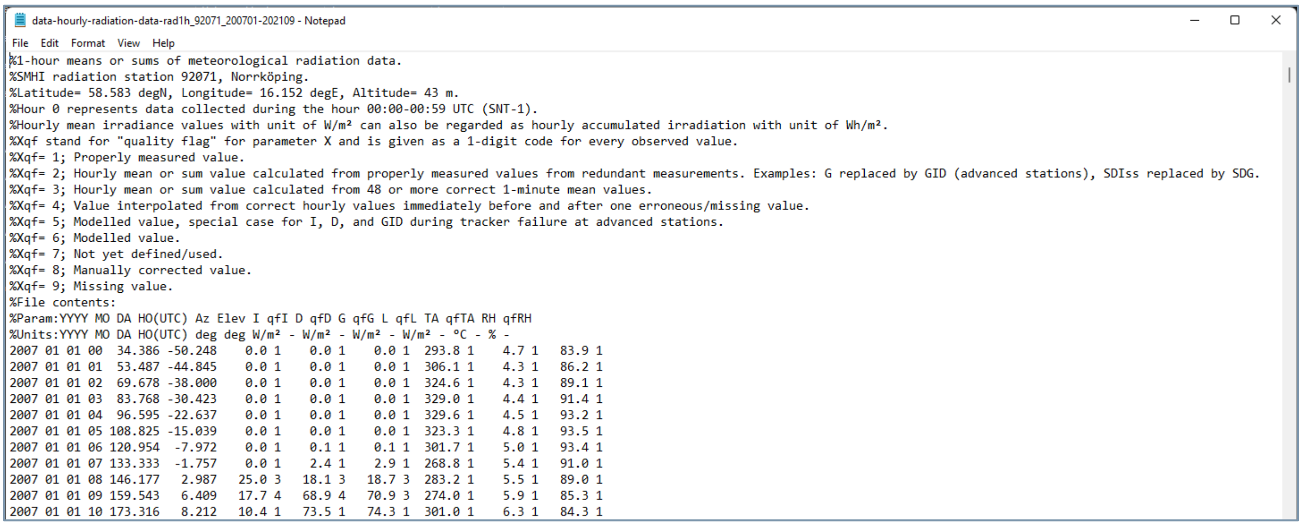
The wind speed hourly data for the library is taken from the IEEE open access data base titled "8 years of hourly heat and electricity demand for a residential building". The web link for the data is "https://ieee-dataport.org/open-access/8-years-hourly-heat-and-electricity-demand-residential-building". From the downloaded data wind speed is manually extracted and put into the combi table.

Similarly, the hourly domestic power consumption data is also taken from the above said IEEE open access database. The database screenshot showing wind speed and electricity demand values are shown in Figure 4. The demand data extracted from the data base is stored in multiple text file corresponding to the scenarios (1 to 3). The data from the database directly corresponds to the scenario-2 (group of houses) demand, for the other scenarios the data is downscaled and upscaled accordingly and then stored in the text files.

For country scenario of electrical grid, solar generation data, wind generation data and electrical demand data for "Netherland" for the year 2016 is extracted from the "Open Power System Data". The data source file screenshot is shown in figure 5. The web link for the data is https://data.open-power-system-data.org/time_series/2020-10-06.

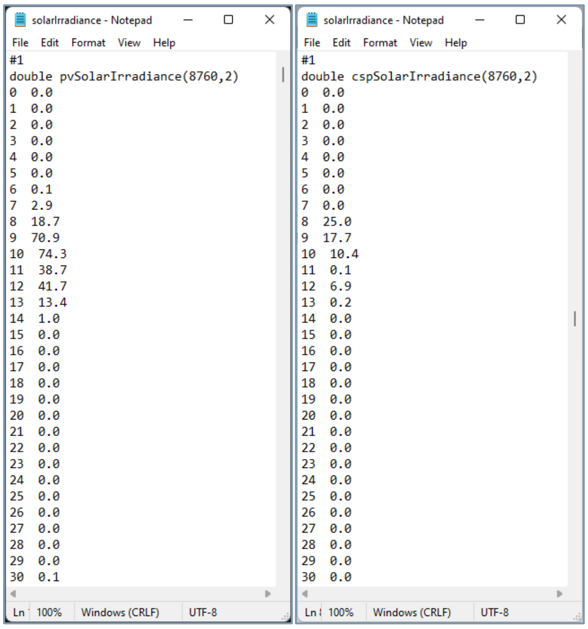
For country scenario of thermal grid, solar irradiance data, air temperature data and space heating demand data for "Netherland" for the year 2013 is extracted from the "Open Power System Data". The data source file screenshot is shown in figure 6. The web link for the solar irradiance and air temperature data is https://data.open-power-system-data.org/weather_data/2020-09-16 and for space heating demand data is https://data.open-power-system-data.org/when2heat/2022-02-22.

The above said data extraction is done using a python script which is placed in the resource folder. All the data sources and extracted text files used in the library is stored in the resource folder (As shown in Figure 7.



```
data-hourly-radiation-data-rad1h_92071_200701-202109 - Notepad
File  Edit  Format  View  Help
%1-hour means or sums of meteorological radiation data.
%SMHI radiation station 92071, Norrköping.
%Latitude= 58.583 degN, Longitude= 16.152 degE, Altitude= 43 m.
%Hour 0 represents data collected during the hour 00:00-00:59 UTC (SNT-1).
%Hourly mean irradiance values with unit of W/m² can also be regarded as hourly accumulated irradiation with unit of Wh/m².
%Xqf stand for "quality flag" for parameter X and is given as a 1-digit code for every observed value.
%Xqf= 1; Properly measured value.
%Xqf= 2; Hourly mean or sum value calculated from properly measured values from redundant measurements. Examples: G replaced by GID (advanced stations), SDIss replaced by SDG.
%Xqf= 3; Hourly mean or sum value calculated from 48 or more correct 1-minute mean values.
%Xqf= 4; Value interpolated from correct hourly values immediately before and after one erroneous/missing value.
%Xqf= 5; Modelled value, special case for I, D, and GID during tracker failure at advanced stations.
%Xqf= 6; Modelled value.
%Xqf= 7; Not yet defined/used.
%Xqf= 8; Manually corrected value.
%Xqf= 9; Missing value.
%File contents:
%Param:YYYY MO DA HO(UTC) Az Elev I qfI D qfD G qfG L qfL TA qfTA RH qfRH
%Units:YYYY MO DA HO(UTC) deg deg W/m² - W/m² - W/m² - W/m² - °C - % -
2007 01 01 00  34.386 -50.248    0.0 1    0.0 1    0.0 1  293.8 1    4.7 1   83.9 1
2007 01 01 01  53.487 -44.845    0.0 1    0.0 1    0.0 1  306.1 1    4.3 1   86.2 1
2007 01 01 02  69.678 -38.000    0.0 1    0.0 1    0.0 1  324.6 1    4.3 1   89.1 1
2007 01 01 03  83.768 -30.423    0.0 1    0.0 1    0.0 1  329.0 1    4.4 1   91.4 1
2007 01 01 04  96.595 -22.637    0.0 1    0.0 1    0.0 1  329.6 1    4.5 1   93.2 1
2007 01 01 05 108.825 -15.039    0.0 1    0.0 1    0.0 1  323.3 1    4.8 1   93.5 1
2007 01 01 06 120.954  -7.972    0.0 1    0.1 1    0.1 1  301.7 1    5.0 1   93.4 1
2007 01 01 07 133.333  -1.757    0.0 1    2.4 1    2.9 1  268.8 1    5.4 1   91.0 1
2007 01 01 08 146.177   2.987   25.0 3   18.1 3   18.7 3  283.2 1    5.5 1   89.0 1
2007 01 01 09 159.543   6.409   17.7 4   68.9 4   70.9 3  274.0 1    5.9 1   85.3 1
2007 01 01 10 173.316   8.212   10.4 1   73.5 1   74.3 1  301.0 1    6.3 1   84.3 1
```

Figure-2: Raw solar irradiance data file sourced from the SMHI



```
solarIrradiance - Notepad
File  Edit  Format  View  Help
#1
double pvSolarIrradiance(8760,2)
0  0.0
1  0.0
2  0.0
3  0.0
4  0.0
5  0.0
6  0.1
7  2.9
8  18.7
9  70.9
10  74.3
11  38.7
12  41.7
13  13.4
14  1.0
15  0.0
16  0.0
17  0.0
18  0.0
19  0.0
20  0.0
21  0.0
22  0.0
23  0.0
24  0.0
25  0.0
26  0.0
27  0.0
28  0.0
29  0.0
30  0.1
Ln  100%  Windows (CRLF)  UTF-8
```

```
solarIrradiance - Notepad
File  Edit  Format  View  Help
#1
double cspSolarIrradiance(8760,2)
0  0.0
1  0.0
2  0.0
3  0.0
4  0.0
5  0.0
6  0.0
7  0.0
8  25.0
9  17.7
10  10.4
11  0.1
12  6.9
13  0.2
14  0.0
15  0.0
16  0.0
17  0.0
18  0.0
19  0.0
20  0.0
21  0.0
22  0.0
23  0.0
24  0.0
25  0.0
26  0.0
27  0.0
28  0.0
29  0.0
30  0.0
Ln  100%  Windows (CRLF)  UTF-8
```

Figure-3: Segregated solar irradiance data files for power & thermal grid models

	A	E	H
1	Time	wind_speed[M/S]	electricity_demand_values[kw]
2	01-12-2010 00:00	5	289.5675565
3	01-12-2010 01:00	7	260.1685203
4	01-12-2010 02:00	7	247.2735849
5	01-12-2010 03:00	2	257.9558777
6	01-12-2010 04:00	3	258.2550812
7	01-12-2010 05:00	3	277.5774811
8	01-12-2010 06:00	4	337.4235034
9	01-12-2010 07:00	2	436.8706332
10	01-12-2010 08:00	3	426.7612808
11	01-12-2010 09:00	2	337.8045938
12	01-12-2010 10:00	2	312.6359362
13	01-12-2010 11:00	6	281.6173953
14	01-12-2010 12:00	4	257.7538837
15	01-12-2010 13:00	3	240.3376889
16	01-12-2010 14:00	4	231.5101002
17	01-12-2010 15:00	5	252.0345536
18	01-12-2010 16:00	3	329.0286003
19	01-12-2010 17:00	3	488.6252909
20	01-12-2010 18:00	4	588.6959924

Figure-4: IEEE Open access data file showing wind speed & domestic power demand data

	A	HP	HR	HS
1	utc_timestamp	NL_load_actual_entsoe_transparency	NL_solar_generation_actual	NL_wind_generation_actual
8763	2016-01-01T00:00:00Z	10580	0	1482
8764	2016-01-01T01:00:00Z	10082	0	1225
8765	2016-01-01T02:00:00Z	9614	0	1149
8766	2016-01-01T03:00:00Z	9366	0	937
8767	2016-01-01T04:00:00Z	9369	0	620
8768	2016-01-01T05:00:00Z	9612	0	339
8769	2016-01-01T06:00:00Z	9973	0	219
8770	2016-01-01T07:00:00Z	10280	0	84
8771	2016-01-01T08:00:00Z	10608	29	31
8772	2016-01-01T09:00:00Z	11212	132	18
8773	2016-01-01T10:00:00Z	11532	233	17
8774	2016-01-01T11:00:00Z	11636	284	28
8775	2016-01-01T12:00:00Z	11703	281	66
8776	2016-01-01T13:00:00Z	11829	215	169
8777	2016-01-01T14:00:00Z	11935	123	294
8778	2016-01-01T15:00:00Z	12444	46	443
8779	2016-01-01T16:00:00Z	13617	9	561
8780	2016-01-01T17:00:00Z	13664	0	663
8781	2016-01-01T18:00:00Z	13393	0	893

Figure-5: Open power system data file showing solar, wind & domestic demand power data

	A	BJ	BK
1	utc_timestamp	NL_temperature	NL_radiation_direct_horizontal
289299	2013-01-01T01:00:00Z	6.706	0
289300	2013-01-01T02:00:00Z	6.489	0
289301	2013-01-01T03:00:00Z	6.417	0
289302	2013-01-01T04:00:00Z	6.529	0
289303	2013-01-01T05:00:00Z	6.749	0
289304	2013-01-01T06:00:00Z	6.879	0
289305	2013-01-01T07:00:00Z	6.902	0.0003
289306	2013-01-01T08:00:00Z	6.839	0.3076
289307	2013-01-01T09:00:00Z	6.923	3.8352
289308	2013-01-01T10:00:00Z	7.085	24.9787
289309	2013-01-01T11:00:00Z	7.185	63.4547
289310	2013-01-01T12:00:00Z	7.049	74.4341
289311	2013-01-01T13:00:00Z	6.624	35.5017
289312	2013-01-01T14:00:00Z	5.902	8.68
289313	2013-01-01T15:00:00Z	5.033	0.2587

	A	JP
1	utc_timestamp	NL_heat_demand_space
43847	01-01-2013 00:30	18168
43848	01-01-2013 01:30	16428
43849	01-01-2013 02:30	12692
43850	01-01-2013 03:30	10470
43851	01-01-2013 04:30	10293
43852	01-01-2013 05:30	10764
43853	01-01-2013 06:30	11060
43854	01-01-2013 07:30	12437
43855	01-01-2013 08:30	14741
43856	01-01-2013 09:30	18028
43857	01-01-2013 10:30	21223
43858	01-01-2013 11:30	21100
43859	01-01-2013 12:30	21787
43860	01-01-2013 13:30	19944

Figure-6: Open power system data file showing solar irradiance, Air temperature & space heating demand power data

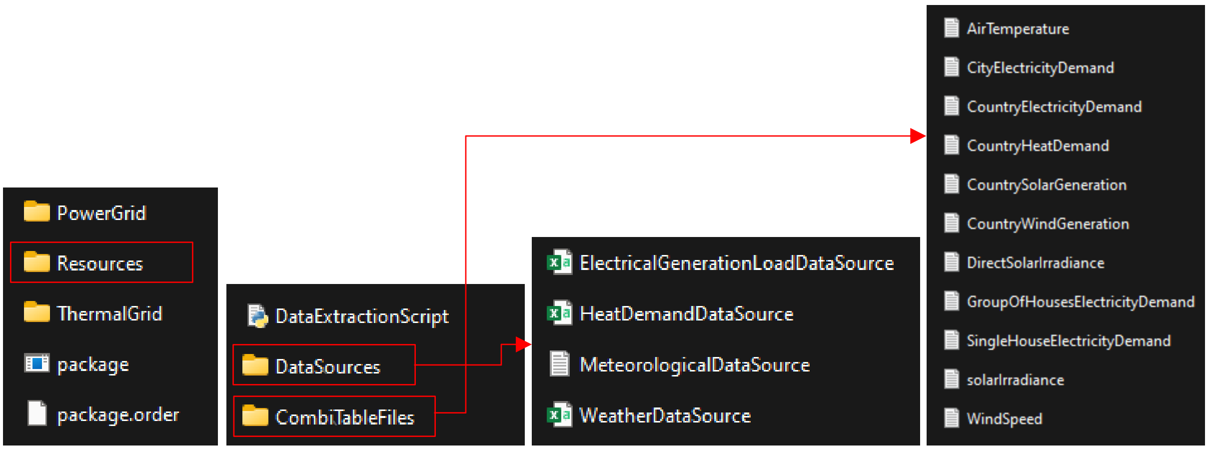


Figure-7: Resource folder, Data sources and extracted data text files

1.2.2.1. SYSTEM PARAMETERS

This module is a record file containing all the parameters required for each library component. This record file is dragged on to each library example and corresponding parameter values are entered. Additionally, this record also contains the data file links corresponding to the wind speed profile, solar radiation profile data, solar generation data for a country, wind generation data for a country and domestic demand profile data. Table 1 shows the set of parameters considered in the system parameter record file.

Parameters	
Air density	Energy storage capacity
Wind speed data file	Max allowable charge %
Turbine rotor radius	Min allowable charge %
Turbine generation efficiency	T&D efficiency
Number of turbines	Voltage
Wind farm rated power	Energy storage rated power
PV panel tilt angle	EV car charging capacity
Solar irradiance data file	EV bike charging capacity
PV generation efficiency	EV car charging rated power
PV panel surface area	EV bike charging rated power
Number of PV panels	Max number of cars per station
Solar generation data file	Max number of bikes per station
Solar generation factor	Number of charging stations

Table-1: System parameter record file with default value for scenario-1.

1.2.2.2. WIND POWER DATA

In this model wind speed data is converted to wind power per unit area of the turbine rotor area. The hourly wind speed ‘v’ (m/s) data is taken from the text file using a combi-table, using the following equation (1) corresponding wind power per unit area ‘P_{wa}’ (W/m^2) is calculated. Where ‘ρ’ is the air density (kg/m^3). The graphical representation of the model is shown in Figure 8. The calculated wind power per unit area is also assigned to a signal (Real) output port.

$$P_{wa} = \frac{1}{2} * \rho * v^3 \tag{1}$$

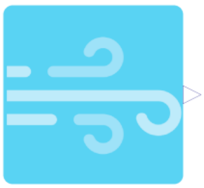


Figure-8: Graphical representation of wind power data model

1.2.2.3. SOLAR IRRADIANCE DATA

In this model solar irradiance on the solar panel is calculated from the horizontal surface irradiance or global irradiance data and the solar panel tilt angle. The hourly global irradiance data or horizontal surface data ‘E_e’ (W/m^2) is taken from the text file using a combi-table, using the following equation (2) the solar irradiance on the solar panel ‘E_{module}’ (W/m^2) is calculated. The solar panel tilt angle ‘β’ (degree) is taken as a parameter. The graphical representation of the model is shown in Figure 9. The calculated solar irradiance is also assigned to a signal (Real) output port.

$$E_{module} = E_e * \cos(\frac{\pi * \beta}{180}) \quad (2)$$

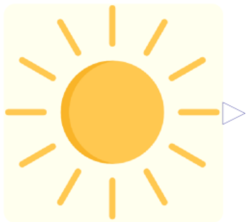


Figure-9: Graphical representation of solar power data model

1.2.2.4. SOLAR GENERATION DATA

This model is used to import solar generation data for a country. The data text file containing hourly solar generation power data (W) is imported using a combi-table. The imported solar generation power is passed onto the electrical port. This model is applicable only in the country grid scenario. The graphical representation of the model is shown in Figure 10.

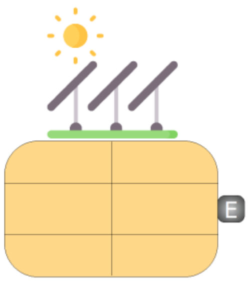


Figure-10: Graphical representation of solar generation data model

1.2.2.5. WIND GENERATION DATA

This model is used to import wind generation data for a country. The data text file containing hourly wind generation power data (W) is imported using a combi-table. The imported wind generation power is passed onto the electrical port. This model is applicable only in the country grid scenario. The graphical representation of the model is shown in Figure 11.

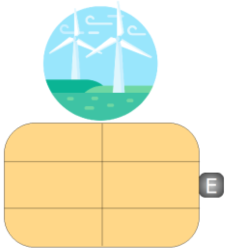


Figure-11: Graphical representation of wind generation data model

1.2.2.6. GENERATION FACTOR

This model enables to carry out sensitivity studies on the generation capacities of renewable power. From the previous models solar & wind generated power is either increased or decreased by a factor used in this model. The default value of the factor is 1, which indicates the actual power generation according to the extracted data. This factor helps to study the impact of increase / decrease of renewable power. The factor can be changed in the range 0 to large number. The graphical representation of the model is shown in Figure 12. The outlet power equation (3) is as below,

$$P_{Out} = Factor * P_{In} \quad (3)$$

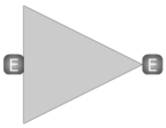


Figure-12: Graphical representation of generation factor model

1.2.3. COMPONENTS

This sub package contains all the power grid components required to represent a typical micro grid. They are namely “Solar Farm”, “Wind Farm”, “Power Management System”, “Energy Storage”, “Conventional Grid”, “Domestic Consumer”, “Charging Station”, “KPI”.

1.2.3.1. SOLAR FARM

This model consists of number of solar panels in a solar farm. The electrical power generated by the solar farm is calculated using the solar irradiance falling on each of the panels, number of panels and surface area of each panel. The solar panels in the solar farm are considered to have same surface area. The electrical power generated ‘Ps’ (W) is calculated using the following formula (4). The solar irradiance falling on the solar cell module 'E_{module}' (W/m^2) is taken from the "Solar Irradiation Data" module using a signal (Real) input port, the surface area of each solar panel 'A_p' (m^2), number of solar panels 'n_p' in the solar farm and electrical power generation efficiency 'η_{se}' are considered as parameters. The graphical representation of the model is shown in Figure 13. The calculated generated electrical power is also assigned to the electrical output port.

$$P_S = \eta_{se} * E_{module} * A_p * n_p \quad (4)$$

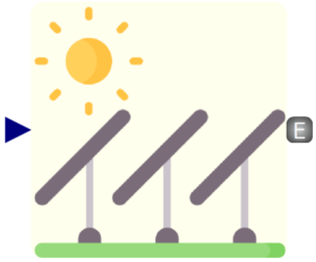


Figure-13: Graphical representation of solar farm model

1.2.3.2. WIND FARM

This model consists of number of wind turbines. The electrical power generated by the wind farm is calculated using the wind speed from the other module, number of wind turbine and rotor radius of the wind turbine. The wind turbines in the farm are considered to have same rotor radius. The electrical power generated 'Pw' (W) is calculated using the following formula (6). The wind power per unit area 'P_{wa}' (W/m^2) is taken from the "Wind Power Data" module using a signal (Real) input port, the rotor swept area 'A_t' (m^2) which is calculated using the parameter turbine rotor radius 'R_r' (m) equation (5), turbine power generation efficiency 'η_{we}' and number of turbines in the wind farm 'n_w' are considered as parameters. The graphical representation of the model is shown in Figure 14.

$$A_t = \pi * {R_r}^2 \quad (5)$$

$$P_w = \eta_{we} * P_{wa} * A_t * n_w \quad (6)$$

The generated power which is transmitted to the grid using the electrical output port is compared with the generation threshold limit parameter, if the wind generated electrical power is greater than the threshold limit then the transmitted power to the grid is clamped to the limit and if it is less than the limit then the that whole amount of power is transmitted to the grid. This threshold limit represents the rated power of the wind turbines.

