Livø - Further Implementation of Energy Supply Solutions

Grid information:

Livø is completely isolated from the mainland. It has its own diesel-powered electricity and heating plant, an ancient, valuable and worth preserving buildings and a tiny community that goes into hibernation when the ferry voyage set in the winter and the tourists go home. The present energy consumption in Livø comprises mainly electricity and heat consumption in buildings and fuel for boats, vehicles and agricultural machinery. The island's electricity supply is from a local diesel power plant operated by the Nature Agency. The diesel engines contributes also to the district heating system, since heat losses are used for the district heating system. The remaining heat supply (the portion that is not hot water) takes place mainly by means of a local district heating plant fired with wood from the island's forests. The thermal demand is higher than the electrical demand in the grid. The district heating system has also a large oil-fired boiler as supplement in particularly cold periods and to use as a backup.

The grid contains three diesel generators 36 kW each. A solar installation with 33.33 kWp and a 25 kW wind installation is under implementation. All the following dynamic simulations of the energy system are carried out in DIgSILENT software. Load measurements are available at køkken (total electrical consumption), Nord (electrical consumption at the radial to the North of the diesel engines) and Syd (electrical consumption at the radial to the North of the diesel engines). Load data that is provided is in 1 min rate, wind data is 1 hr rate and solar radiation measurements is in 1 sec data rate. The time frame considered is from '17-Dec-2012 00:00' - '10-Nov-2013 23:59'.

Single line diagram

The single line diagram of the system is shown in Figure 1a. The belonging set up as seen in the simulation software program DigSILENT is shown in Figure 1b. Electric total load on the grid is shown in Figure 2, estimated solar generation profile in Figure 3 and wind generation profile in Figure 4 for the whole year.