Figure-14: Graphical representation of wind farm model

1.2.3.3. POWER MANAGEMENT SYSTEM

This model is the power management system or the control system of the power grid. The main aim of this control logic is to ensure that demand is always met. This model also represents the interconnection between the generation and demand of the power grid. There are two inlet or generation electrical ports called *“Wind Generation Port”* & *“Solar Generation Port”* to which the generation power modules are to be connected, there are two outlet or demand electrical port called *“Charging Station Demand Port”* & *“Domestic Demand Port”* to which power demand modules are to be connected, there is one storage electrical port to which the energy storage module is to be connected and there is one source sink electrical port which is to be connected to the conventional grid model. There are two Boolean signal ports used to know the charge and discharge status of the energy storage. There are also additional signal (Real) output ports which are used to calculate the KPIs. The graphical representation of the model is shown in Figure 15. The control algorithm is explained using flowchart as shown below in Figure 16.

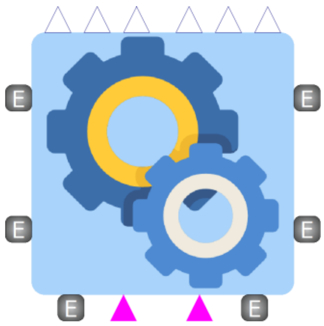


Figure-15: Graphical representation of power management system model

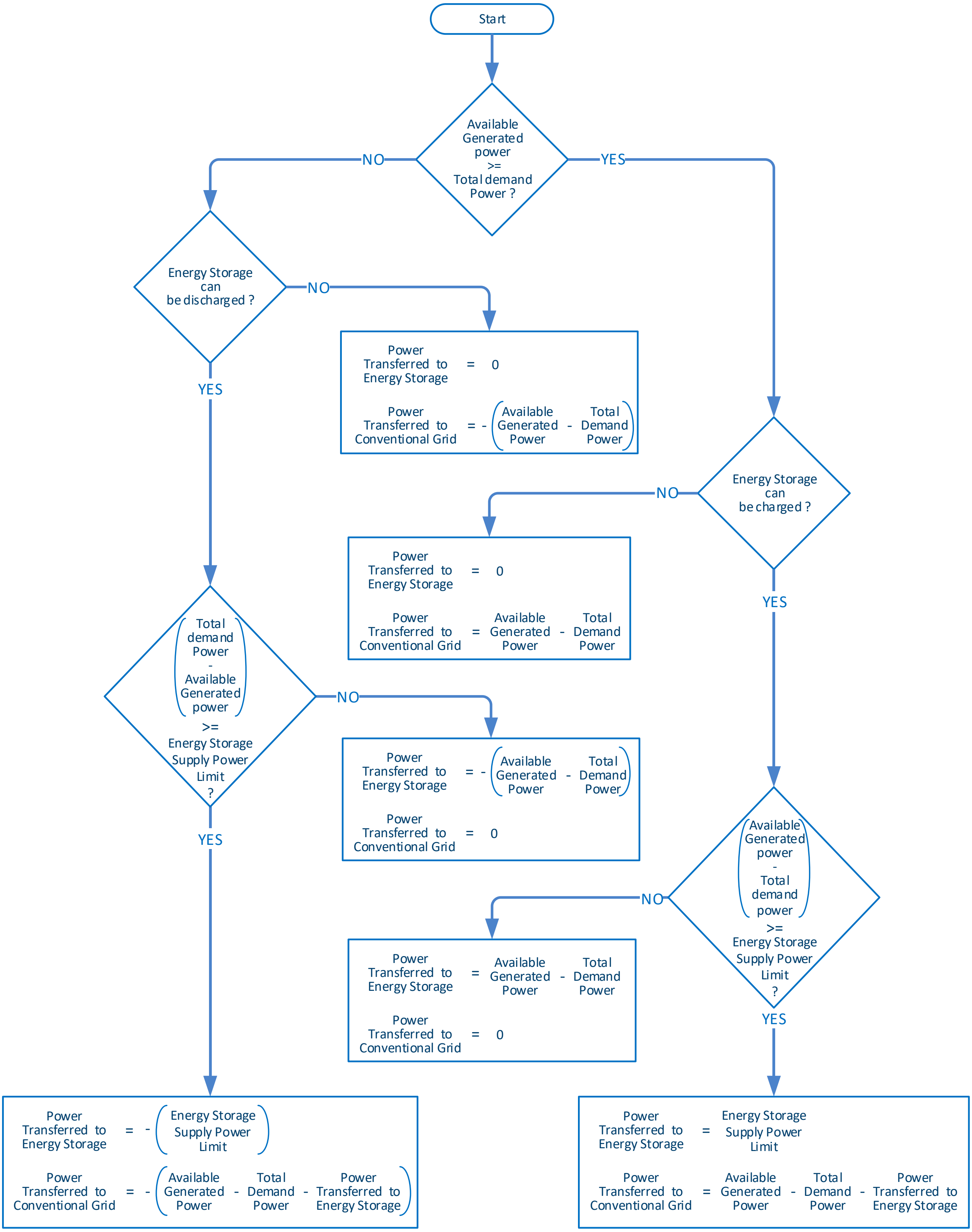


Figure-16: Flow chart of power system management control algorithm

The *"Available Generated Power"* 'P_{ag}' (W) is calculated using the formula (7). The generation power transmitted from wind and or solar farm are 'P_{g1}' (W) and 'P_{g2}' (W), the loss in transmission and distribution is considered using the parameter transmission & distribution efficiency "η_{tnd}". The "Total Demand Power" 'P_{td}' (W) is calculated using the formula (8). The demand powers 'P_{d1}' (W) & 'P_{d2}' (W) are from domestic demand and or charging station demand power. The *"Energy Storage Supply Power Limit"* is a parameter defining the rated power that can be supplied by the grid to the energy storage unit.

$$P_{ag} = \eta_{tnd} * (P_{g1} + \ P_{g2}) \tag{7}$$

$$P_{td} = \eta_{tnd} * (P_{d1} + \ P_{d2}) \tag{8}$$

1.2.3.4. ENERGY STORAGE

The energy storage model is used to excess power which will be at the instance when generation is greater than the demand. The model has one electrical port, two charge and discharge status Boolean port and two signal (Real) port used to calculate the KPIs. The energy stored in the storage 'E_{es}' (Wh) is calculated using the formula (9). The power transferred to and from energy storage 'P_{es}' (W), The maximum or rated energy capacity of the storage is conserved using a parameter 'E_{s_cap}' (Wh), The maximum allowable charge percentage parameter 'C_{max}' (%) and the minimum allowable charge percentage parameter 'C_{min}' (%). The algorithm of charging and discharging is mainly done using the two Boolean flag *"Can Charge"* & *"Can Discharge"*, as shown in Figure 17. The graphical representation of the model is shown in Figure 18.

$$E_{es} = {\int P_{es}\, dt}/{3600} \tag{9}$$

Were, '*t*' in seconds.

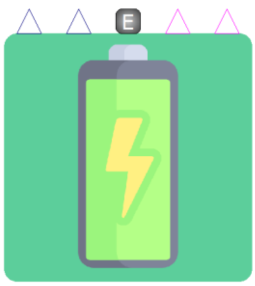


Figure-17: Graphical representation of energy storage model

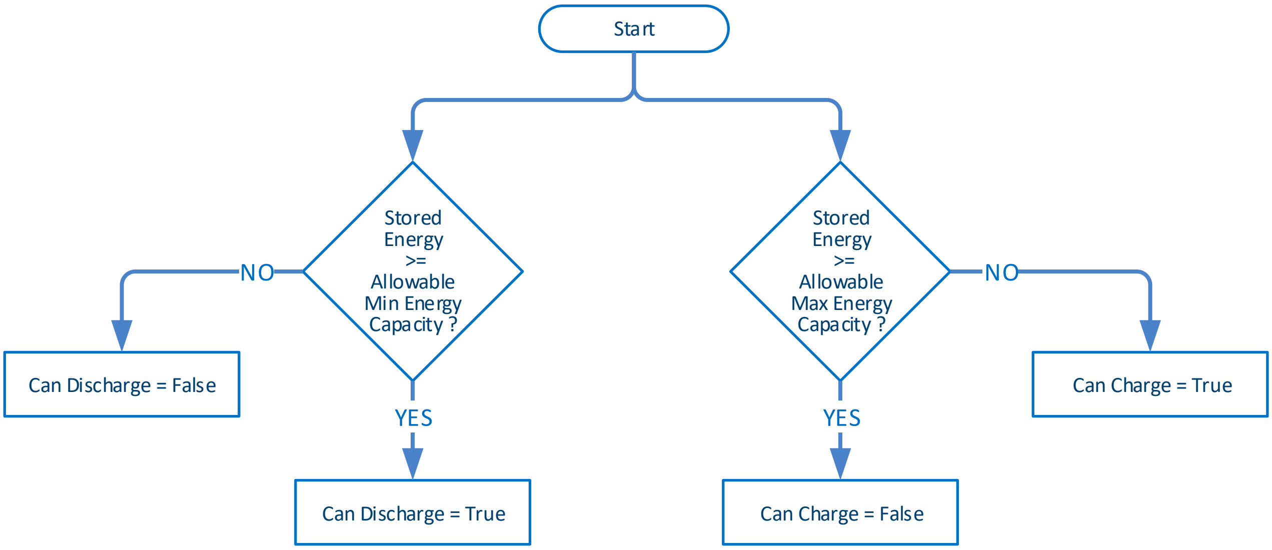


Figure-18: Flow chart of energy storage charging & discharging algorithm

1.2.3.5. CONVENTIONAL GRID

This model is basically an infinite source and sink of power for the power grid. The power from the conventional grid 'P_{grid}' (W) will be supplied to the demand when the generation power and power stored in the energy storage is not sufficient. The power will be given to conventional grid when the generated power is more than the demand and the energy storage is fully charged. The graphical representation of the model is shown in Figure 19.

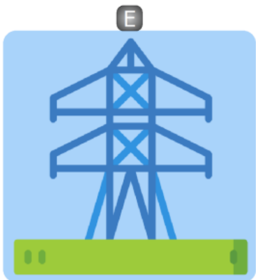


Figure-19: Graphical representation of conventional grid model

1.2.3.6. DOMESTIC CONSUMER

This model contains the power consumption data for domestic demand 'P_{dd}' (W). The hourly power consumption sample data is stored in the form of a text file and is imported to the model using combatable. The sample data has been collected for group of houses (~200 houses) and is up scaled or down scaled for three scale of domestic demand namely Single house data, Group of houses data (~200 houses), City data (~75000 houses). For the fourth scenario of country grid, actual consumption data of a country is extracted. The sample data can be replaced with the user specified data using the data file parameter. The graphical representation of the model is shown in Figure 20.

Figure-20: Graphical representation of domestic consumer model

1.2.3.7. CHARGING STATION

This module consists of power consumption data of electric charging stations. The hourly power consumption data is a simulated or calculated data of the simplified or hypothetical vehicle charging conditions. Here number of stations 'n_{st}', max number of cars & bikes per station, charging duration for cars & bikes, charging capacity for cars & bikes and charging power 'P_{ch_car}' (W) & 'P_{ch_bike}' (W) are the parameters. Using a random number generator, the cars & bikes charging per station 'n_{car}' & 'n_{bike}' is calculated and total charging station demand 'P_{ch}' (W) is calculated using the formula (10). The random number generator will generate the number for the duration of charging and at the end of the duration new random number will be generated. The graphical representation of the model is shown in Figure 21.

$$P_{ch} = n_{st} * (\, n_{car} * P_{ch_{car}} + n_{bike} * P_{ch_{bike}}\,) \qquad (10)$$

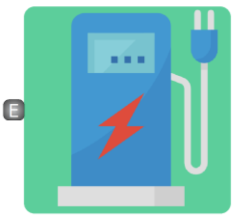


Figure-21: Graphical representation of charging station model

1.2.3.8. KPI

This model consists of "Key Performance indicator" (KPI) to indicate the performance of the power grid. For the power grid the considered KPIs are "Grid power ratio" which is defined as the ratio of power that is supplied to demand from the conventional grid to the total demand power (11), "Storage power ratio" is defined as the ratio of power supplied to the demand from the energy storage to the total demand (12), "Generation power ratio" is defined as the ratio of power supplied to demand from the generation units to the total demand (13), "Storage effectiveness" is defined as ratio of average stored energy in the storage to the maximum storage capacity of the energy storage (14), "Generation effectiveness" is defined as ratio between the difference in total generation and total demand power to the total demand power (15), "Wind generation energy" 'E_w' (Wh) (16), "Solar generation energy" 'E_s' (Wh) (17), "Domestic demand energy" 'E_{dd}' (Wh) (18) and "Charging station demand energy" 'Ech' (19). Figure 22 shows the graphical representation of the model.

$$Grid\ Power\ Ratio = \frac{P_{grid}}{P_{dd} + P_{ch}} \tag{11}$$

$$Storage\ Power\ Ratio = \frac{P_{es}}{P_{dd} + P_{ch}} \tag{12}$$

$$Generation\ Power\ Ratio = \frac{P_s + P_w}{P_{dd} + P_{ch}} \tag{13}$$

$$Storage\ Effectivenes = \frac{\int E_{es}\, dt / 3600}{E_{s\_cap}} \tag{14}$$

$$Generation\ Effectiveness = \frac{(P_{dd} + P_{ch}) - (P_s + P_w)}{P_{dd} + P_{ch}} \tag{15}$$

$$E_w = \int P_w\, dt / 3600 \tag{16}$$

$$E_s = \int P_s\, dt / 3600 \tag{17}$$

$$E_{dd} = \int P_{dd}\, dt / 3600 \tag{18}$$

$$E_{ch} = \int P_{ch}\, dt / 3600 \tag{19}$$

Figure-22: Graphical representation of KPI model

1.2.4. GRID SCENARIOS

This sub package contains the power grid default examples. There are four level of scenario examples based on the amount of consumption or size of the grid. These scenarios are created by dragging and connecting the corresponding previously explained components.

1.2.4.1. SCENARIO-1

This example scenario is considering single house grid. The graphical representation of the example is shown in the Figure 23. For this scenario the parameters considered are as below (Table-2). In this example, the parameters are set such that generated power is less than the demand.

Scenario-1 Parameters		
Number of PV panels		12
Surface area of each PV panel	m^2	2
PV panel generation efficiency	%	20
Energy storage capacity	kWh	5
Energy storage max. power limit	kW	1
Domestic Demand		Single house demand data file is chosen

Table-2: Scenario-1 parameters

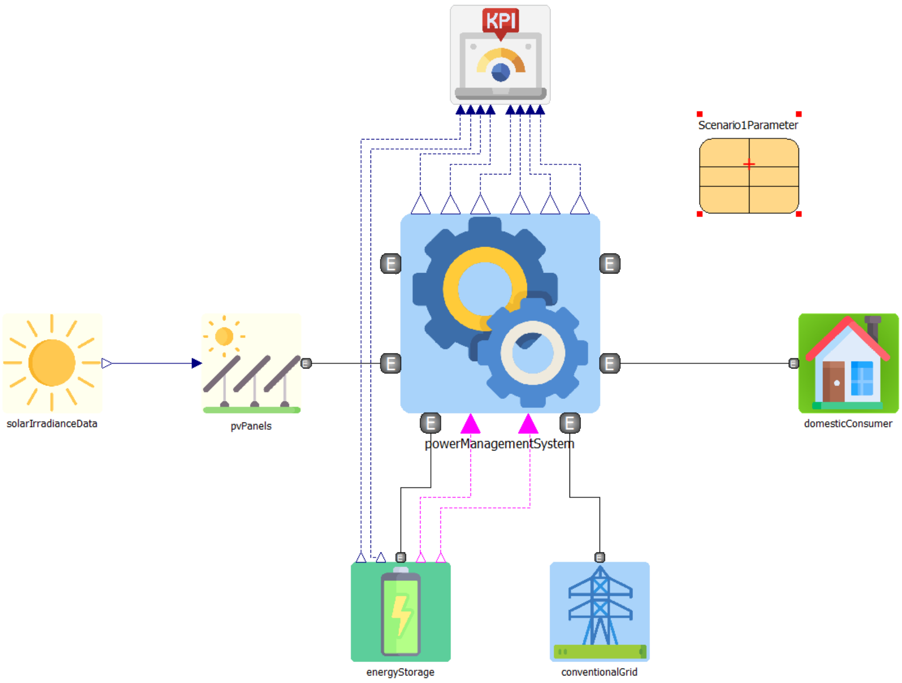


Figure-23: Graphical representation scenario-1 example

1.2.4.2. SCENARIO-2

This example scenario is considering grid for group of houses (Approximately 200 houses). The graphical representation of the example is shown in the Figure 24. For this scenario the parameters considered are as below (Table-3).

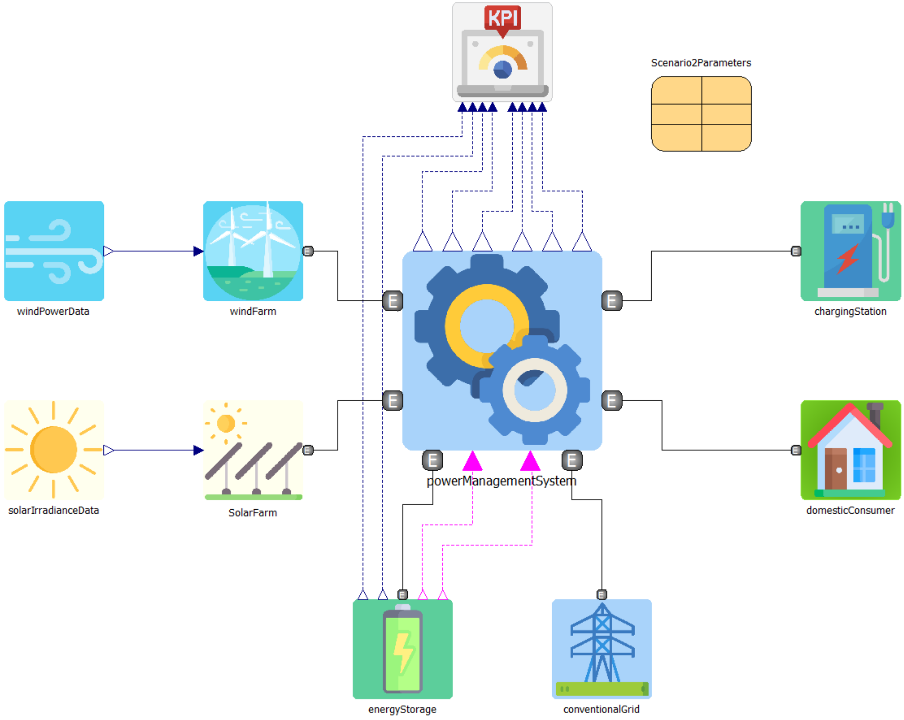


Figure-24: Graphical representation scenario-2 example

Scenario-2 Parameters		
Number of PV panels		1000
Surface area of each PV panel	m^2	2
PV panel generation efficiency	%	40
Wind turbine rotor radius	m	30
Number of turbines		3
Wind power generation efficiency	%	80
Wind power generation limit	MW	2
Energy storage capacity	MWh	5
Energy storage max. power limit	kW	500
Domestic Demand		Group of houses demand data file is chosen
Charging Station		4
EV Bikes per station		20
EV Cars per station		12

Table-3: Scenario-2 parameters

In this example, the parameters are set such that generated power almost same as that of the total demand.

1.2.4.3. SCENARIO-3

This example scenario is considering grid for a city (Approximately 75000 houses). The graphical representation of the example is shown in the Figure 25. For this scenario the parameters considered are as below (Table-4). In this example, the parameters are set such that generated power is more than that of the total demand.

Scenario-3 Parameters		
Number of PV panels		200000
Surface area of each PV panel	m^2	2
PV panel generation efficiency	%	40
Wind turbine rotor radius	m	30
Number of turbines		600
Wind power generation efficiency	%	80
Wind power generation limit	MW	350
Energy storage capacity	MWh	900
Energy storage max. power limit	MW	50
Domestic Demand		City demand data file is chosen
Charging Station		200
EV Bikes per station		20
EV Cars per station		12

Table-4: Scenario-3 parameters

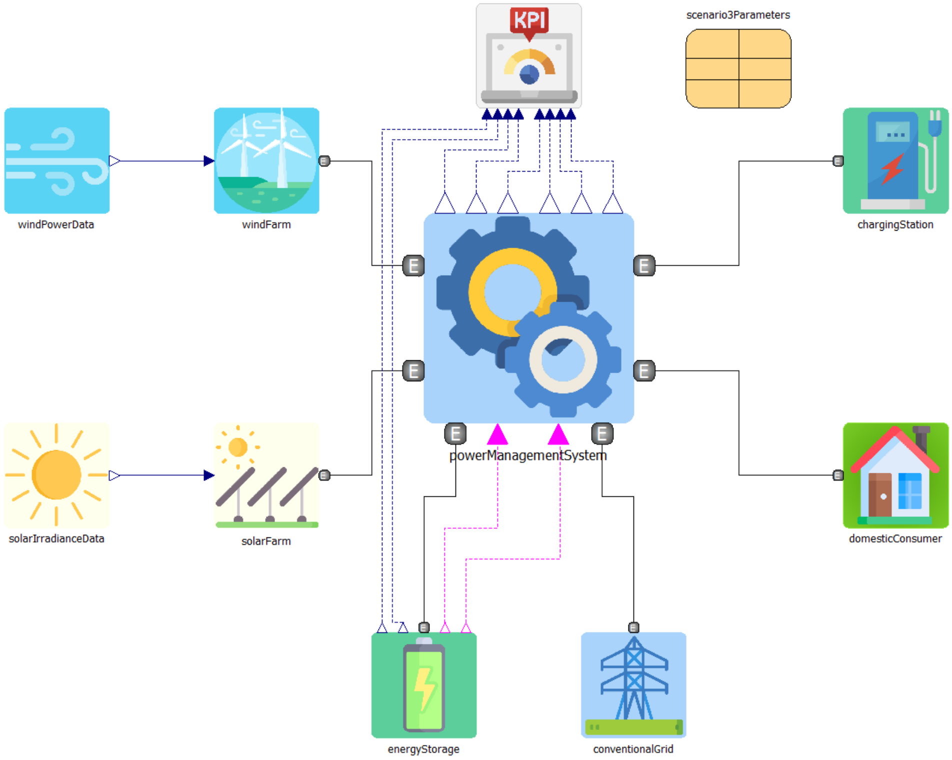


Figure-25: Graphical representation scenario-3 example

1.2.4.4. SCENARIO-4

This example scenario is considering grid for a country (Netherland). The graphical representation of the example is shown in the Figure 26. For this scenario the parameters considered are as below (Table-5). In this example, the parameters are set such that generated power is more than that of the total demand.

Scenario-4 Parameters		
Solar power generation data	W	Netherland data for the year 2016
Solar generation factor		10
Wind power generation data	W	Netherland data for the year 2016
Wind generation factor		10
Energy storage capacity	GWh	100
Energy storage max. power limit	MW	500
Domestic Demand		Netherland data for the year 2016
Charging Station		20000
EV Bikes per station		20
EV Cars per station		12

Table-5: Scenario-4 parameters

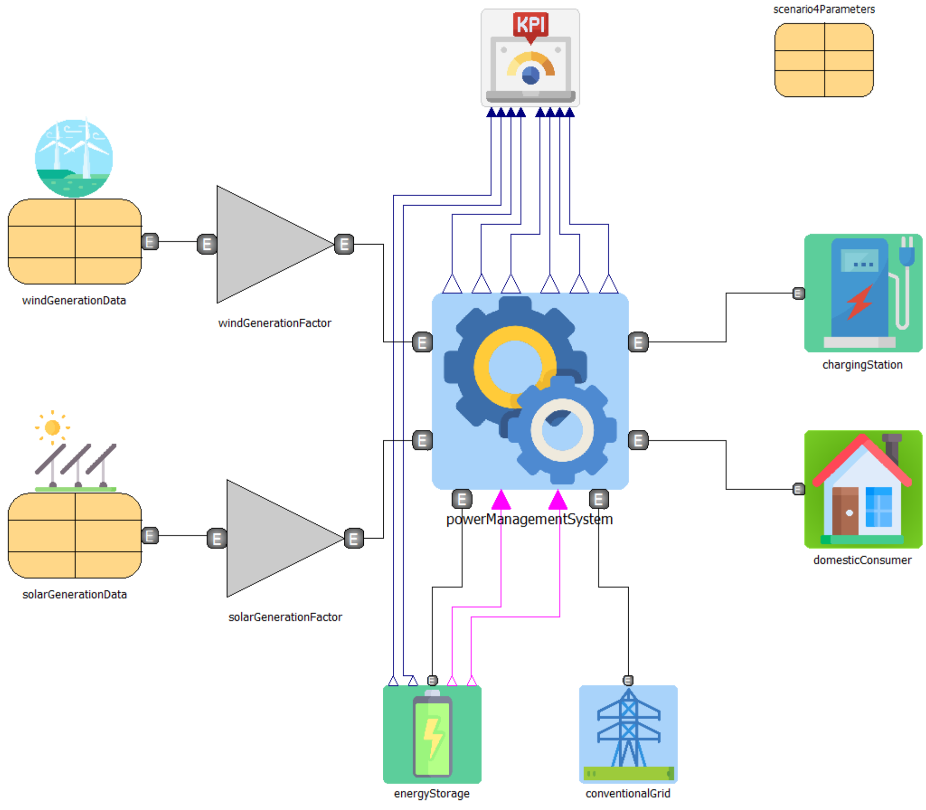


Figure-26: Graphical representation scenario-4 example

1.3. SIMULATION RESULTS

As indicated in the previous section the library examples are configured with default parameters and can be directly simulated. The simulation results for the four scenarios are as follows.

1.3.1. SCENARIO – 1: SINGLE HOUSE GRID

In this scenario grid for a single house example is simulated. For power generation only solar PV modules and corresponding small energy storage are considered. The system parameters considered are shown in table 2.

Annual surface solar irradiance and the irradiance on tilted PV module is plotted as shown in Figure 27. The solar irradiance model is kept same for all the scenarios, the number of PV panels are changed corresponding to the scenarios.

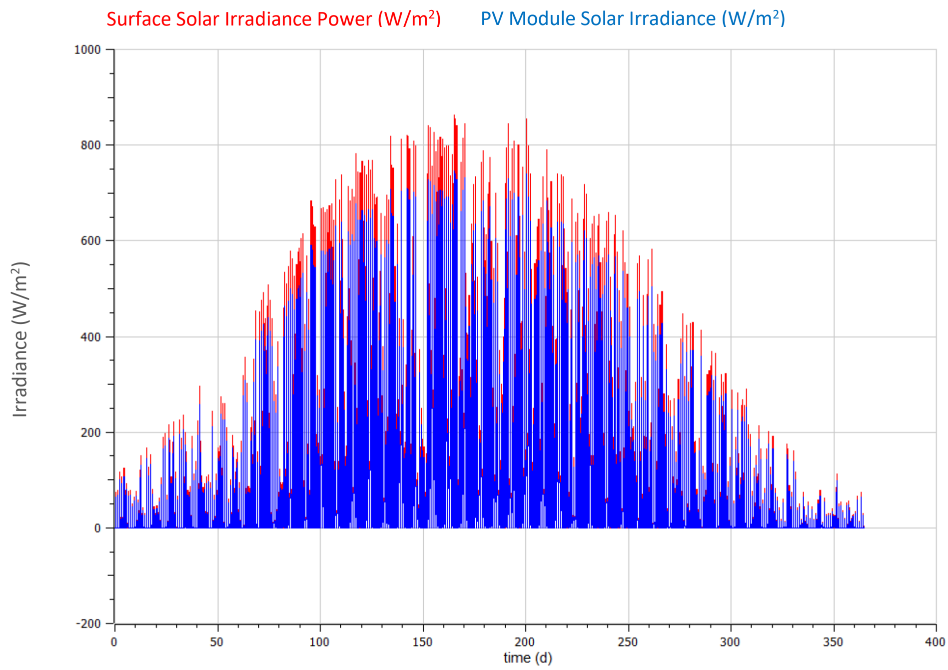


Figure-27: Surface solar irradiance and PV module irradiance

Annual solar power from solar irradiance and generated electrical power are plotted in Figure 28.

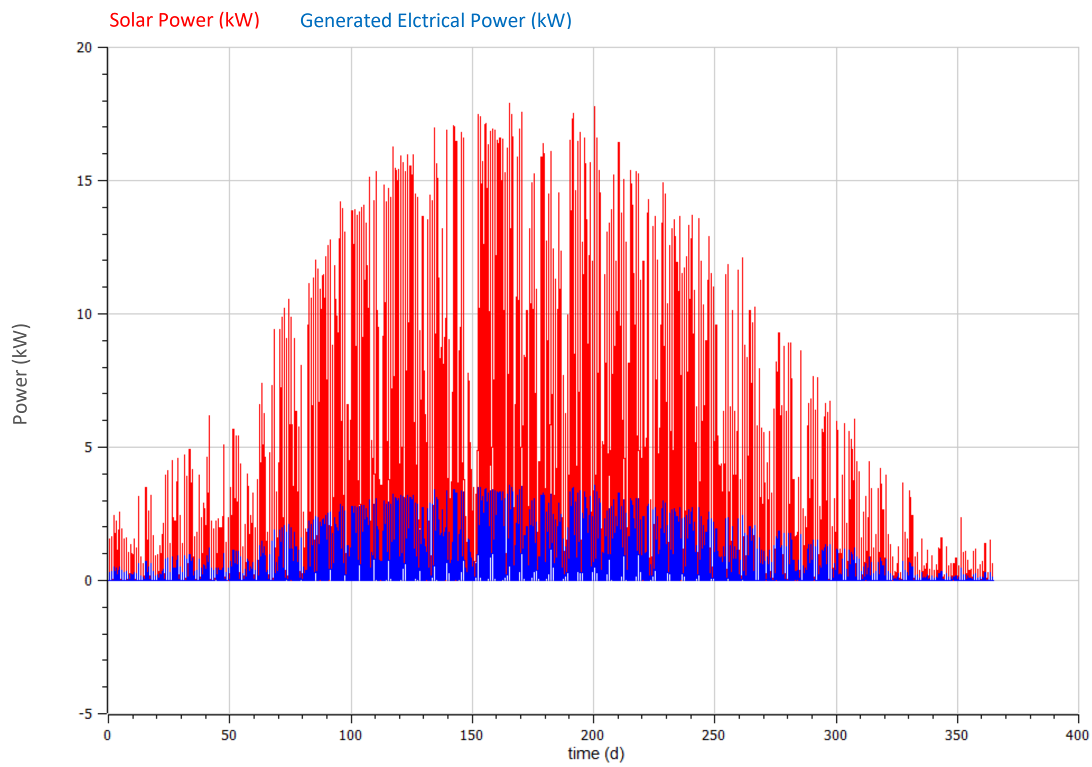


Figure-28: Solar Power and PV module generated electrical power for scenario-1

Annual hourly load demand power from the data file and the demand power subjected to the grid (considering transmittion & distribution losses) are ploted in Figure 29.

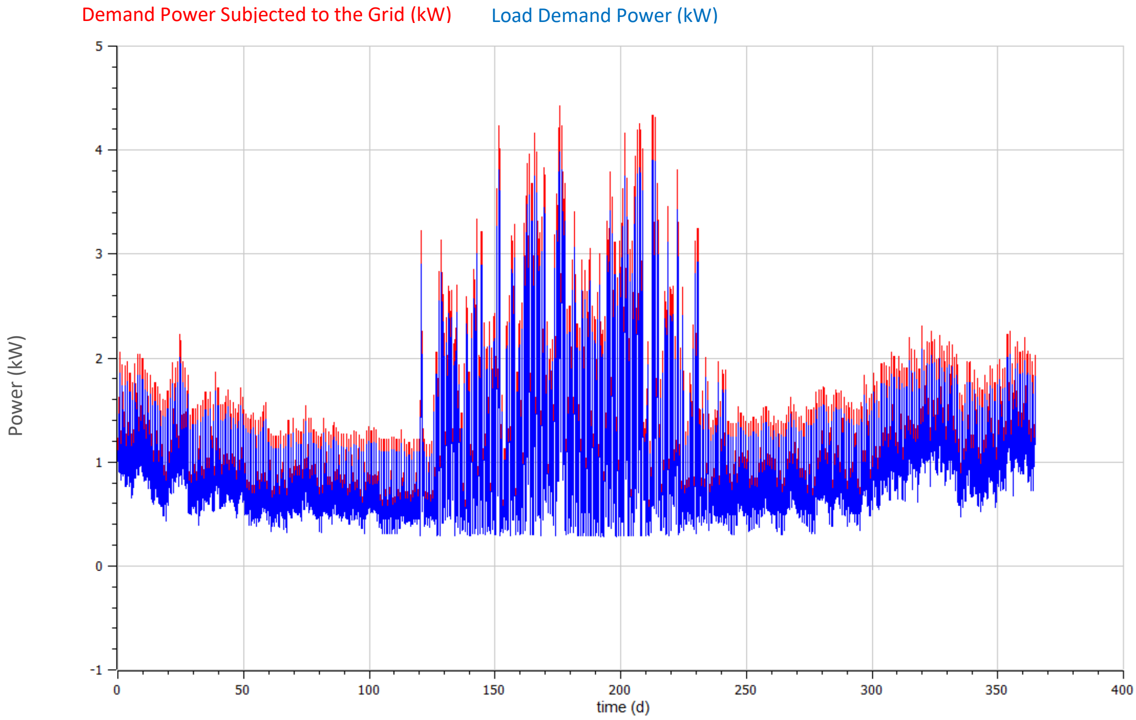


Figure-29: Demand power subjected to the grid and load demand power for scenario-1

Energy storage transferred power to and from the grid (when power is positive the storage is charging and when it is negative it is discharging) is plotted as shown in the Figure 30. The stored energy plot in the energy storage plot is shown in the Figure 31.

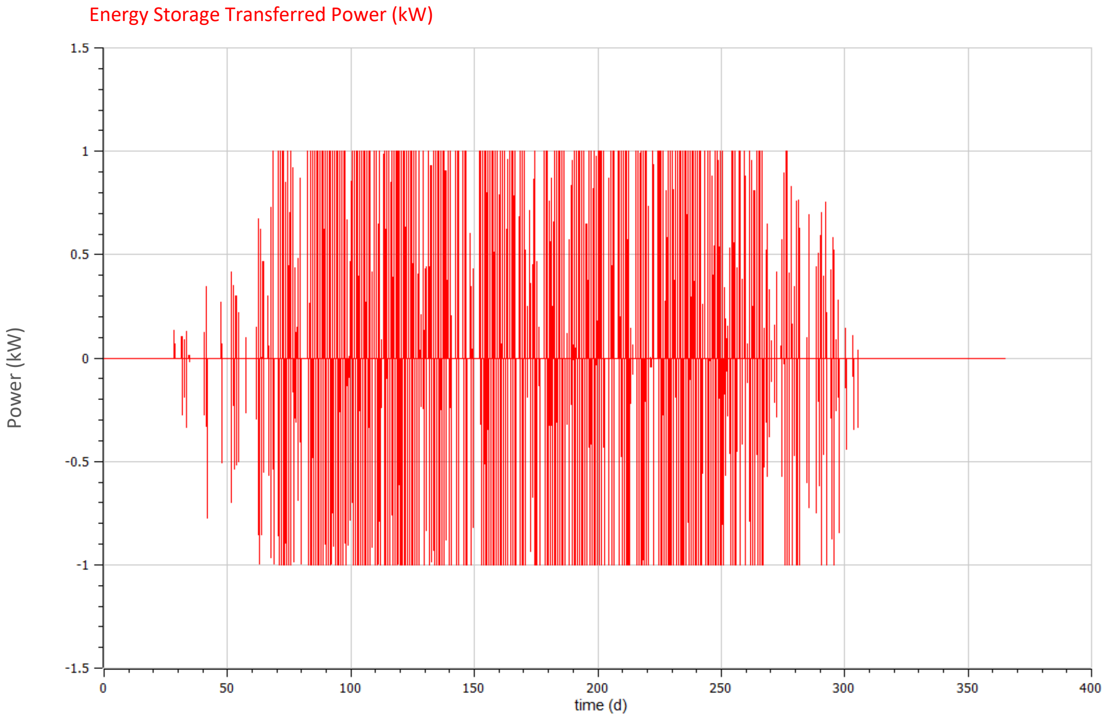


Figure-30: Energy storage transferred power to and from the grid for scenario-1

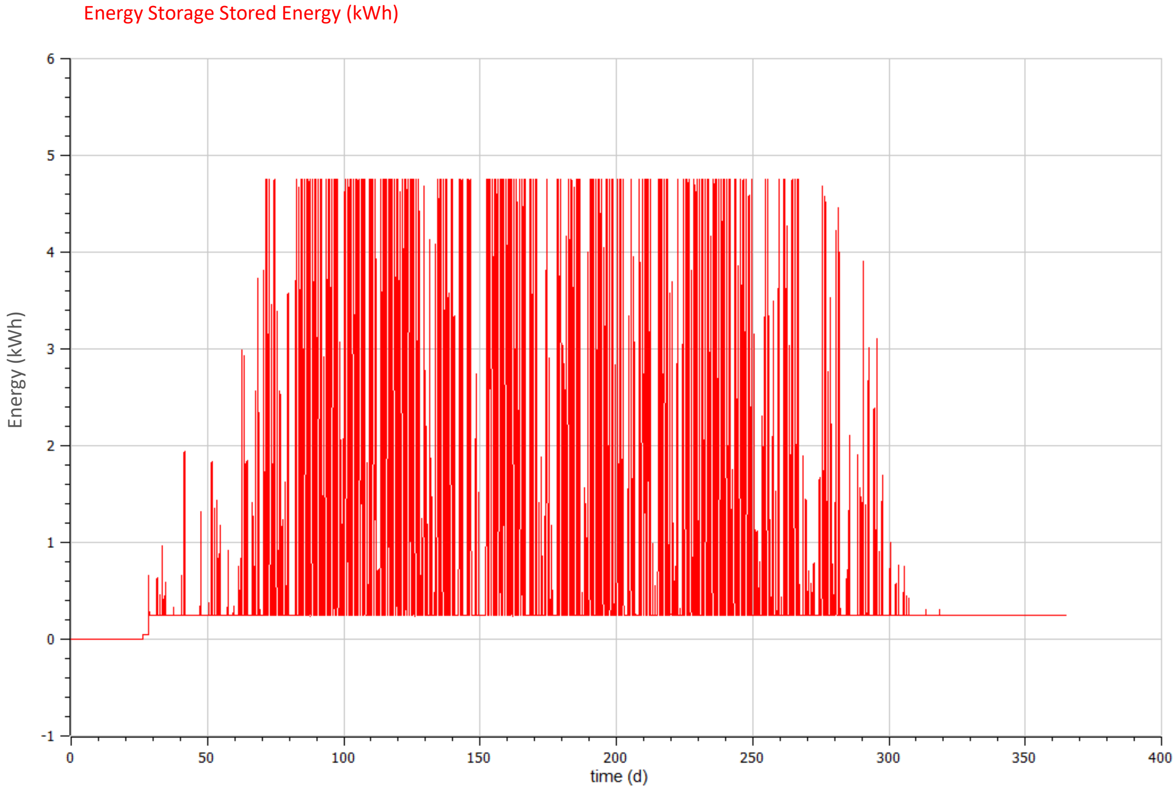


Figure-31: Energy storage stored energy for scenario-1

Power transferred to and from the conventional grid for scenario 1 (when power is positive the renewable grid is supplying power conventional grid and when it is negative conventional grid is supplying power to the renewable grid) is plotted as shown in Figure 32.

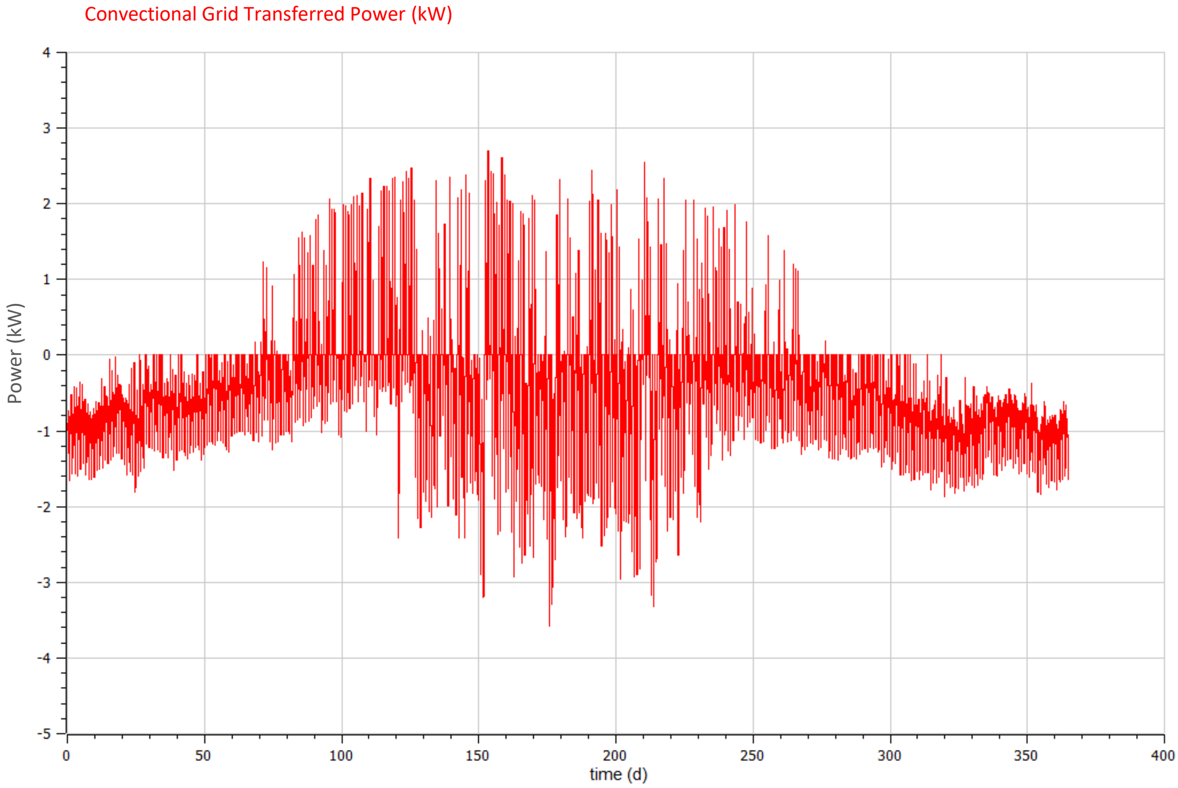


Figure-32: Conventional grid transferred power to and from the renewable grid for scenario-1

Power management system power flow to and from the generation, storage, conventional grid and load is plotted as shown in Figure 33.