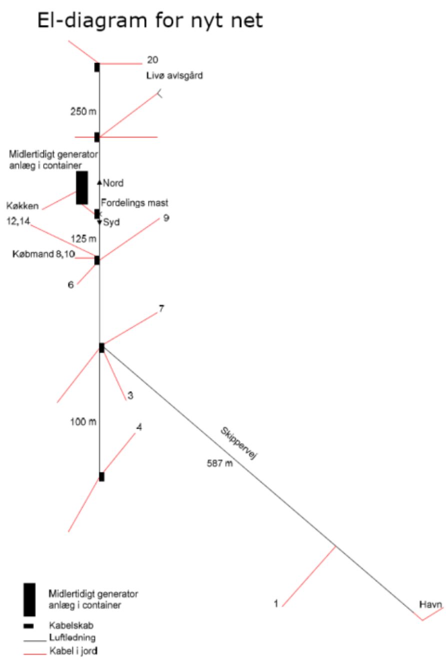

Figure 1a. Single diagram of Livø grid

System Diagram

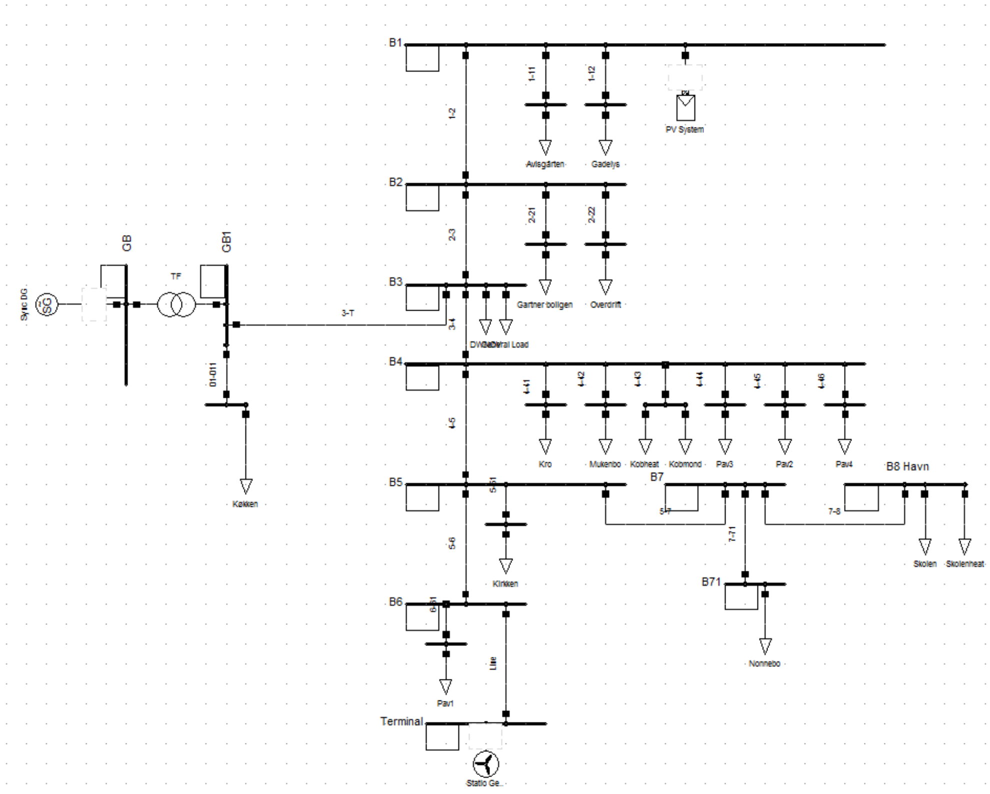

Figure 1b. DIgSILENT model

Electrical demand:

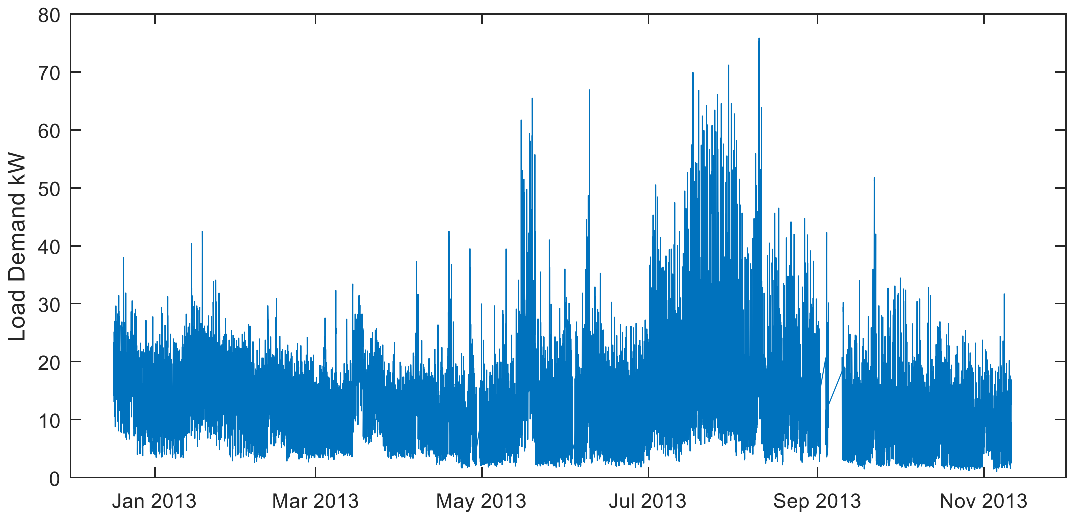

Figure 2. Electrical demand on the Livø grid for a year

Solar generation profile:

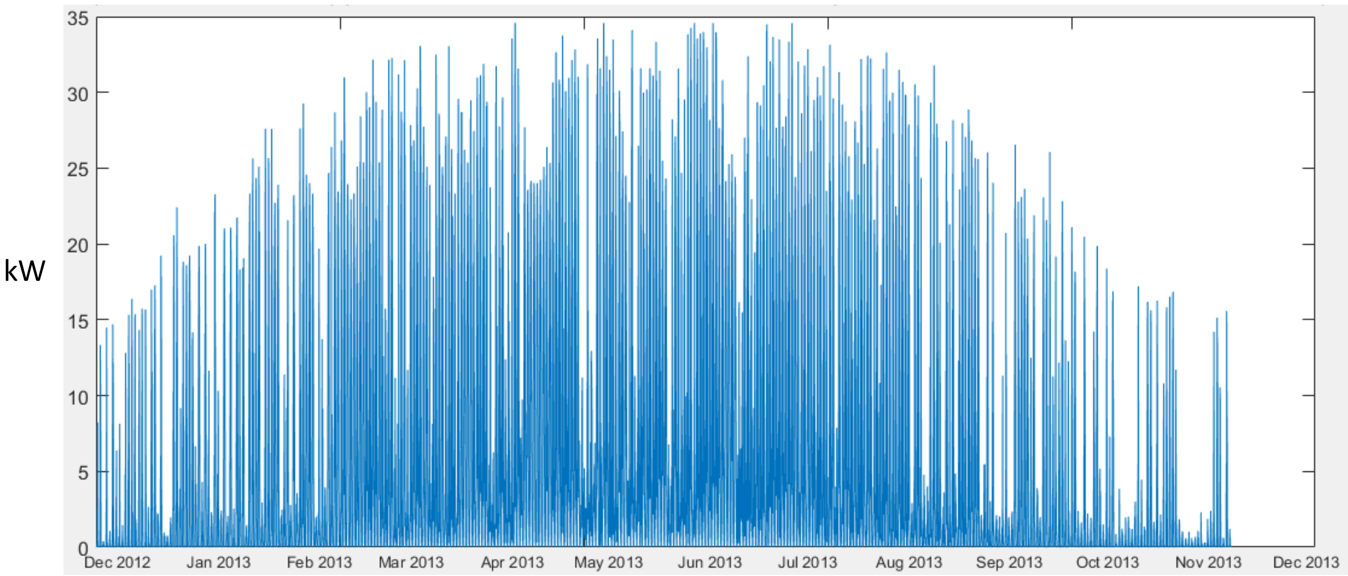

Figure 3. Solar generation for a year

Wind generation profile:

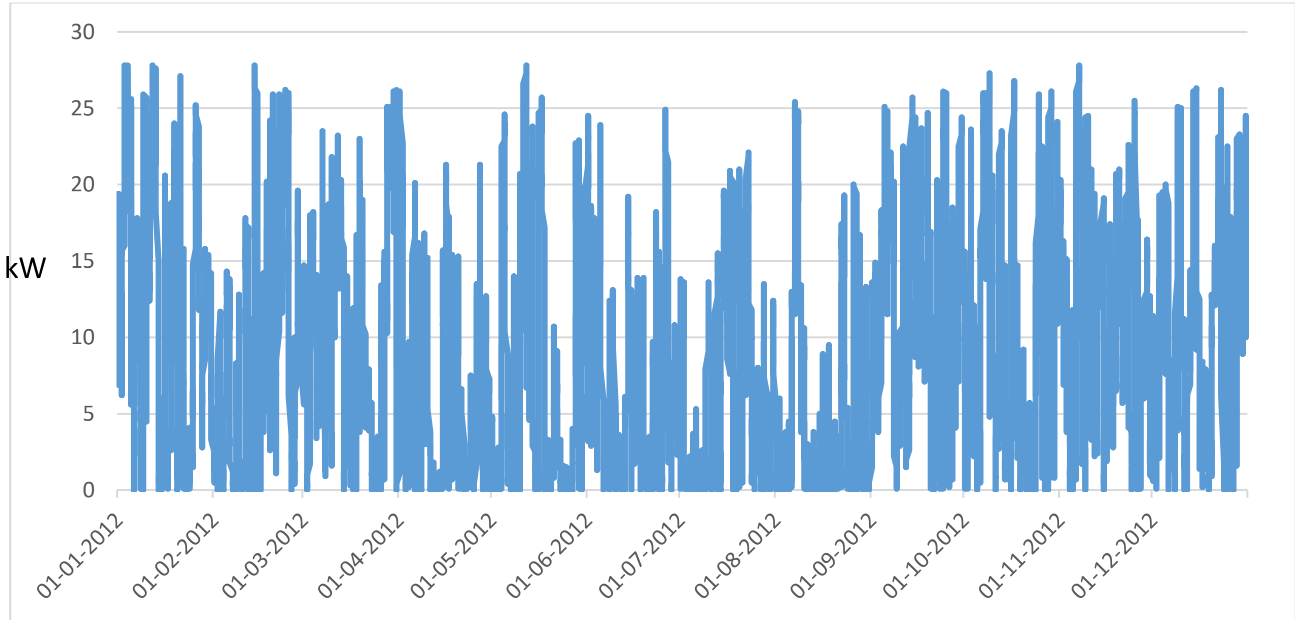

Figure 4. Wind generation for a year

Electrical boiler:

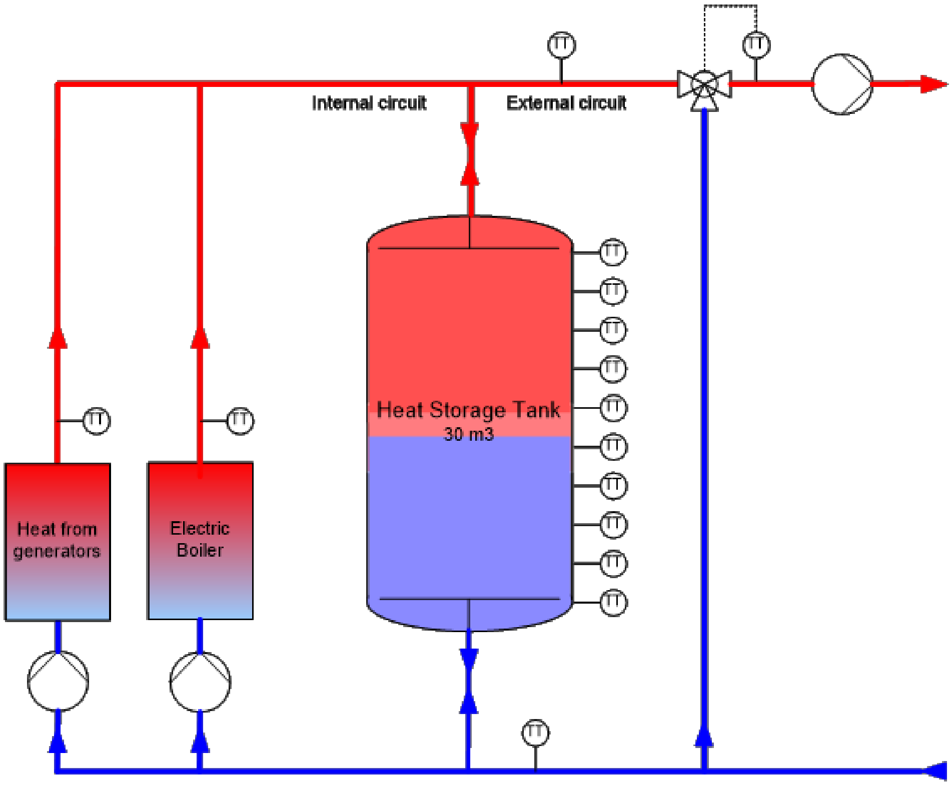

Figure 5. Electrical boiler set-up

The storage tank has a useable volume of 30 m³ the dimensions. The capacity of electric boiler is 67 kW with 4.5 kW ON/OFF steps. The diffusors in top and bottom lowers the velocity of the water flowing in/out of the tank thus establishing the temperature layer stratification. The tank is equipped with 10 pcs. temperature transmitters, giving the temperature of the layers. The energy content will be calculated in the control system on basis of the common return temperature from the DH network and the actual temperature of the individual "layers" around each temperature transmitter. Layers with a temperature below a set limit (lower that what can be used in the DH network) will be excluded from the calculation.

In these simulations as a first case the district heating energy is produced by the cooling of the diesel generators and by the electric boiler as indicated on the sketch in figure 5. The heat storage will be charged/discharged based on the difference between production and consumption in the DH network (internal and external flow rate). The supply temperature to the DH network is adjusted by the shunt to actual climate conditions (based on outdoor temperature). **The electric boiler will produce whenever there is surplus electric energy available**, keeping the generator running as close to its minimum as possible (approx. 11 kW).