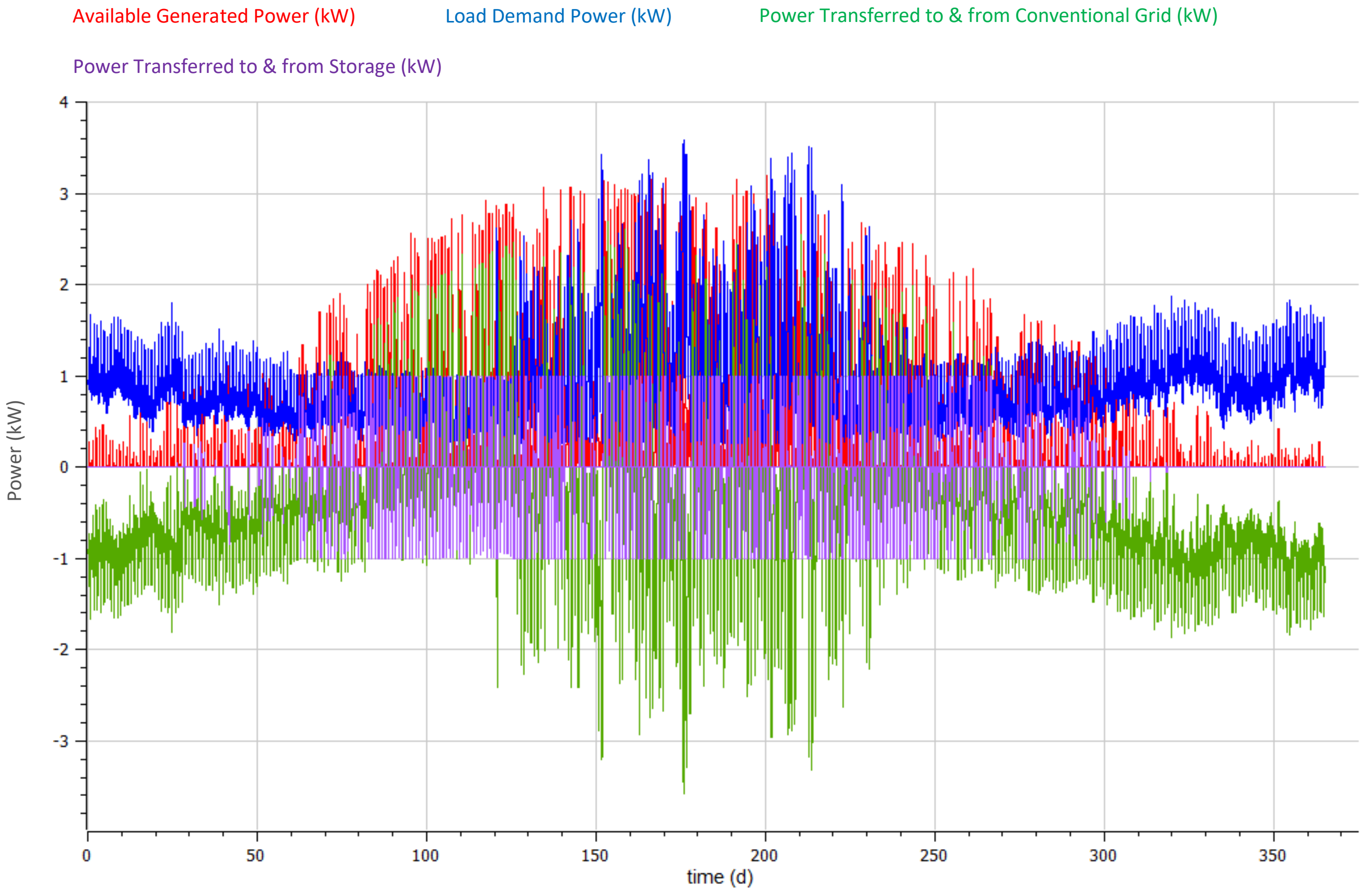


Figure-33: Power management system power plots for scenario-1

KPI summary for scenario 1 is shown in the table 6.

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
3.74 MWhr	6.52 MWhr	0.67 MWhr	9.59 MWhr

Table-6: Annual simulation KPI summary for scenario-1

1.3.2. SCENARIO – 2: GROUP OF HOUSES GRID

In this scenario grid for group of houses considering approximately 200 houses is simulated. For power generation solar PV modules, wind turbines and corresponding energy storage are considered. Two types of loads domestic consumers and charging stations are considered for this scenario. The system parameters selected are shown in table 3.

Annual solar power from solar irradiance and generated electrical power for scenario 2 are plotted in Figure 34.

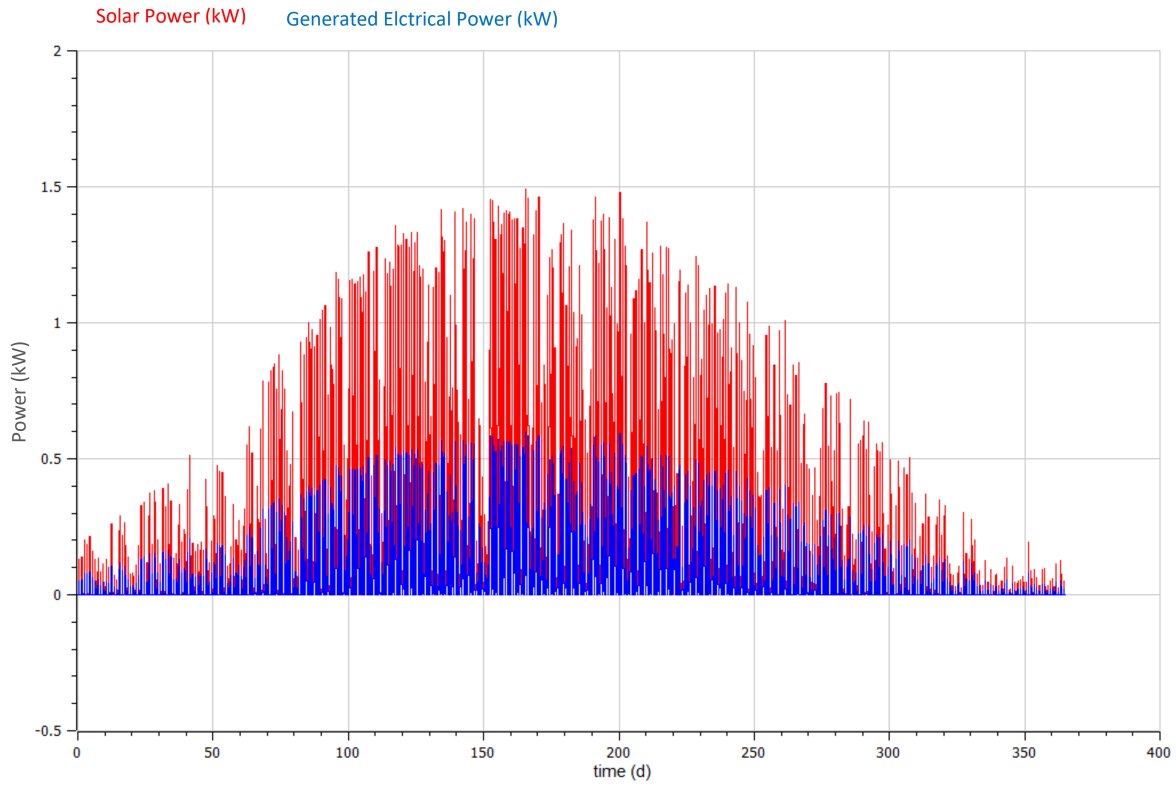


Figure-34: Solar Power and PV module generated electrical power for scenario-2

Annual wind speed data sourced from the data base is plotted in Figure 35. The same wind profile is used for all the applicable scenarios. Corresponding to the wind speed the electrical power generated from the wind turbine is plotted as shown in figure 36.

Figure-35: Annual hourly wind speed profile data

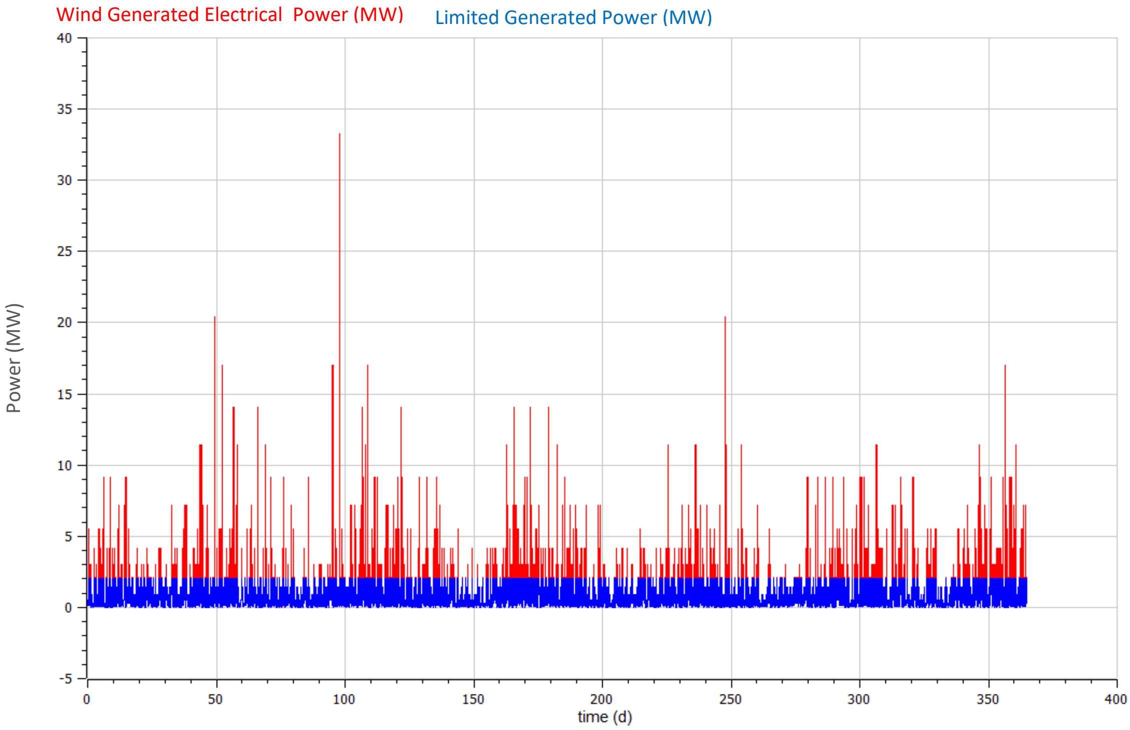


Figure-36: Wind electrical power generated and the rated electrical power for scenario-2.

The electrical generated from wind turbine is limited by the corresponding power capacities of the turbines, the power generated upto the rated capacity is only considered as shown above.

Annual hourly domestic load demand power from the data file and the demand power subjected to the grid (considering transmittion & distribution losses) for scenario 2 are ploted in Figure 37.

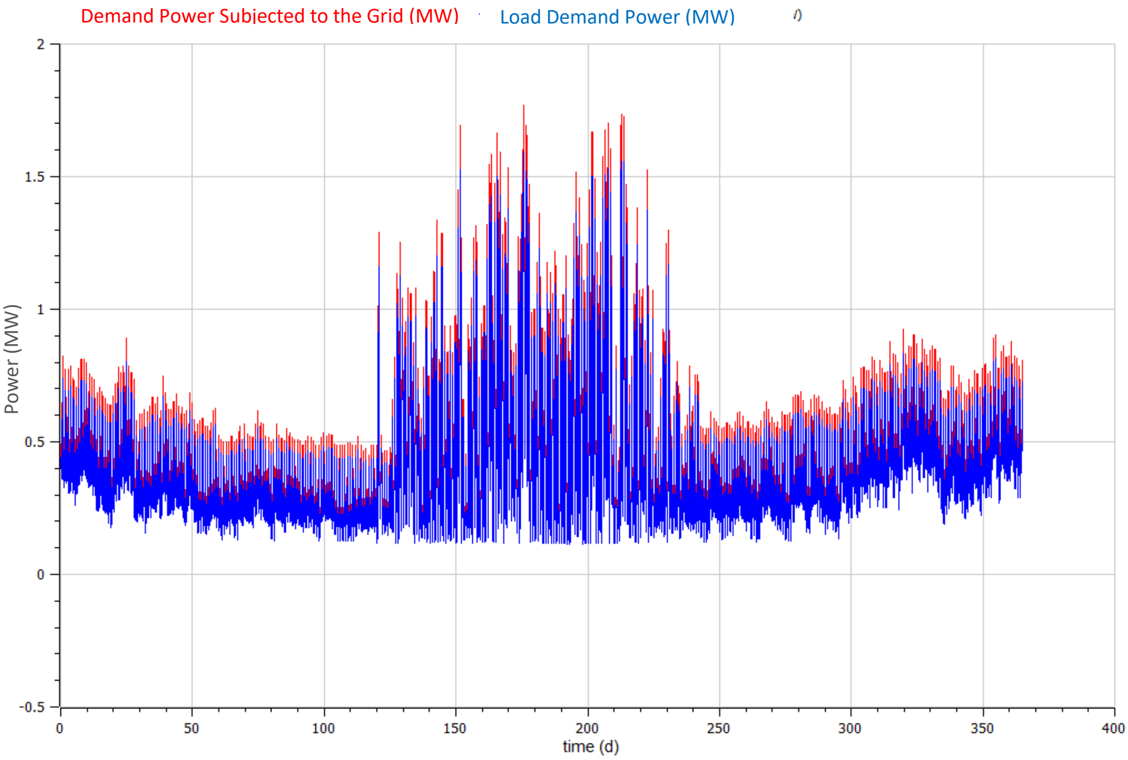


Figure-37: Domestic demand power subjected to the grid and load demand power for scenario-2.

Annual hourly simulated charging station demand power and the demand power subjected to the grid (considering transmittion & distribution losses) for scenario 2 are ploted in Figure 38.

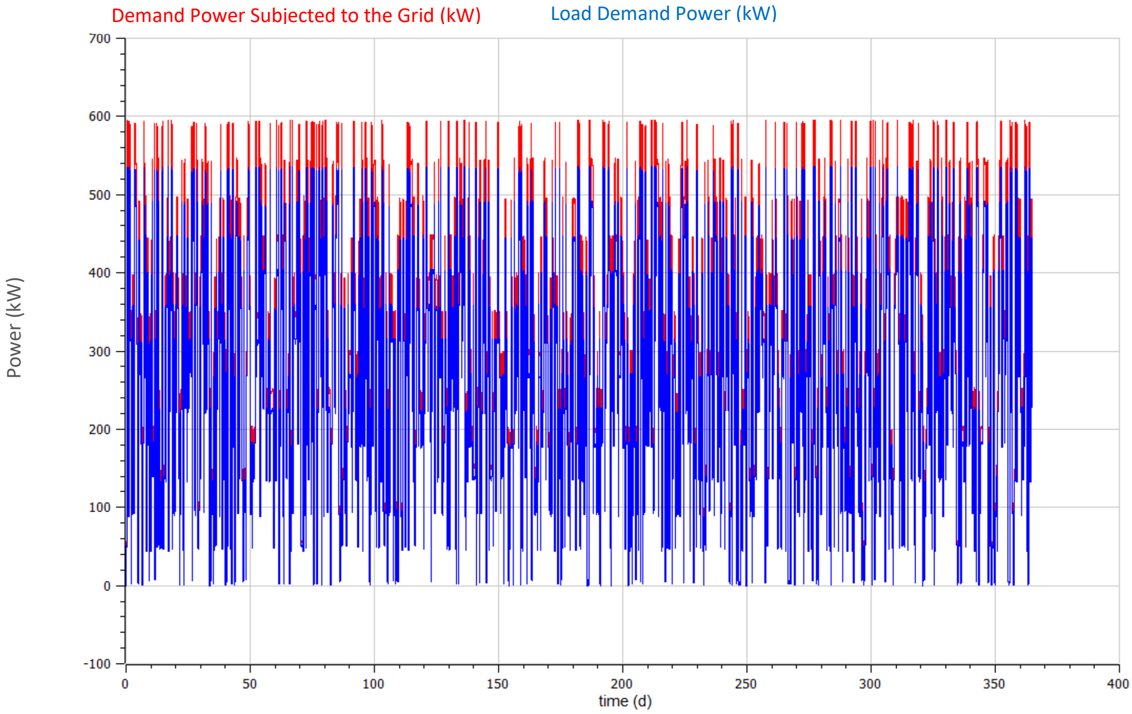


Figure-38: Charging station demand power subjected to the grid and load demand power for scenario-2.

Energy storage transferred power to and from the grid for scenario 2 (when power is positive the storage is charging and when it is negative it is discharging) is plotted as shown in the Figure 39. The stored energy plot in the energy storage plot is shown in the Figure 40.

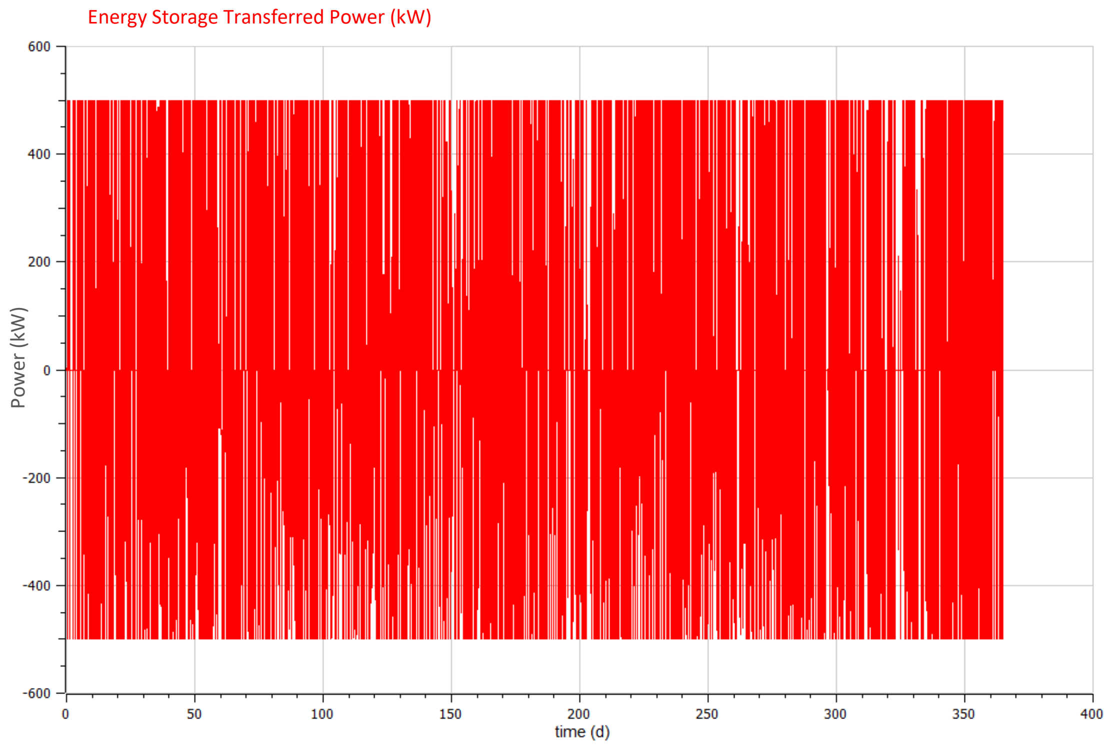


Figure-39: Energy storage transferred power to and from the grid for scenario-2

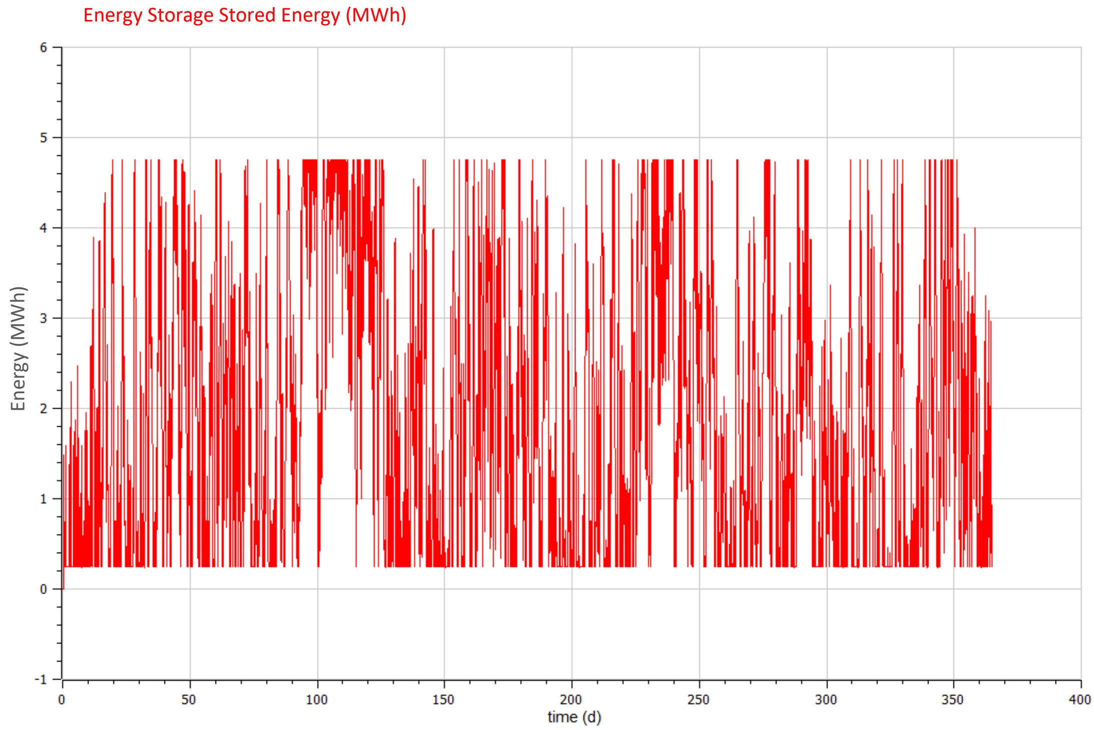


Figure-40: Energy storage stored energy for scenario-2

Power transferred to and from the conventional grid (when power is positive the renewable grid is supplying power conventional grid and when it is negative conventional grid is supplying power to the renewable grid) for scenario 2 is plotted and shown in the Figure 41.

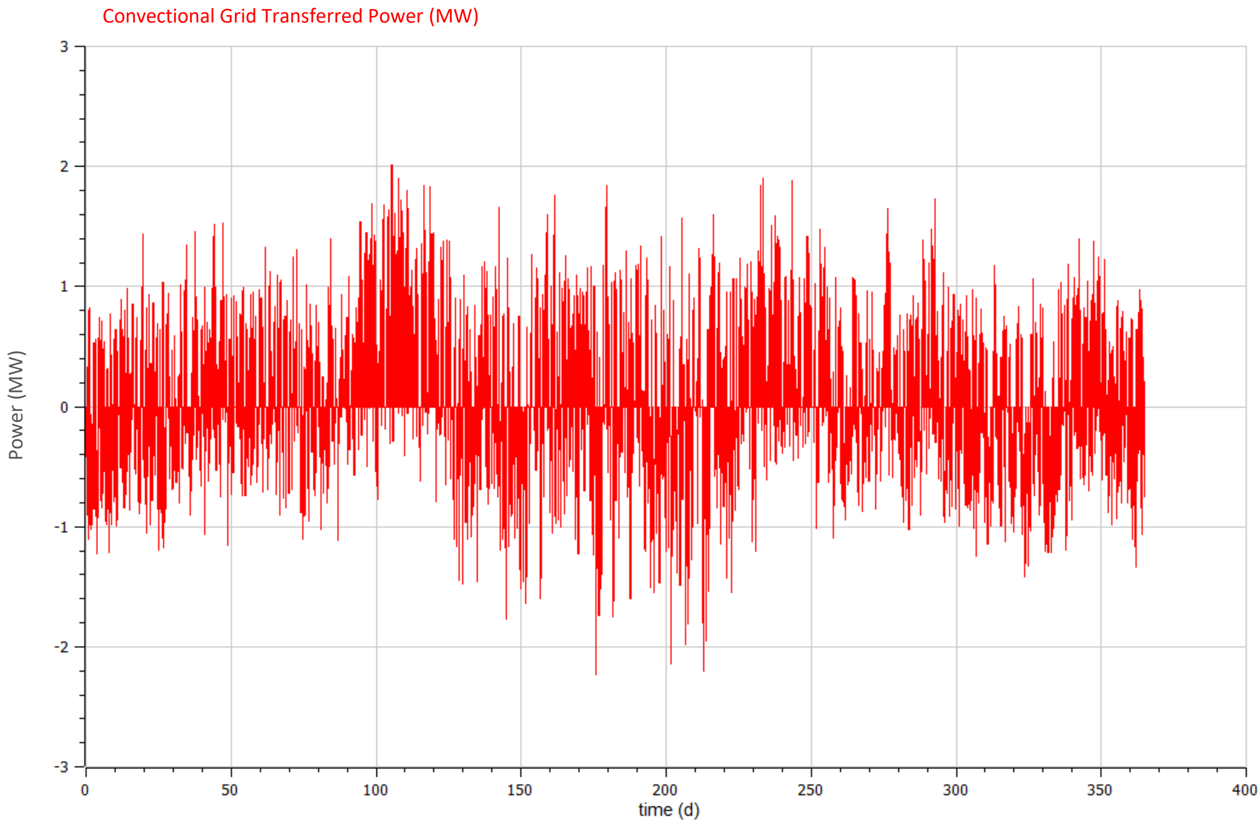


Figure-41: Conventional grid transferred power to and from the renewable grid for scenario-2

Power management system power flow to and from the generation, storage, conventional grid and load is plotted and shown in the Figure 42.

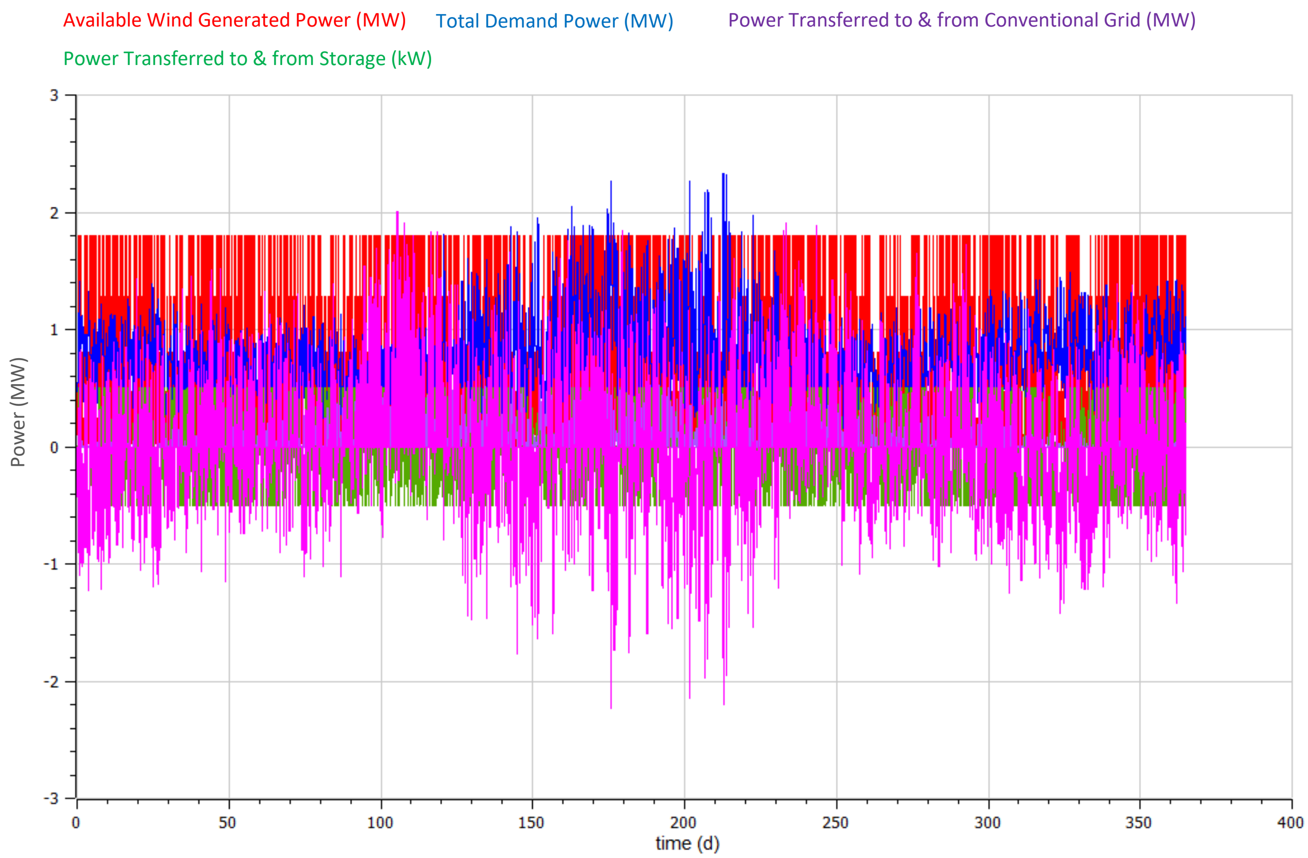


Figure-42: Power management system power plots for scenario-2.

KPI summary for scenario 2 is shown in the table 7.

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
6.98 GWhr	1.04 GWhr	1.56 GWhr	6.46 GWhr

Table-7: Annual simulation KPI summary for scenario-2

1.3.3. SCENARIO – 3: CITY GRID

In this scenario city grid example considering approximately 75000 houses is simulated. For power generation solar PV modules, wind turbines and corresponding energy storage are considered. Two types of loads domestic consumers and charging stations are considered for this scenario. The system parameters selected are shown in table 4. The plots are similar to that as shown for scenario 2, scenario 3 is a scaled-up version of scenario 2 to depict a typical city grid.

KPI summary for scenario 3 is shown in the table 8.

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
1332.96 GWhr	85.23 GWhr	567.27 GWhr	850.21 Whr

Table-8: Annual simulation KPI summary for scenario-3

1.3.4. SCENARIO – 4: COUNTRY GRID

In this scenario country grid example Netherland country generation and demand data used and grid is simulated. For power generation solar generation and wind generation power is imported from the data file. For this scenario the generation factors (solar & wind) are made as '10'. Corresponding energy storage is considered. Two types of loads domestic consumers and charging stations are considered for this scenario. The domestic demand power is imported from the data file. The system parameters selected are shown in table 5.

The figure 43 shows the factored solar generation power and figure 44 shows the factored wind generation power.

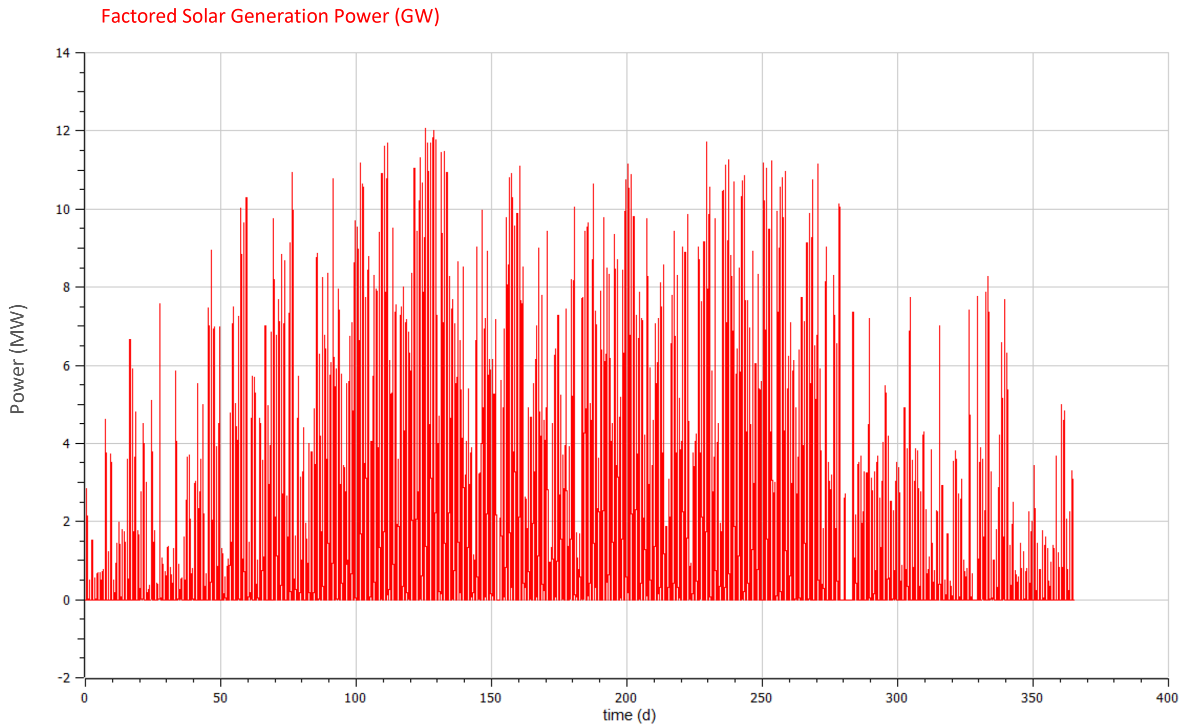


Figure-43: Factored solar generation power plot for scenario-4.

The figure 45 shows the domestic power consumption profile as imported for the country.

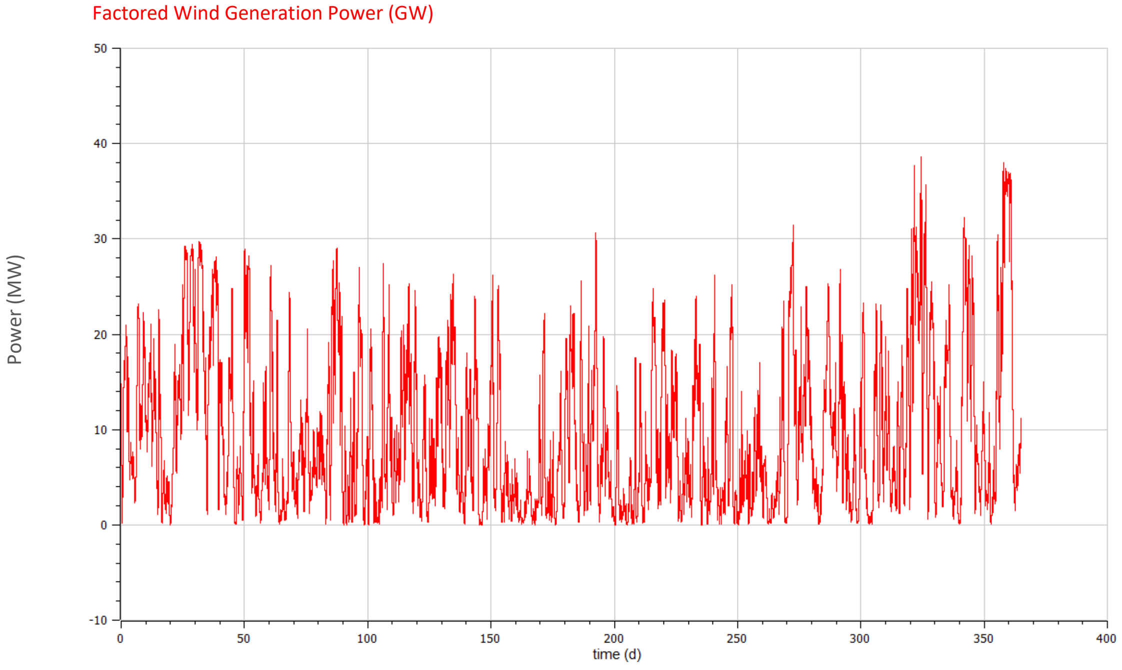


Figure-44: Factored wind generation power plot for scenario-4.

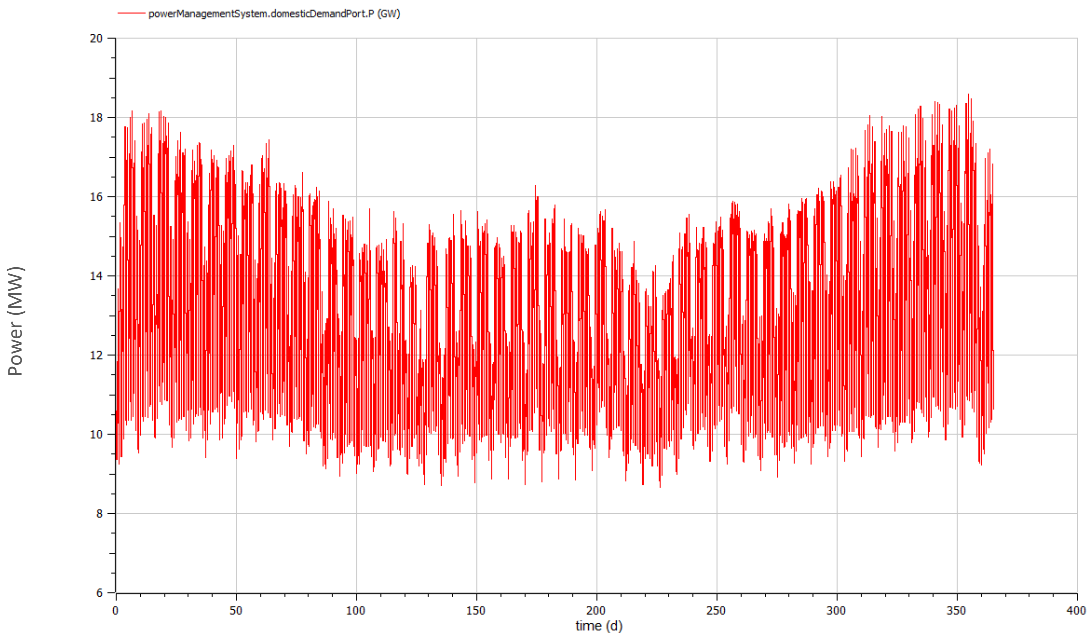


Figure-45: Domestic power consumption profile for scenario-4.

Remaining plots of scenario 4 is similar to that of scenario 3. KPI summary for scenario 4 is shown in the table 9.

Total Energy Generated	Total Energy Transferred from Conventional Grid	Total Energy Transferred to Conventional Grid	Total Energy Demand
89 TWhr	61.3 TWhr	10.8 TWhr	139.5 TWhr

Table-9: Annual simulation KPI summary for scenario-4

2. THE THERMAL GRID LIBRARY

2.1. LIBRARY OVERVIEW

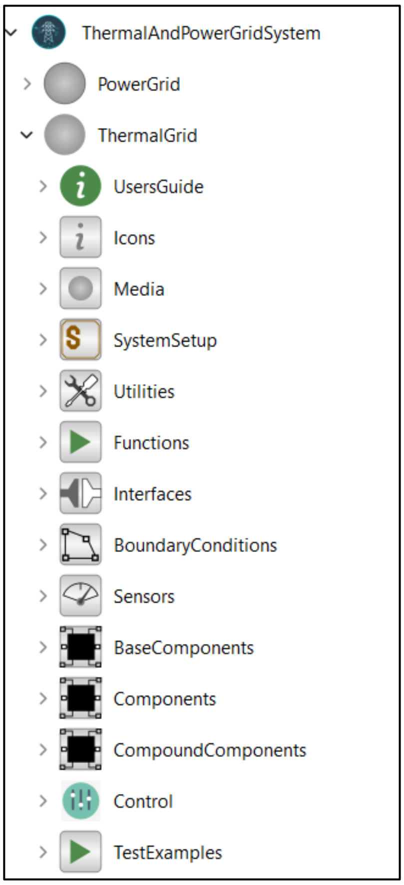


Figure-46: Thermal Grid Library

Figure 46, shows the sub-packages contained in the Thermal Grid package.

System Setup: This package contains three classes, Modeling Constants, Ambient Conditions and System Fluid. The basic fluid properties and conditions used for simulation can be set using this package.

Utilities: The following models are available as utilities. These are external structures to the system provided to aid the system performance.

- Solar Irradiance Data
- User Demand Data
- KPI

Functions: Functions to calculate single and double derivatives are available. An angle modifier calculator is also available to calculate Beam solar irradiation angle based on incident angle. The table used for reference was obtained from Absolicon T160 datasheet.

Interfaces: The following connectors are available under this package for transfer of information between models.

- Water Port
- Heat Port
- Bus
- temp Connector

Boundary Conditions: Several boundary models are provided for testing models.

Sensors: Temperature sensors provided to extract temperature data from any model by connecting any port.

Base Components: Partial models of base components. These are explained in the next section.

Components: Component models that may be used for small simulation scenarios, such as energy consumption of a single house. These are explained in the next section.

Compound Components: Component models that may be used for large simulation scenarios such as energy consumption of a residential community. These are explained in the next section.

Control: Various controller specific to scenarios as well as some generic controllers such as tank controllers are provided as part of this package.

Test Examples: Examples of components are also listed apart from scenario simulations.

2.2. LIBRARY SECTION DETAILS

2.2.1. SYSTEM SETUP

2.2.1.1. MODEL CONSTANTS

This model contains the modeling constants used for this library modeling.

2.2.1.2. AMBIENT CONDITIONS

Ambient conditions such as pressure, ambient temperature, ground temperature is maintained as a record. The hierarchy is defined with inner/outer to maintain a single copy of the ambient conditions throughout a simulation scenario. This enables the changes made to be reflected within each model used to build the scenario.

2.2.1.3. SYSTEM FLUID

This package inherits the Modelica Media package. This is used to calculate the thermodynamic properties of the media in the component models. The medium used is water in the current library. However, this is easily replaceable to model other relevant media, eg, heat transfer fluid.

2.2.2. UTILITIES

2.2.2.1. SOLAR IRRADIANCE DATA

 This model reads solar irradiance data from a text file solarIrradianceData to access the table cspSolarIrradiance to retrieve hourly direct solar irradiation data. This model can be used as an input file to the SolarCSP model that accepts hourly data as input.

2.2.2.2. KPI

 Key Performance Indicators are calculated within this model. The various inputs given to the scenario and outputs generated as sent as inputs to this model to generate the KPI values.

2.2.3. INTERFACES

2.2.3.1. WATER PORT

The connector which transfers fluid properties. The concept of stream variables is incorporated here. The potential variable is “pressure”, the flow variable is “mass flow rate” and the stream variable is “specific enthalpy”. Stream variables are specific properties transported by the flow variable via purely convective transport. The stream variable describes the property of outgoing fluid, irrespective of the actual direction of the flow.

The definition of the connector is given below:

connector WaterPort "Fluid inlet/outlet connector" AbsolutePressure;

Modelica.Units.SI.AbsolutePressure pressure "Potential variable";
flow Modelica.Units.SI.MassFlowRate;
massFlowRate(start=0.0) "Positive when flowing into the system, negative otherwise";
stream Modelica.Units.SI.SpecificEnthalpy specificEnthalpy "Stream variable";

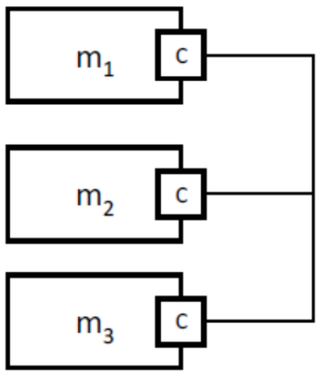


Figure-47: Models m1, m2,m3 connected via stream connectors

The inbuild connection equations for the model given in Figure 47 would be:

Identical potential variables:
m1.c.pressure = m2.c.pressure;
m1.pressure = m3.c.pressure;

Flow variables add to zero:
m1.c.massFlowRate + m2.c.massFlowRate + m3.massFlowRate = 0;

Stream variable values can be accessed using the following two operators:
inStream(): value of stream variable assuming entering flow (massFlowRate > 0) irrespective of actual flow direction

inStream() definition:

```
inStream(m_i.c.h_outflow) = h_mix_in_i;
 0 = sum(m_j.c.m_flow for j in 1:N);
 0 = sum(m_j.c.m_flow*
 (if m_j.c.m_flow > 0 or j==i then h_mix_in_i else mj.c.h_outflow
 for j in 1:N);
```

actualStream(): actual value of v inside the component close to the interface, depending on flow directions.

actualStream() definition:

```
actualStream(port.h_outflow) = if port.m_flow > 0
then inStream(port.h_outflow)
else port.h_outflow;
```

2.2.3.2. HEAT PORT

This connector transfers the heat and temperature data from heat generation models. The flow variable is heat energy and the potential variable is temperature.