Heat storage tank modelling:

The Heat Storage Tank (HST) is stratified into 10 layers. The energy balance for the temperature node i is as follows

$$(m_i c)_s \frac{dT_{s,i}}{dt} = \delta_i^c (\dot{m}c)_c (T_{\text{room}} - T_{s,i}) + \dot{Q}_{h,i} - \delta_i^{cw} (\dot{m}c)_{\text{cw}} (T_{s,i} - T_{\text{cw}}) - U_{eff} A_i (T_{s,i} - T_o)$$
$$+ \delta_i^+ \dot{m}_i c (T_{s,i-1} - T_{s,i}) + \delta_i^- \dot{m}_{i+1} c (T_{s,i} - T_{s,i+1}) - A_q \frac{\lambda_{eff}}{z} (T_{s,i} - T_{s,i-1})$$

$$\dot{m}_i = \dot{m}_c - \dot{m}_{cw} \, for \; i = 2, .., N-1$$

$$\dot{m}_i = 0 \; for \; i = 1 \; and \; i = N$$

where, suffix c – collector or heat source from DG and boiler ; suffix cw – cold water ; suffix s – storage tank; $\dot{m}_i$ – mass flow ; T_{room} – room temperature (20^{o}); T_{cw} – cold water temperature (15^{o}) ; U_{eff} – Heat transfer coefficient of storage walls ; λ_{eff} – vertical heat conductivity ; z – Height of each layer in the storage tank (633 mm); A_i - the exterior surface (diameter - d_i =3100 mm); A_q - the cross section area of the respective node (diameter - d_q =2500 mm).

$$\delta_i^c = \begin{cases} 1 & for \; i = 1 \\ 0 & for \; i \neq 1 \end{cases}$$ i.e. Heat supply into the top layer

$$\delta_i^{cw} = \begin{cases} 1 & for \; i = N \\ 0 & for \; i \neq N \end{cases}$$ i.e. Cold water return into the bottom layer

$$\delta_i^+ = \begin{cases} 1 & for \; \dot{m}_i > 0 \\ 0 & for \; \dot{m}_i \leq 0 \end{cases}$$ i.e. energy input from $i-1$ to layer i

$$\delta_i^- = \begin{cases} 1 & for \; \dot{m}_{i+1} < 0 \\ 0 & for \; \dot{m}_{i+1} \geq 0 \end{cases}$$ i.e. energy input from $i-1$ to layer i

The heat supply is present at the first layer and the subsequent layers are warmed by the effective thermal conduction and forced convection from the preceding layers.

Diesel Generation:

The total Diesel Generator (DG) output at any given time is

- 42% electrical output
- 48% thermal output
- 10% losses

The Diesel generators are producing heat only from engine cooling water (just a minor heat source) when they are in operation. There will always be one generator operating in this phase of the project for making green energy supply at Livø (until we get a battery storage) and the generator shall always be operating at or above its minimum load which is approx. 11 kW to enable stabile electrical conditions.

The electric boiler will produce heat whenever there is surplus electricity available (from solar panels and/or from wind turbine). Surplus is when the electricity demand of the network is met, and the diesel generator is "pushed back" to its minimum load. The heat from the generators and the heat from the electric boiler is stored in the heat storage tank to level out difference between

DH production and demand. If the heat storage tank is full (high temperature top to bottom) the solar panels or the wind turbine will have to be limited in production or switched off.

Heat storage tank (HST) dynamics are influenced by the amount of heat supplied to the HST and the amount of heat demand taken from HST. The heat supply is from DG and electrical boiler. Subtracting the heat supply available (DG+Electrical boiler) from the total thermal demand for that hour, is the difference that is met by the oil boiler. The temperature rise/fall in the heat storage tank is completely dependent on the heat from the DG+electric boiler not on the oil boiler. The temperature limits are 65-80 degress, whenever the temperature in the HST falls below 65 deg, if there is no energy available from RES during this situation then DG is used to give power to fire Electric Boiler for maintaining the temperature limits.

District heating

The district heating (DH) in the grid is mainly space heating demand and hot water demand. The DH demand is from permanent residents and Livø feriecenter. The estimated hourly annual heat consumption is shown in Figure 6. It can observed from the figure that the heat is consumption is high in April, July and August months due the fact that there are large number of tourists than in winter.

The sources of the thermal energy and their output for every hour are

- an oil boiler of 580 kW (580*(1000/3600))=161.11 Wh
- wood boiler of 125 kW (125*(1000/3600))= 34.72 Wh
- DG of 108 kW (108*(1000/3600)*(0.42/0.48)) = 26.25 Wh
- electric boiler is fired in two cases
    - when there is excess electricity from the solar and wind turbine after meeting the electrical demand
    - when the temperature in the HST is below the limits

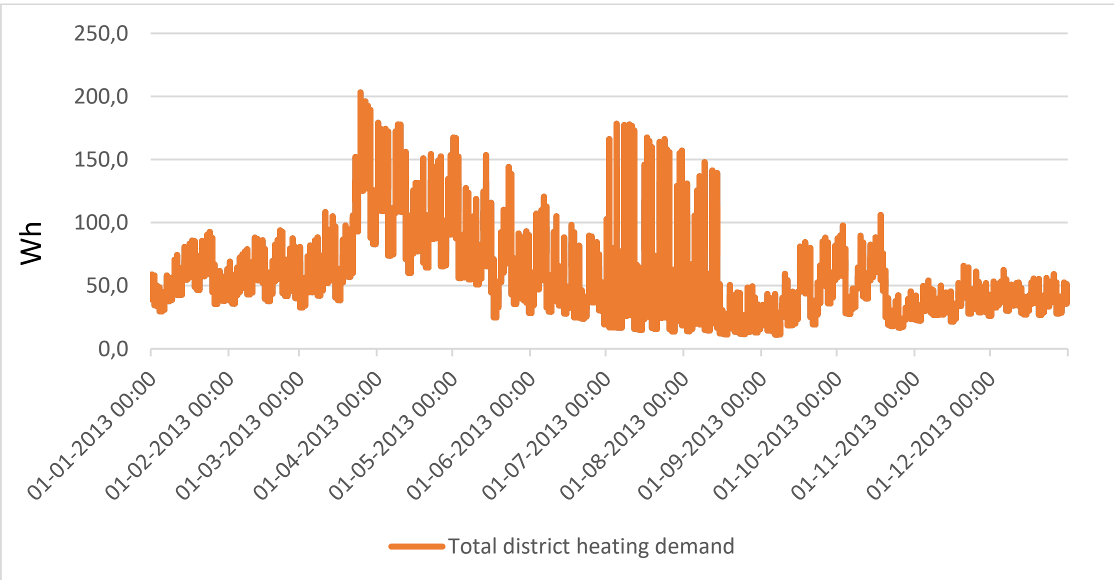

Figure 6. DH demand on Livø grid

Case study

Simulations are carried out for three months i.e. Jan, April and July

Scenario – 1: January month

Heat production from the DG and heat from electric boiler are stored in the heat storage tank. The electrical boiler is fired whenever there is excess production from solar and wind. Further thermal demand than what can be achieved from the storage tank is met by the oil boiler therefore the difference between DH production and DH demand is first met by the heat storage tank and then the oil boiler. Figure 7 shows the electrical demand for the January month not taking the electrical boiler into account.