2.2.3.3. BUS

An expandable bus is incorporated to simplify the diagram view of test examples. This was mainly done to make separate models for the scenario and the scenario controller.

2.2.3.4. TEMP CONNECTOR

This connector is made to transfer temperature from one node to the next within stratified tank model.

2.2.4. COMPONENT MODELS

All the components under Base Components, Components and Compound Components are coupled under this section.

2.2.4.1. SOLAR CSP MODELS

There are two Solar CSP models available in the package, SolarCSP and SolarCSP2 models. The SolarCSP model accepts monthly average global irradiation data and The SolarCSP2 model used in the ScenariosRealData package under TestExamples, accepts hourly direct irradiation data externally to calculate the total power output. The model also calculates the heat loss.

Figure-48: Icon view of Solar CSP

Governing Equations

Instantaneous Energy:

$$q_{instantaneous} = \varepsilon_{collector} * DNI$$

Heat Loss:

$$Q_{loss} = h_1(T_{medium} - T_{ambient}) + h_2(T_{medium} - T_{ambient})^2$$

Energy Output:

$$Q = n_{collectors} * a_{collector} * q_{instantaneous}$$

where,
$\varepsilon_{collector}$ = collector efficiency
DNI = Direct Normal Irradiation
l = length of pipe
ρ = density of water
$T_{collector}$ = collector fluid medium temperature
$T_{ambient}$ = ambient temperature
h_1 = Heat Loss coefficient of collector at ambient temperature (W/m2.K)
h_2 = Temperature dependence of Heat Loss coefficient of collector (W/m2K2)

2.2.4.2 BIOMASS BOILER MODEL

The biomass boiler is the secondary source of heat generation. The calorific value, fuel rate and boiler efficiency is user-defined to run at full capacity when the primary source of heat generation proves insufficient.

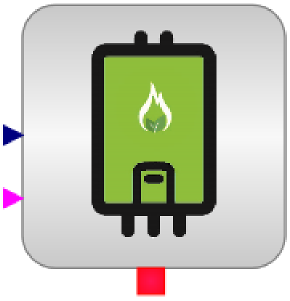


Figure-49: Icon view of Biomass boiler

Governing Equations:

Energy Output:

$$Q = \varepsilon_{boiler} * CV * \dot{m}_f$$

where,

ε_{boiler} = boiler efficiency
CV = calorific value
$\dot{m}_f$ = fuel mass flow rate

2.2.4.3 PIPE MODELS

The pipe models are used to facilitate fluid transportation modeling. The base model Pipe can be found under Base Components. This model calculates the friction coefficient of the pipe, pressure drop across the pipe as well as energy losses.

To model single pipes, two pipe models are provided under the Components package, i.e supplyPipe, shown in Figure no.50(a) and return Pipe as shown in Figure no. 50(b). These models extend the Pipe model and use different icons for easier identification in complex scenarios.

Figure-50: (a) Icon view of supply Pipe, (b) Icon view of return Pipe

To model pipeline systems, two pipeline system models are provided under the Components package, i.e hotPipelineSystem, shown in Figure no. 51(a) and coldPipelineSystem as shown in Figure no. 51(b), These models extend the Pipe model and use different icons for easier identification in complex scenarios.

Figure-51: (a) Icon view of hotPipelineSystem, (b) Icon view of coldPipelineSystem

Governing equations:

Pressure drop:

$$\Delta P = \frac{2fl\rho v^2}{d}$$

Heat Flow:

$$Q_{pipe} = \rho \dot{m} C_p (T_{pipe} - T_{ambient})$$

Heat Loss:

$$Q_{loss} = Q_{pipe} * Q_{percentage\ loss}/100)$$

where,

f = pipe friction coefficient

l = length of pipe

ρ = density of water

v = velocity of water flow

d = diameter of pipe

$\dot{m}$ = mass flow rate of water

T_{pipe} = temperature of water in pipe

$T_{ambient}$ = ambient temperature

Q_{pipe} = heat flow through pipe

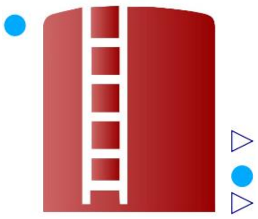
$Q_{percentage\ loss}$ = percentage heat loss

Q_{loss} = heat loss to environment

2.2.4.4 TANK MODELS

The tank models are to facilitate fluid storage modeling. The tanks are assumed to be open to atmosphere with bottom discharge. Additional to the input and output connectors, a level sensor and output stream temperature sensor are provided. The base model Tank can be found under Base Components. The input-output enthalpy change, level of medium in the tank, enthalpy storage, output pressure is modelled here. This is a partial model and cannot be used for modeling scenarios.

Under the Components package, hotTank and coldTank models, as shown in Figure 52(a) and 52(b) respectively, are provided with different icons for easy visual representation in complex scenarios.



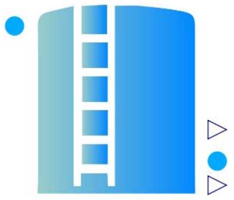


Figure-52: (a) Icon view of hotTank, (b) Icon view of coldTank.

Governing equations:

Surface Area:

$$A_s = 2\pi r_{tank} h_{tank}$$

Heat Loss:

$$Q_{loss} = UA_s(T_{tank} - T_{ambient})$$

Heat stored in tank:

$$H_{tank} = \rho l h_{tank} A_{tank}$$

$$\frac{dH_{tank}}{dt} = \dot{m_{in}} h_{in} - \dot{m_{out}} h_{out} - Q_{loss}$$

Level of tank:

$$A_{tank} \frac{d(l * \rho)}{dt} = \dot{m_{in}} - \dot{m_{out}}$$

where,

A_s= surface area of tank
A_{tank} = cross-sectional area of tank
h_{tank} = height of tank
r_{tank} = radius of tank
T_{tank} = temperature of water in tank
$T_{ambient}$ = ambient temperature
ρ = density of water

l = level of water in tank
U = heat transfer coefficient of tank
$\dot{m}_{in}$ = mass flow rate of input water stream
$\dot{m}_{out}$ = mass flow rate of output water stream
Q_{loss} = convective heat loss

2.2.4.5 PORT EXCHANGE MODEL

The port exchange model comes as a replacement of a heat exchange model. As this library has modeled only the heat transfer medium, i.e, water, the provision of a port exchange model is necessary to exchange the heat transfer information from the Supply models such as Solar CSP and Boiler, into the transfer medium, i.e water. It can also be said that the Heat Port information is passed into the Water Port.

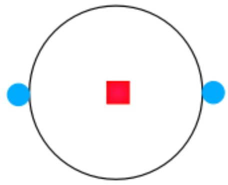


Figure-53: Icon view of Port Exchange

2.2.4.6 PUMP MODEL

The pump model's objective is to calculate the power consumed by the pump and pressure drop across it. Apart from the input/output water ports, there is a switch provided to turn the pump on or off.

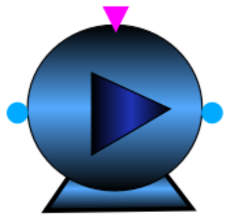


Figure-54: Icon view of Pump

Governing Equations:

Pressure Difference:

$$\Delta P = P_{in} - P_{out}$$

Pump Head:

$$h_{pump} = \Delta P/\rho g$$

Pump Power:

$$P_{pump} = \dot{m_{in}} * h_{pump} * g/\varepsilon_{pump}$$

where

ΔP = pressure difference
P_{in}, P_{out} = Pressure of inlet and outlet streams respectively
ρ = density of water
g = acceleration due to gravity

h_{pump} = pump head
$\dot{m_{in}}$ = inlet mass flow rate
ε_{pump} = efficiency of pump
P_{pump} = Power consumed by pump

2.2.4.7 VALVE MODELS

There are two valve models available in the components package, on/ff valve and linear valve. The pump Cv values are user-defined. The fractional valve opening of linear valve is also user-defined. The model calculates the pressure drop across the valve.

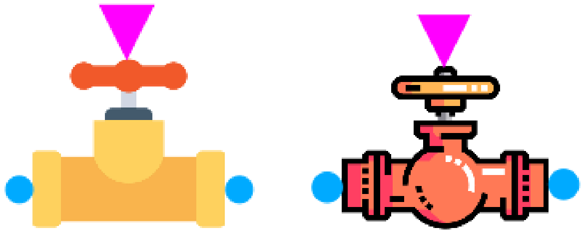


Figure-55: (a) Icon view of Linear Valve (b) Icon view of On/Off Valve

Governing Equations:

Pressure Difference:

$$\Delta P = P_{in} - P_{out}$$

Outlet Mass Flow Rate:

On/off Valve - $\dot{m_{in}} = \dot{m_{out}} = Cv * \Delta P$

Linear Valve - $\dot{m_{in}} = \dot{m_{out}} = Cv * x * \Delta P$

where,

ΔP = pressure difference

P_{in}, P_{out} = Pressure of inlet and outlet streams respectively

$\dot{m_{in}}$ = inlet mass flow rate

$\dot{m_{out}}$ = outlet mass flow rate

Cv = valve flow coefficient

x = fractional valve opening

2.2.4.8 DOMESTIC CONSUMPTION MODELS

Space heating is the domestic consumption that is considered. The average data per household per year is taken and daily data demand is calculated. The heat is utilized and the return temperature of the outlet stream is also calculated in the model. It is assumed that each house has four residents.

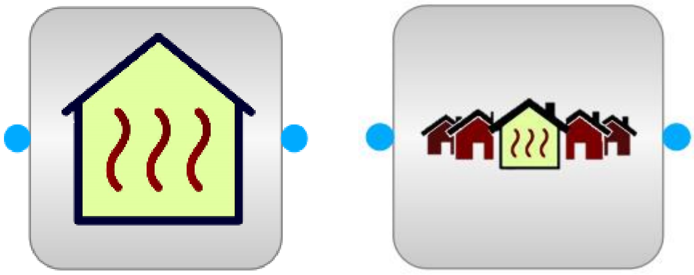


Figure-56: (a) Icon view of Single Domestic (b) Icon view of Residential Community

2.2.4.2 INDUSTRIAL CONSUMPTION MODELS

Industrial consumption mode is similar to domestic consumption. The model calculates the return temperature based on the average yearly demand. It is assumed that the demand of each industry is the same.

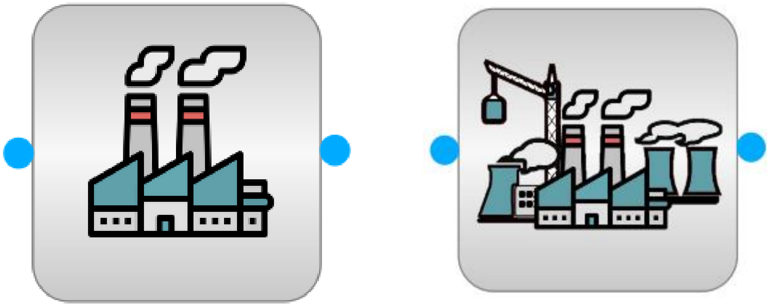


Figure-57: (a) Icon view of Single Industry (b) Icon view of Industrial Complex

2.2.5. CONTROL

The control models are built as state machines. The logic of a scenario controller is added as a flowchart below.

LEGEND

T_SUP	Supply Tank Temperature
T_DH	District Heating Temperature
T_DH_min	District Heating Minimum Temperature
T_DH_max	District Heating Maximum Temperature
T_TES	Thermal Energy Storage Temperature

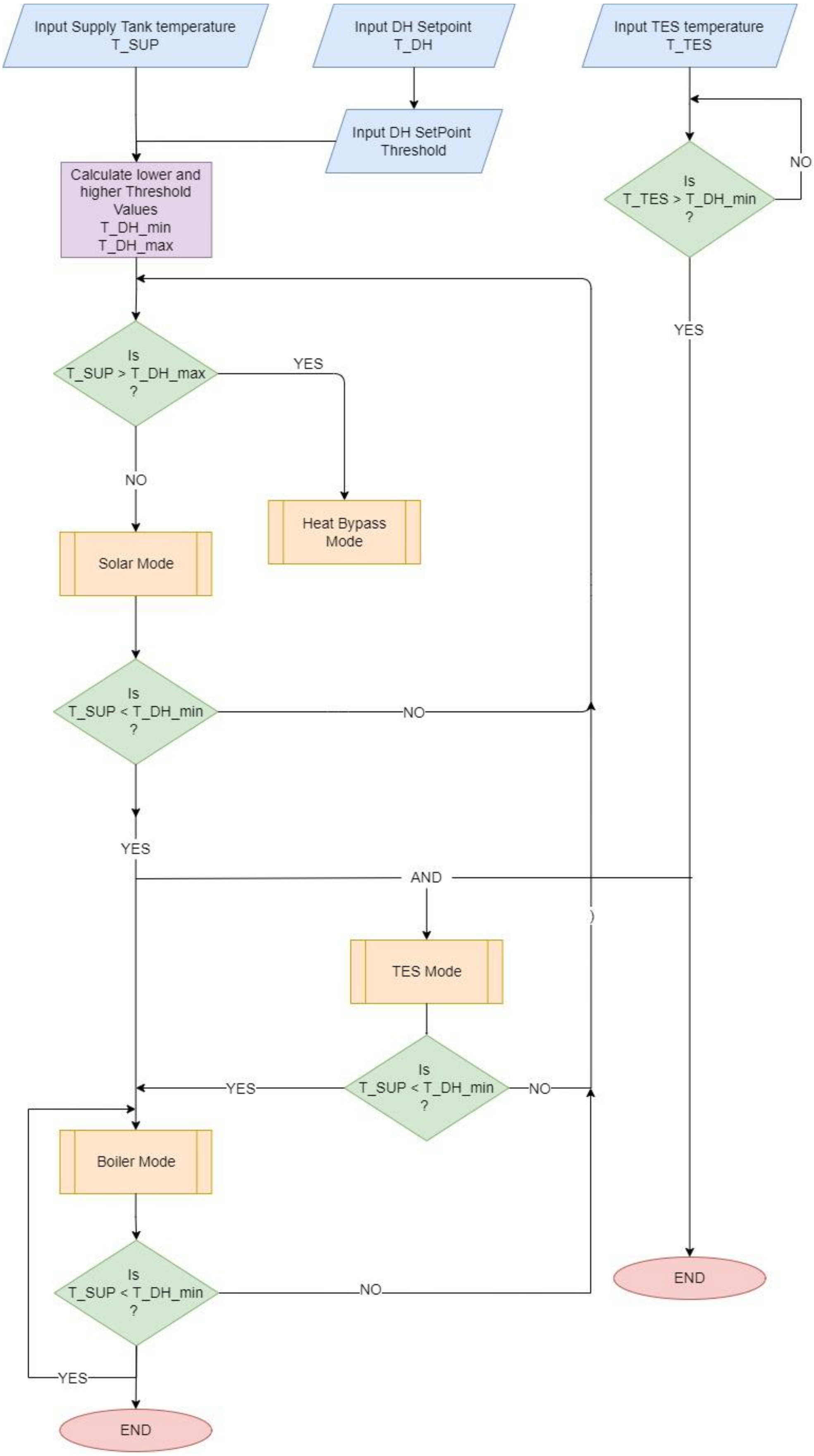


Figure-58: Control Logic of a scenario

2.3. SIMULATION SCENARIOS

2.3.1. SCENARIO 1: ANNUAL SIMULATION OF SINGLE HOUSE

The model of this scenario is shown in Figure 59. The scenario is modeled and connected to the controller model using an expandable bus. This is to avoid confusion between connector lines and increase readability.

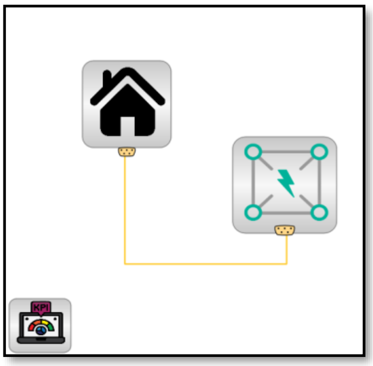


Figure-59: Scenario 1 Simulation

The primary heat source is Solar CSP and the secondary heat source is biomass boiler. The cold water supply is stored in the cold water tank. This water is supplied to the port exchange connected to the Solar CSP as well as the port exchange connected to the biomass boiler, for heat transfer. There is also a line that bypasses the heat sources to provide cold water for temperature regulation. The solar datablock connected as input to the Solar CSP model, is taken from the Utilities package and generates hourly direct irradiation data. The hot water thus generated is stored in the hot water supply tank. The temperature of the supply tank is a user-defined parameter. This is controlled using the controller model, shown in Figure 60. Space heating is the consumption considered as the domestic usage. The water is then returned to the cold tank, hence forming a closed loop.

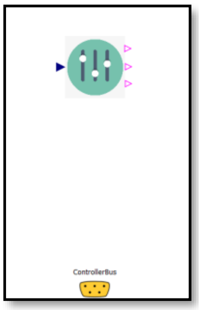


Figure-60: Scenario 1 Controller

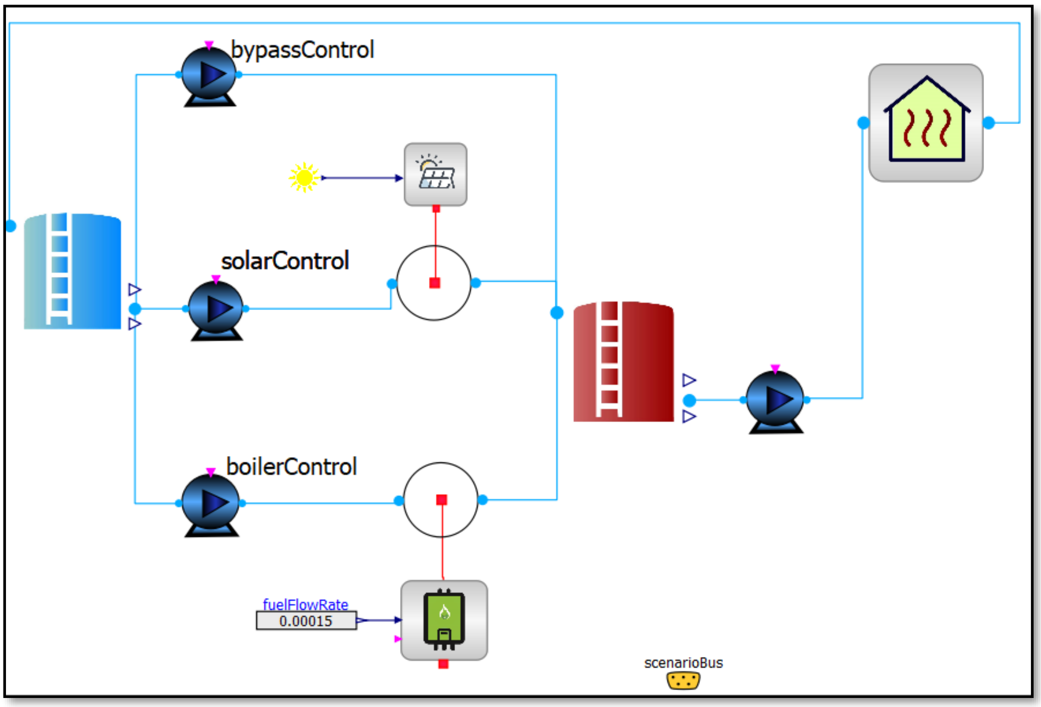


Figure-61: Scenario 1

2.3.1.1 SIMULATION RESULTS

Direct irradiation data (W/m2) and the corresponding output power (W) from 20 collectors is shown below in the Figure 62. The temperature of water from the solar CSP is plotted in Figure 63. During the winter months, less heat is generated and hence the primary source proves insufficient. When the primary source is unable to maintain the temperature setpoint, the biomass boiler line opens. The secondary source, the biomass boiler, has a fixed power output of 1500W. The water heated by the boiler is at 99°C.