Electrical Demand

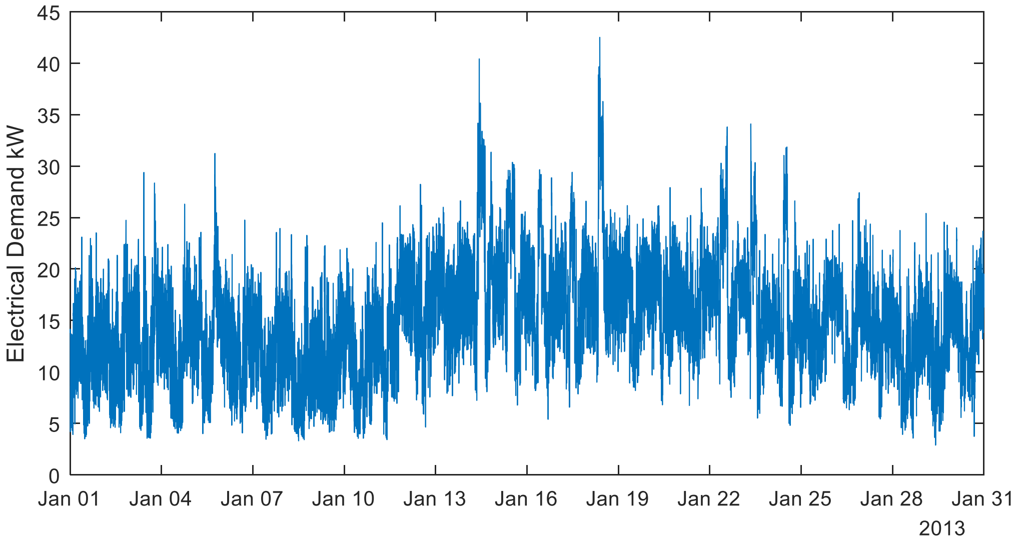

Figure 7. Electrical demand for January month without demand for the electrical boiler

Diesel Production

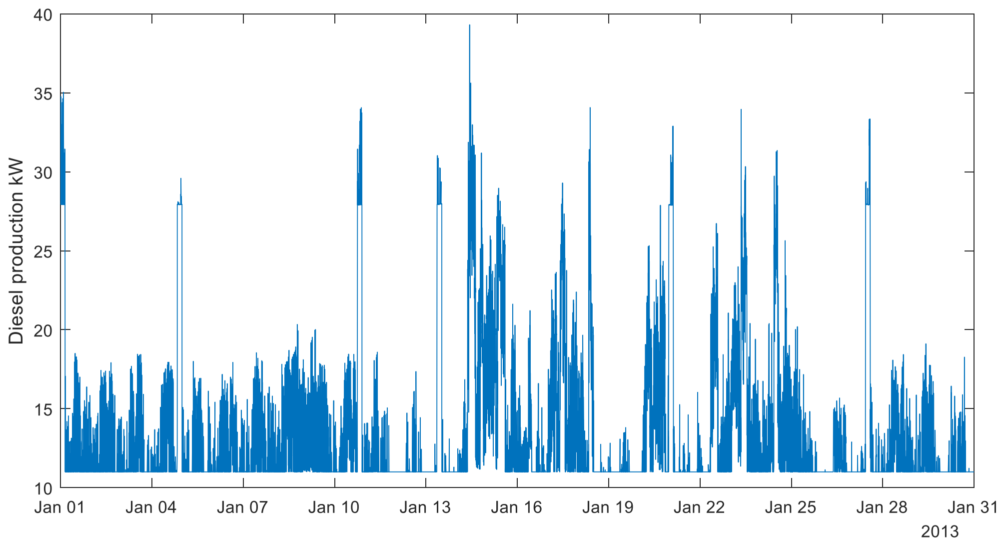

Figure 8. Production from DG for January month including production for the electrical boiler

Figure 8 shows the DG production in which the minimum production is kept at 11kW to enable stable operating conditions. Figures 9 & 10 show the solar and wind production respectively. In all the simulations it is considered that the wind power is to be used for the electric demand prior to the solar power. This option is established in the DIgSILENT software giving merit order of a source. Due to this condition, it can be seen from Figures 13 & 14, there is less wind surplus than the solar surplus.