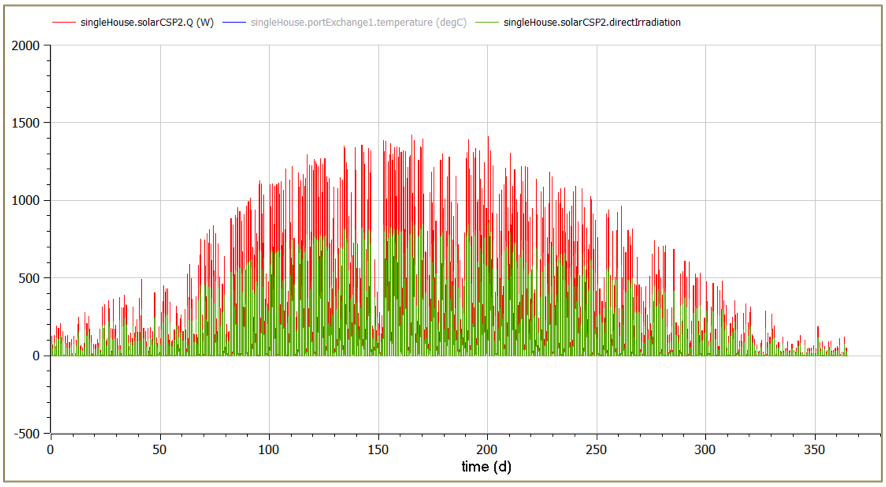


Figure-62: Direct irradiation data/m2 and Power Output of Solar CSP field

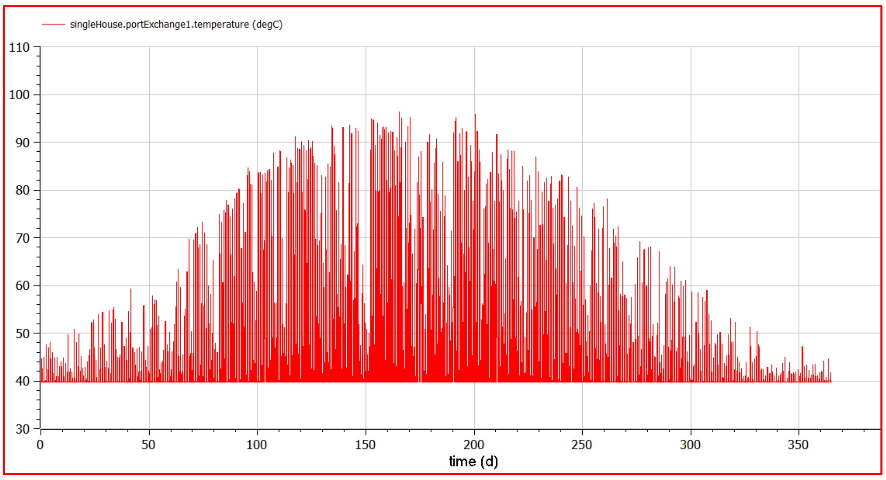


Figure-63: Output temperature of solar heated water

The temperature of hot water supply varies between the low and high limits of the user-defined setpoint.

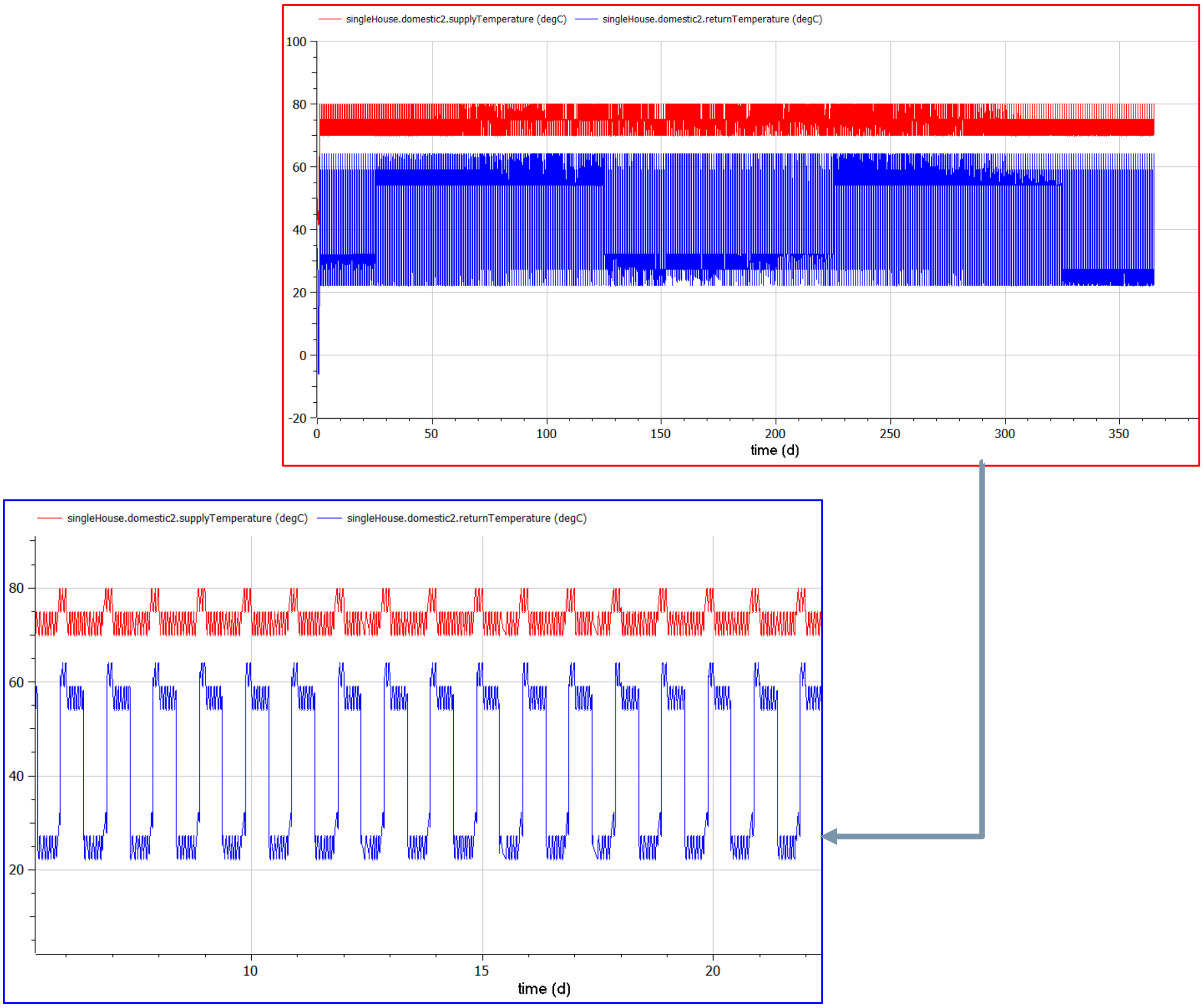


Figure-64: Supply and return temperatures of water at domestic consumption

The domestic supply temperature and return temperature are plotted in the above figure. The heat demand per house per year is taken 7000 kWh, assuming four residents per house.

The controller modes switching between solar and boiler modes as source of heat generation during summer and winter are shown in Figure 65. In summers, Solar CSP covers most of the demand, as opposed to winters when the boiler is utilized more often.

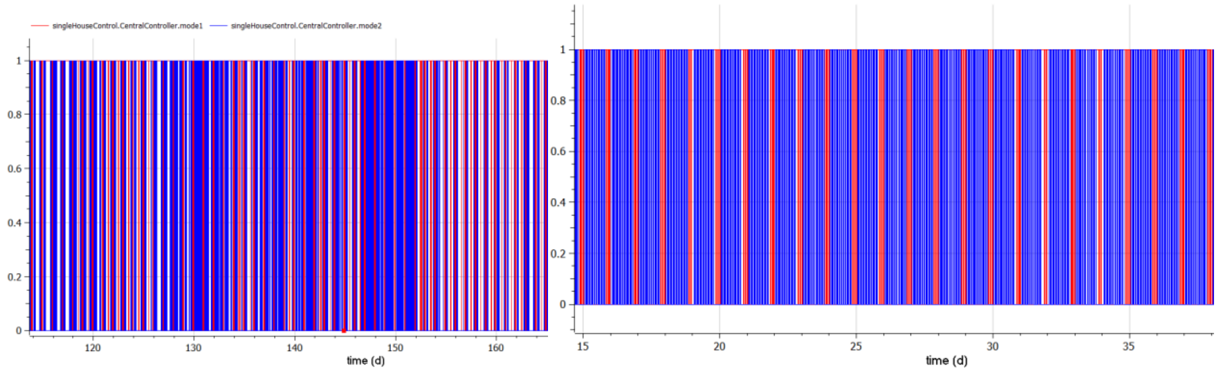


Figure-65: (a) Controller Modes during Summer (b) Controller Modes during winter

2.3.2. SCENARIO 2: ANNUAL SIMULATION OF RESIDENTIAL COMMUNITY OF ~250 HOUSES

The model of this scenario is shown in Figure 66. The scenario is modeled and connected to the controller model using an expandable bus. This is to avoid confusion between connector lines and increase readability.

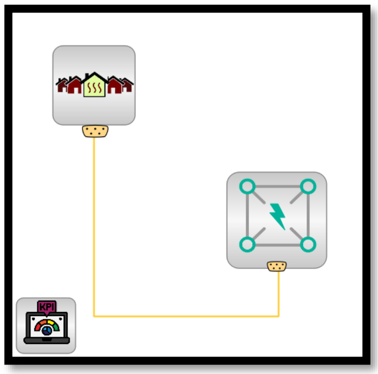


Figure-66: Scenario 2 Simulation

The primary heat source is Solar CSP and the secondary heat source is the thermal energy storage. This stores excess heat energy during summers and utilizes this energy during energy deficit winter days. The biomass boiler becomes the tertiary heat source, supplying heat when the temperature of thermal energy stored is insufficient. In this model, irrespective of the season, the ability of the thermal storage to discharge heat is checked when solar heat is insufficient before utilising the biomass boiler. Here, there is a separate solar field with 2000 collectors for the purpose of charging the TES. Water is pumped to the port exchange connected to this field during the daytime. It has a capacity of storing water for six months usage of the demand indicated in this model. As in the previous model, the supply tank temperature is controlled by the Central Controller and sources are decided accordingly. The logic for this controller is indicated in Figure 67.

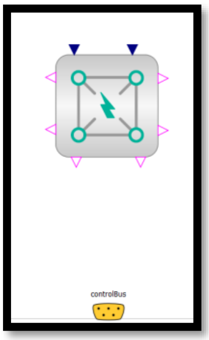


Figure-67: Scenario 2 Controller

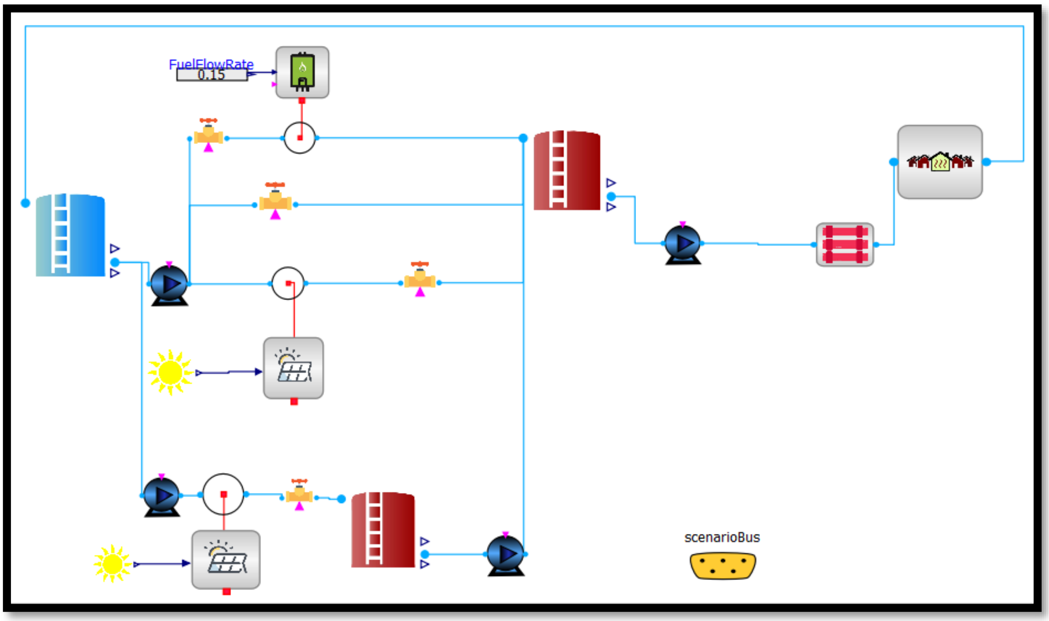


Figure-68: Scenario 2

2.3.1.2 SIMULATION RESULTS

Direct irradiation per unit area and Output power (W) from 200 collectors is shown below in figures 69 and 70. The temperature of water from the solar CSP is plotted in fig 71. Another solar field of 2000 collectors is connected to a thermal storage. Hence the thermal storage is the secondary heat source and the biomass boiler is the tertiary supply. When the primary source is unable to maintain the temperature setpoint, thermal energy storage (TES) is utilized if the temperature is sufficient, failing which, the biomass boiler line opens. The biomass boiler, has a fixed power output of 1500W. The water heated by the boiler is at 99°C.

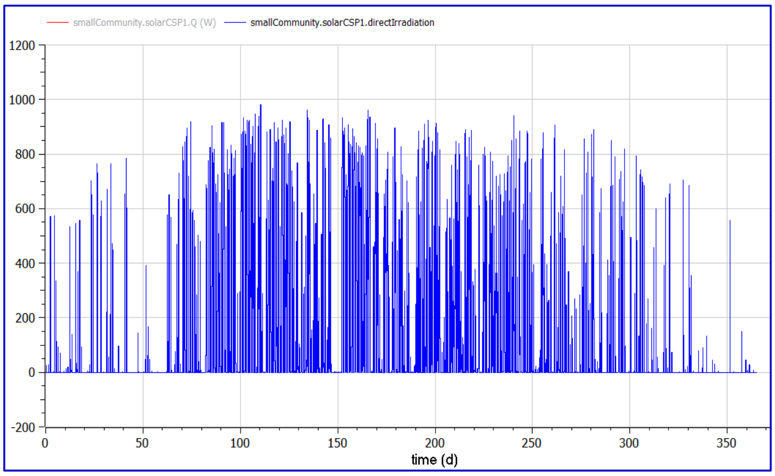


Figure-69: Direct irradiation /m2

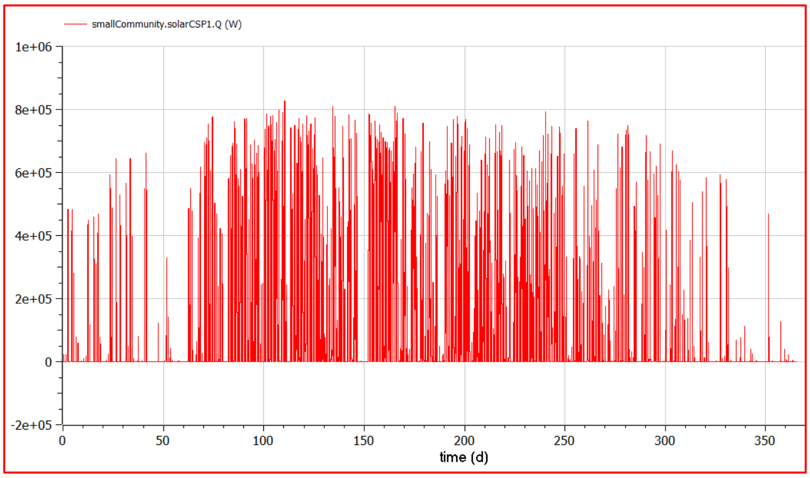


Figure-70: Output power (W)

The thermal storage temperature variation through the year is plotted below. There is no stratification considered. Stratification models are available and are under construction under Components package.

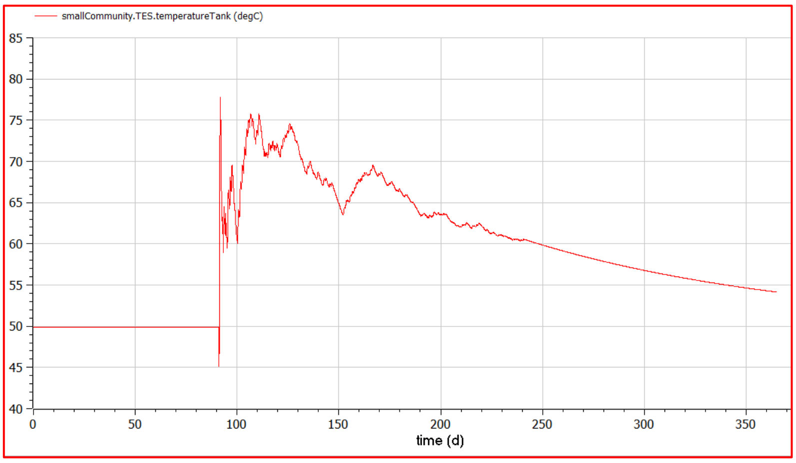


Figure-71: Thermal Energy Storage Temperature

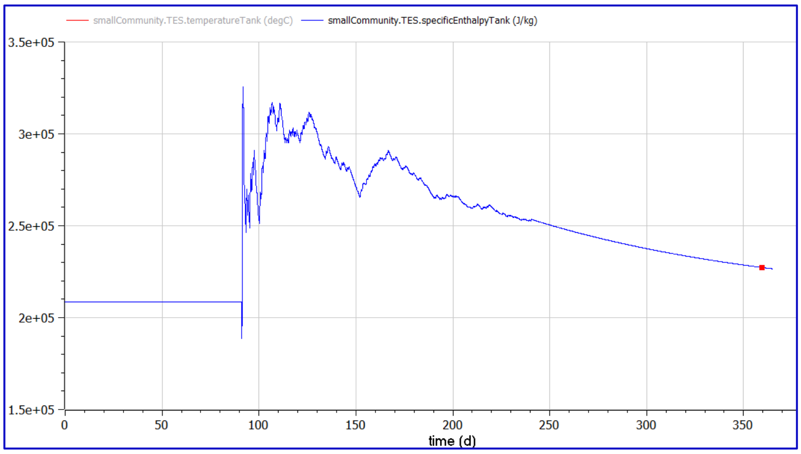


Figure-72: Energy stored in the TES

The domestic supply temperature and return temperature are plotted in the below figure. The heat demand per house per year is taken 7000 kWh, assuming four residents per house. This simulation is done for approx. 250 houses.

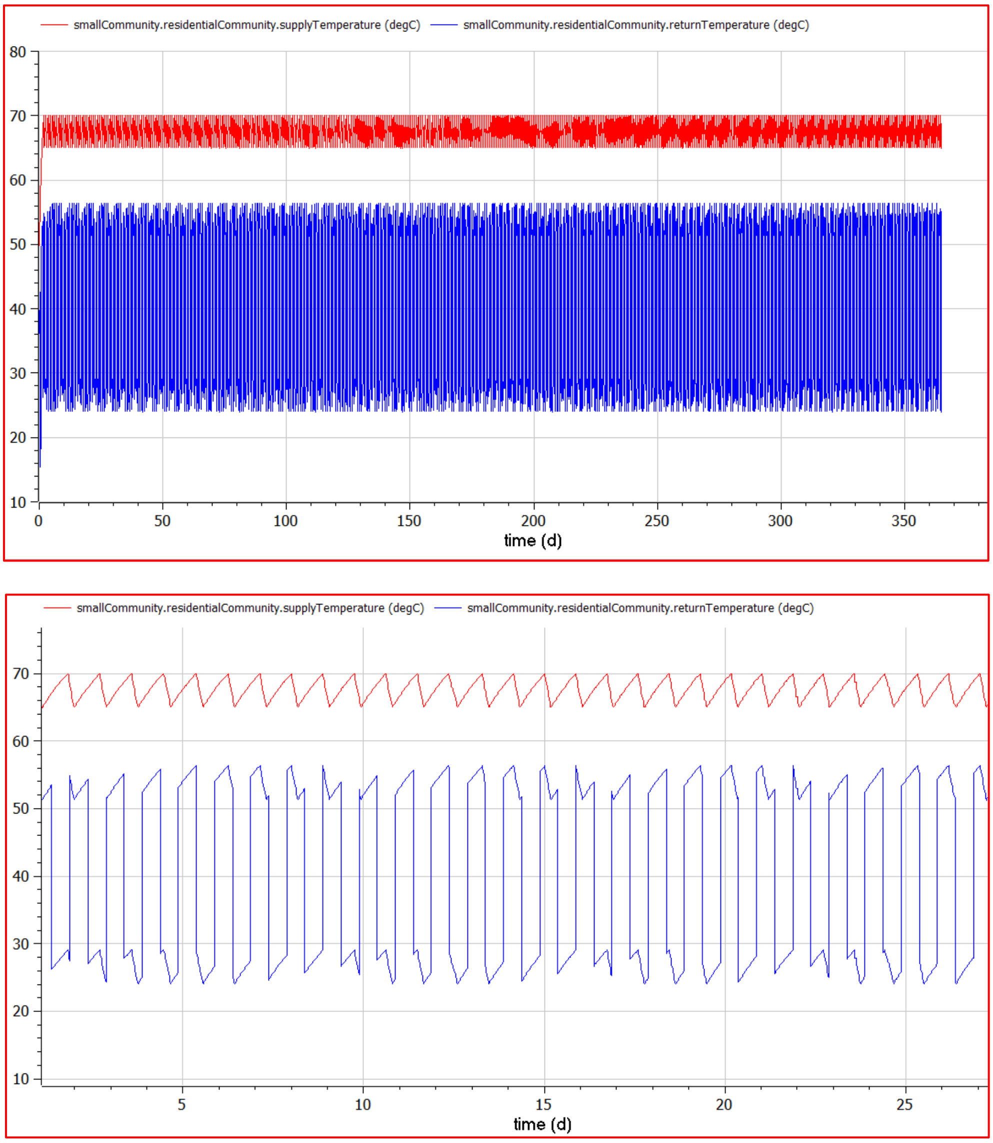


Figure-73: Supply and return temperatures of water at domestic consumption

2.3.3. SCENARIO 3: ANNUAL SIMULATION OF NETHERLAND

The model of this scenario is shown in Figure 74. The scenario of Netherland country is modelled and connected to the controller model using an expandable bus. This is to avoid confusion between connector lines and increase readability.

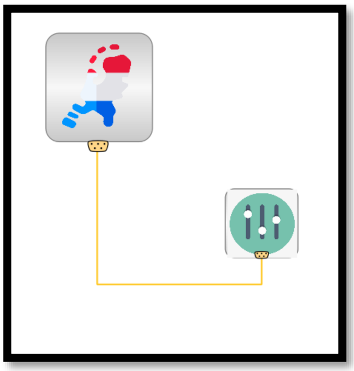


Figure-74: Scenario 3 Simulation

The heat demand, solar irradiance and air temperature of Netherlands for the year 2013 is considered for this scenario. The primary heat source is Solar CSP and the secondary heat source is the thermal energy storage. This stores excess heat energy during summers and utilizes this energy during energy deficit winter days. The biomass boiler becomes the tertiary heat source, supplying heat when the temperature of thermal energy stored is insufficient. In this model, irrespective of the season, the ability of the thermal storage to discharge heat is checked when solar heat is insufficient before utilising the biomass boiler. Here, there is a separate solar field with 80000000 collectors for the purpose of charging the TES. Water is pumped to the port exchange connected to this field during the daytime. It has a capacity of storing water for six months usage of the demand indicated in this model. As in the previous model, the supply tank temperature is controlled by the Central Controller and sources are decided accordingly. The logic for this controller is indicated in Figure 75.

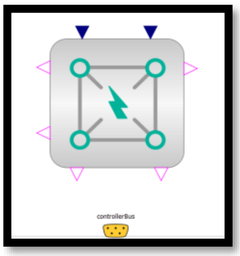


Figure-75: Scenario 3 Controller

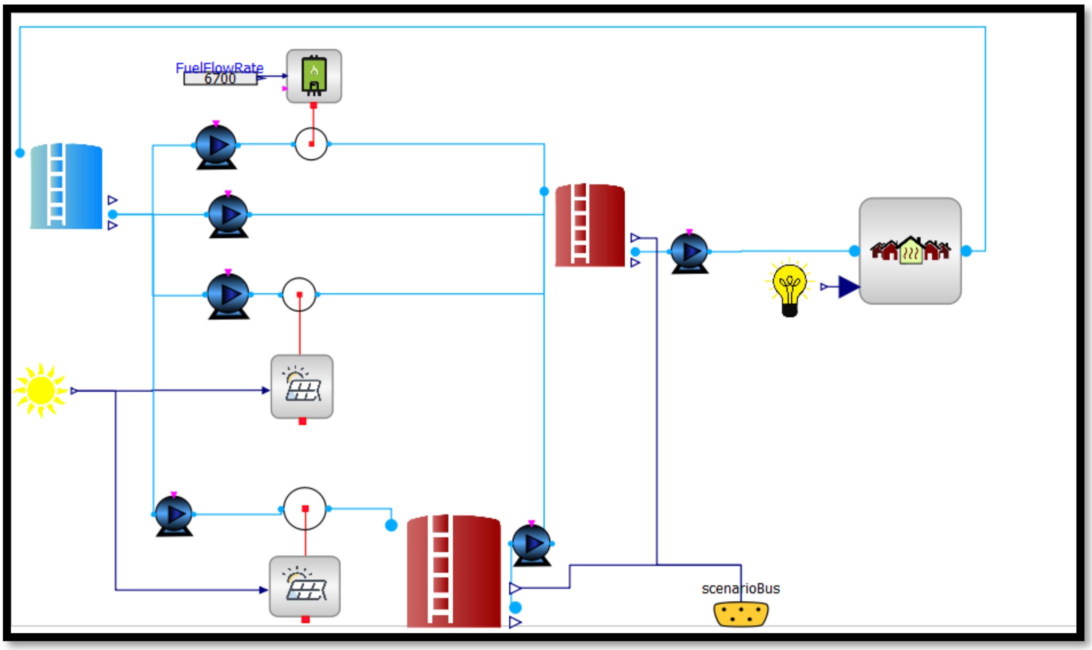


Figure-76: Scenario 3

2.3.3.1. SIMULATION RESULTS

Direct irradiation per unit area and Output power (W) from 1900000 collectors is shown below in figures 77 and 78. Another solar field of 80000000 collectors are connected to a thermal storage. Hence the thermal storage is the secondary heat source and the biomass boiler is the tertiary supply. When the primary source is unable to maintain the temperature setpoint, thermal energy storage (TES) is utilized if the temperature is sufficient, failing which, the biomass boiler line opens. The biomass boiler, has a fixed power output of 6700W. The water heated by the boiler is at 99°C.

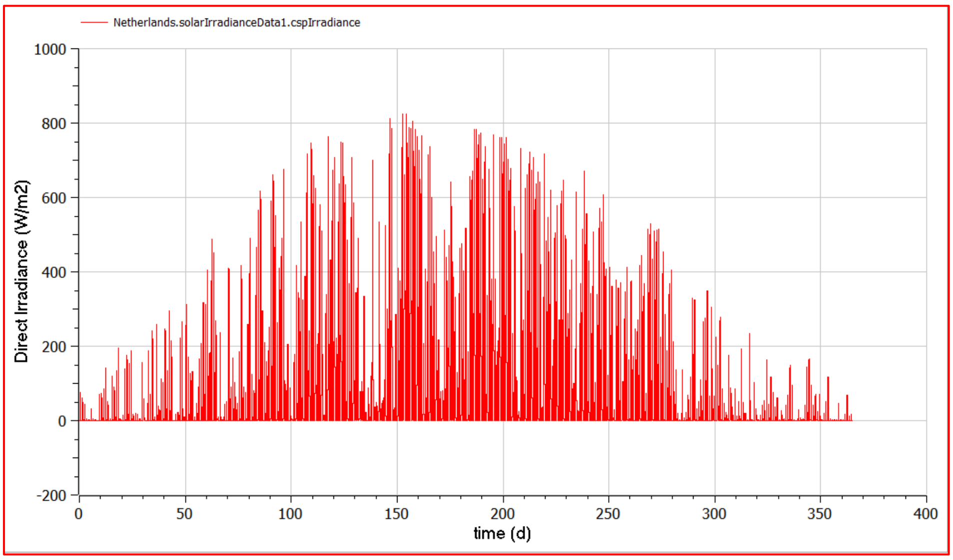


Figure-77: Direct irradiation /m2

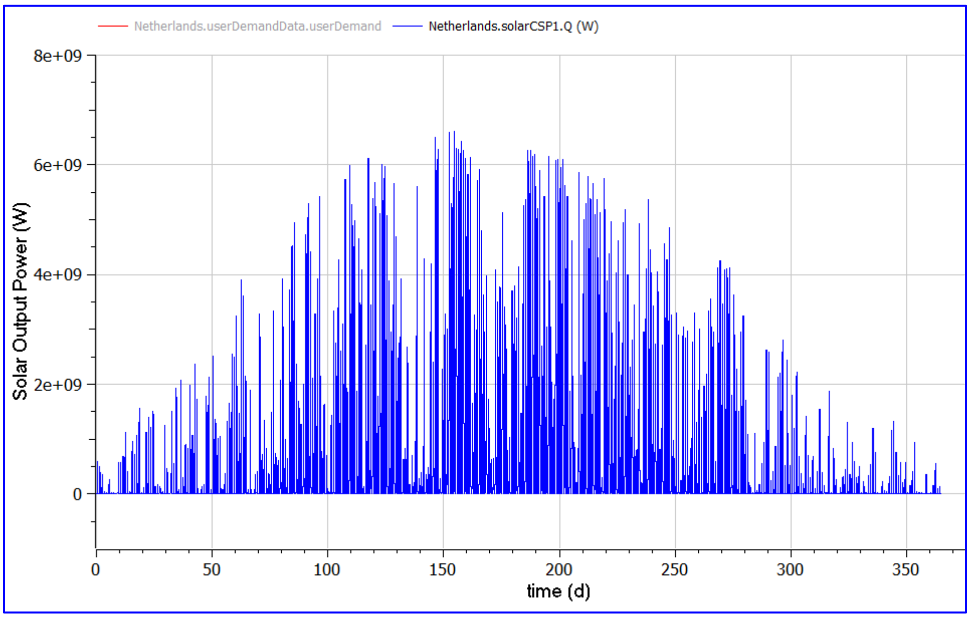


Figure-78: Solar Output power (W)

The thermal storage temperature variation through the year is plotted below. There is no stratification considered. Stratification models are available and are under construction under Components package.

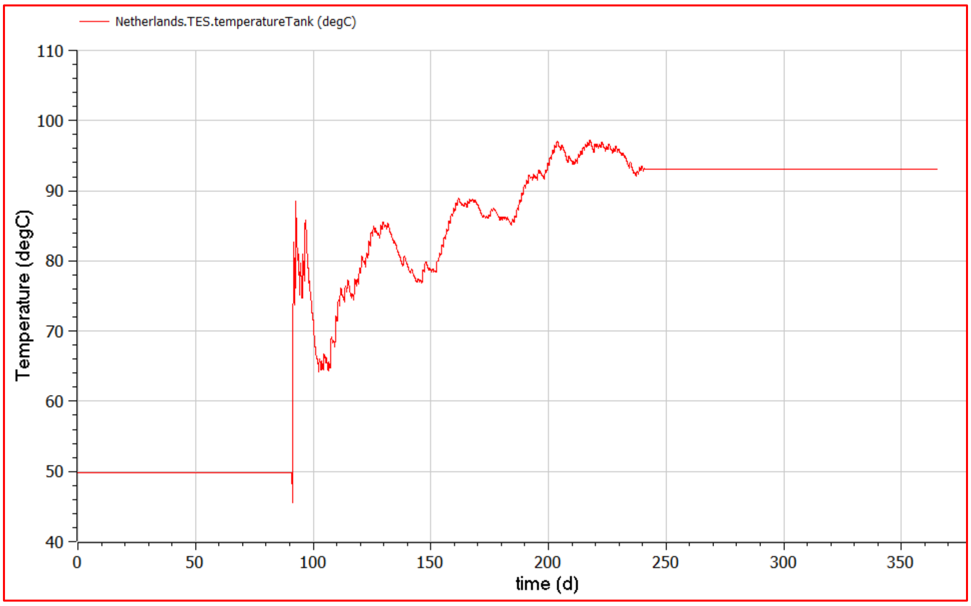


Figure-79: Thermal Energy Storage Temperature

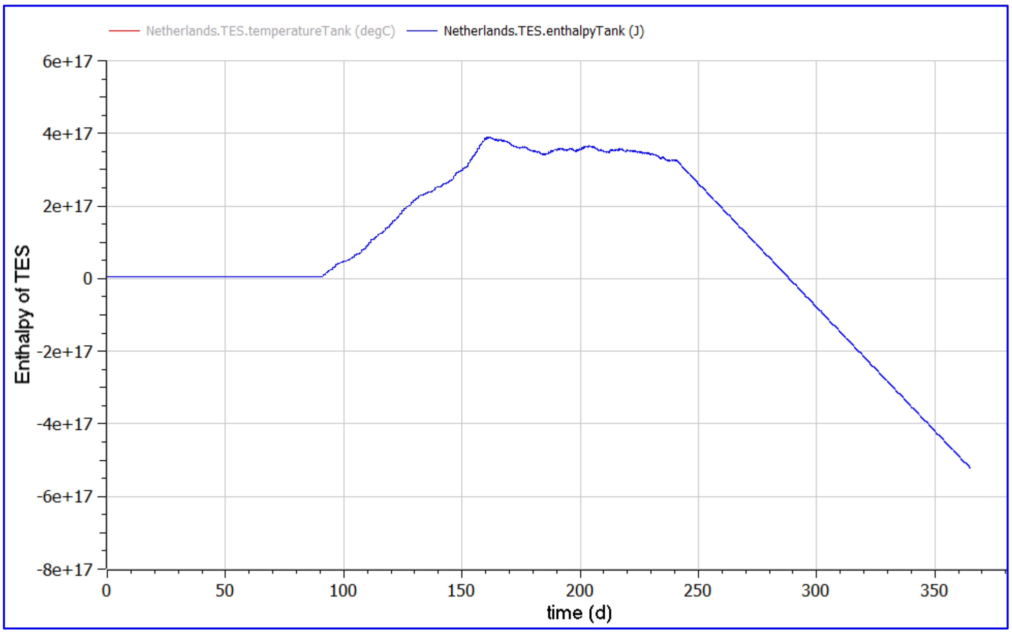


Figure-80: Energy stored in the TES

The domestic supply temperature and return temperature are plotted in the below figure 81. The heat demand data extracted for the country is shown in figure 82.

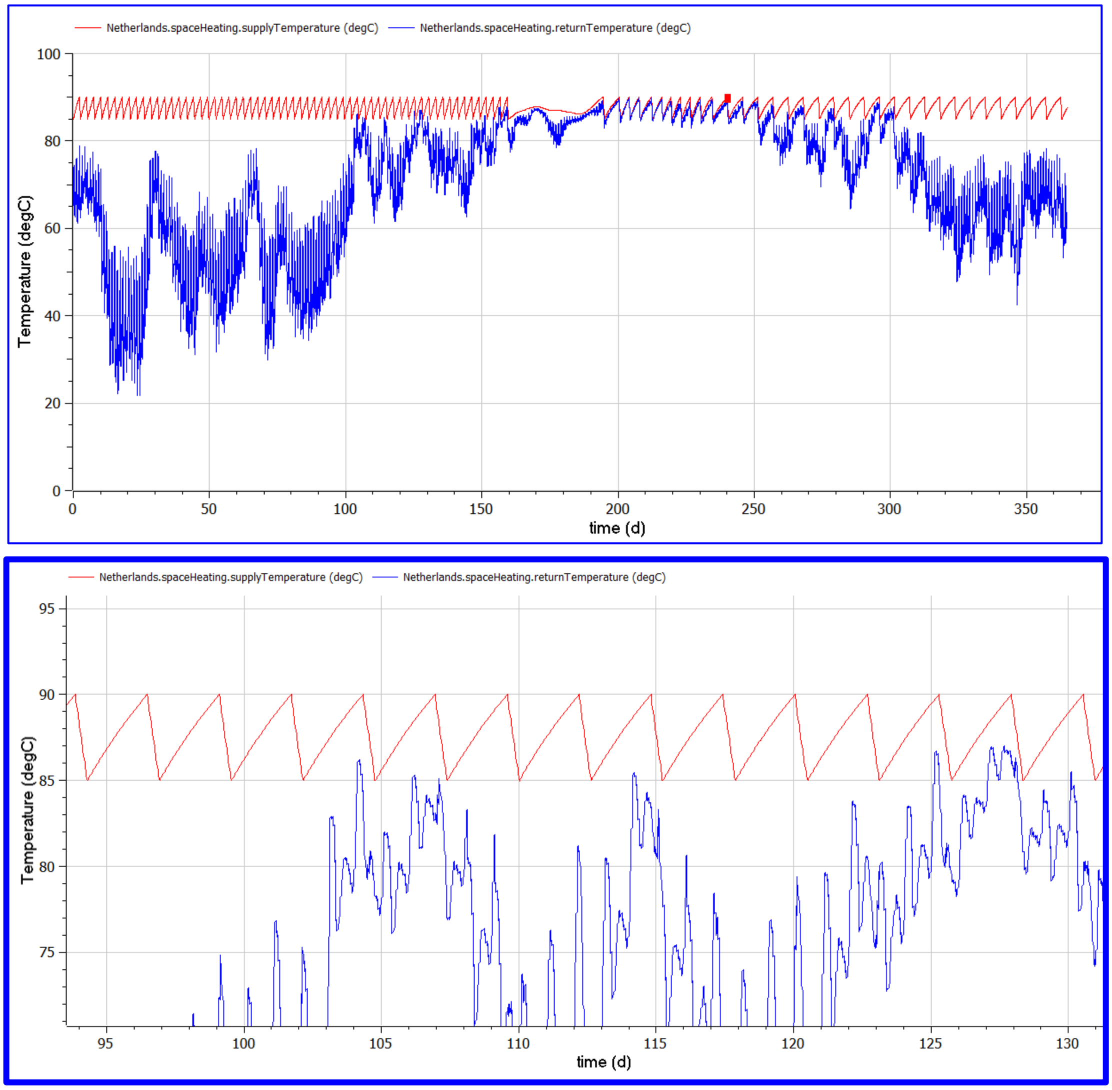


Figure-81: Supply and return temperatures of water at domestic consumption

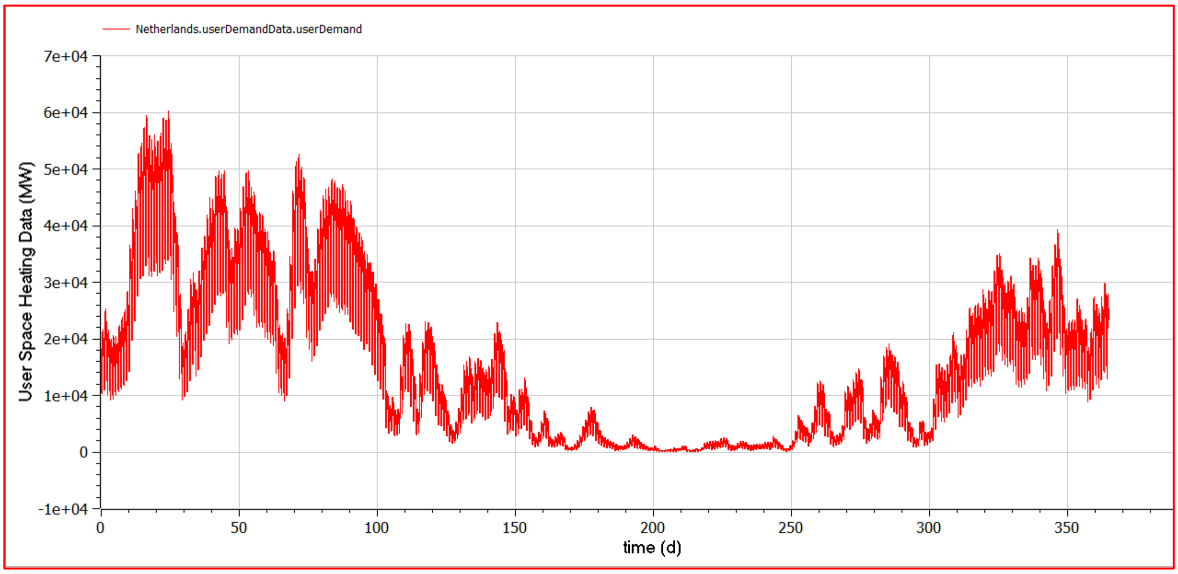


Figure-82: Space heating domestic demand for Netherlands

The controller modes switching between solar, boiler and TES discharge modes are shown in Figure 83.

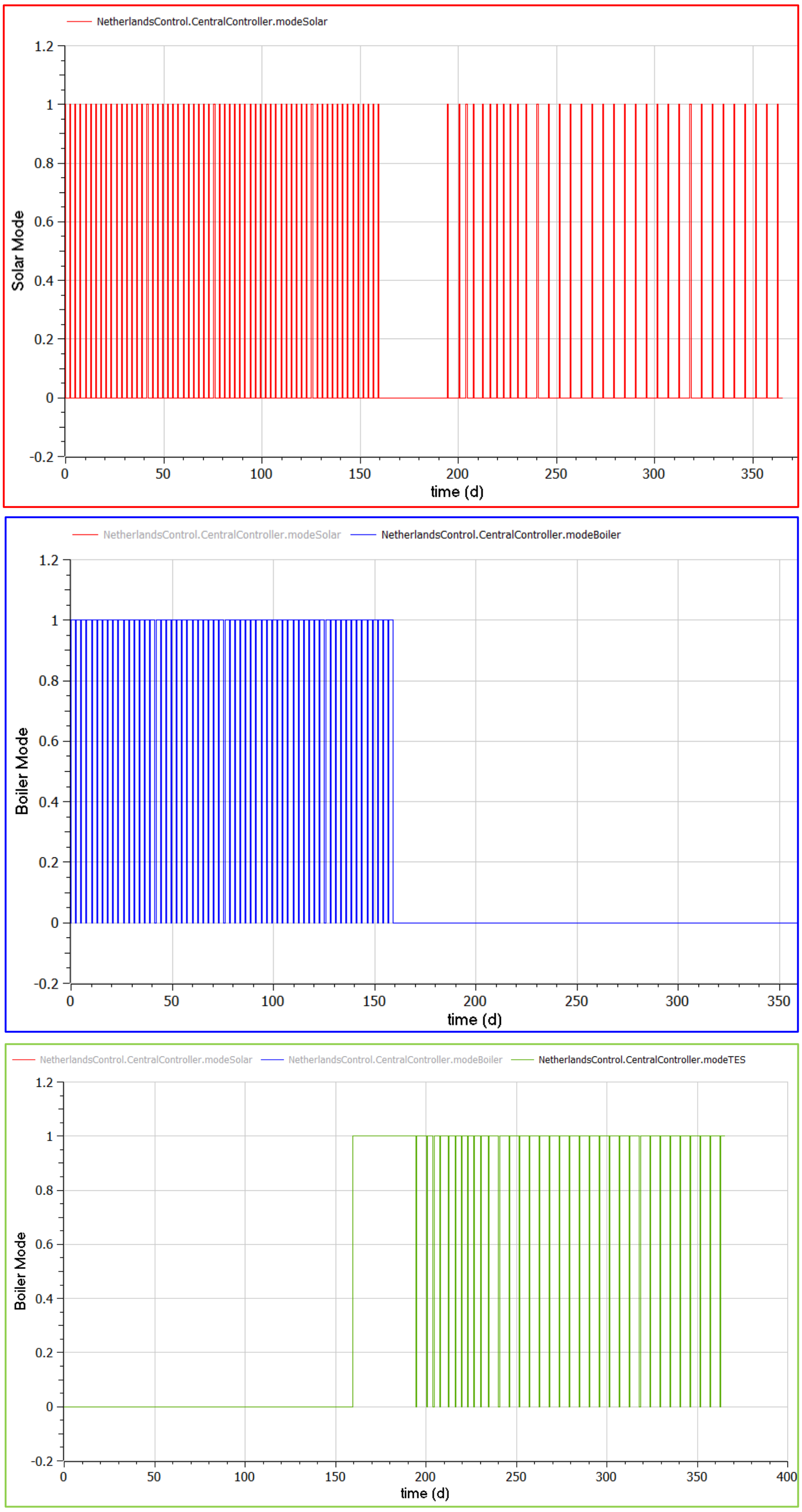


Figure-83: Control modes Solar mode, Boiler mode and TES discharge mode for scenario -3.