Solar Production

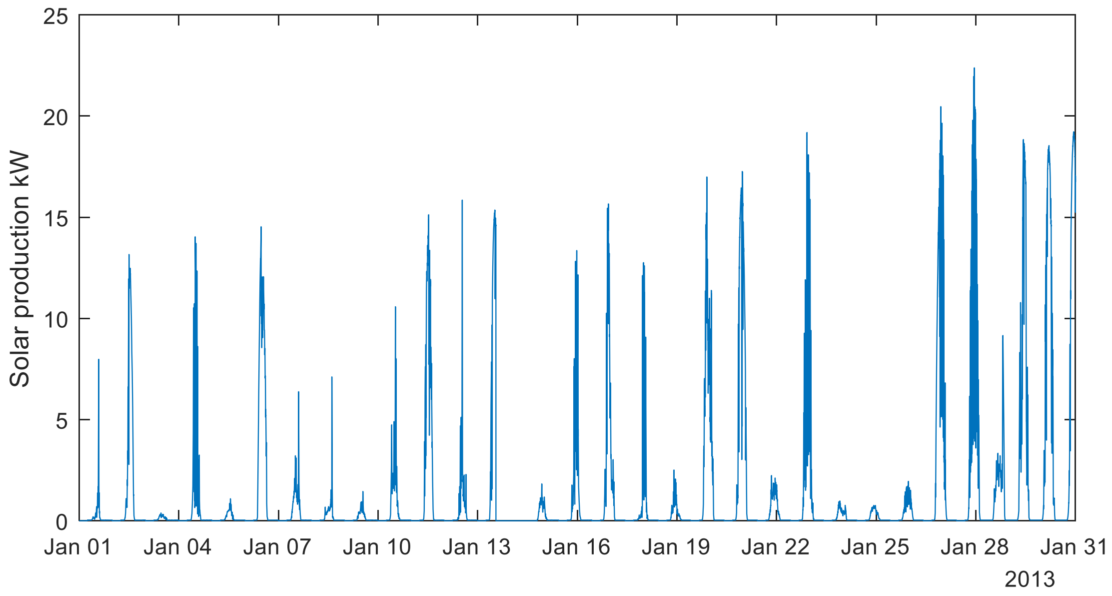

Figure 9. Solar production for January month

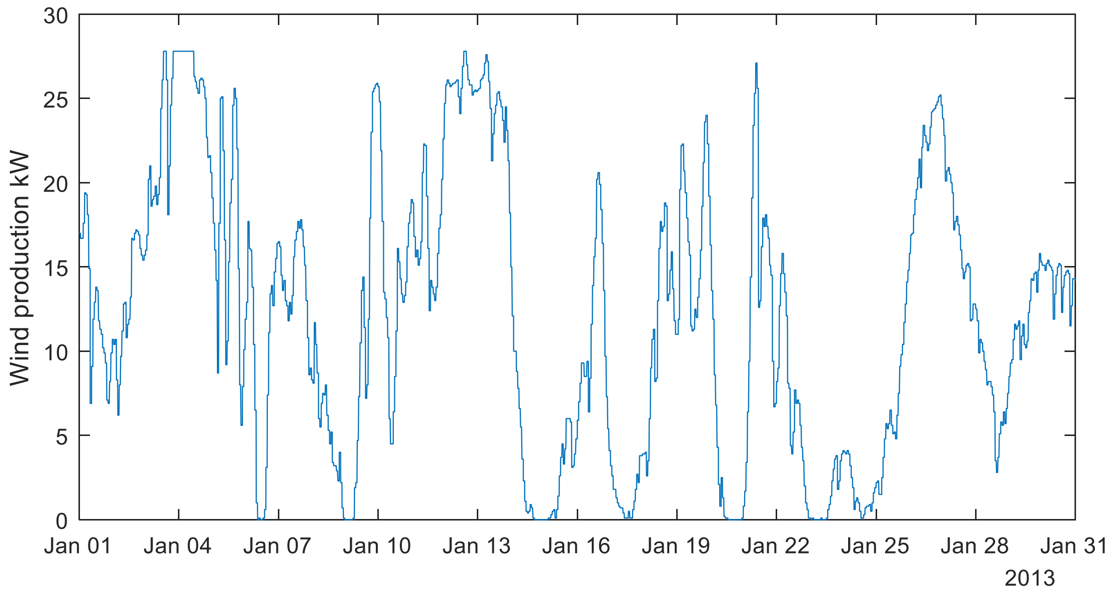

Figure 10. Wind production for January month

Figure 11 shows the thermal power share from DG, wind/solar surplus and oil boiler. It can be observed that the share from DG and wind/solar surplus is very less when compared with the oil boiler[BBJ1]. Figures 12 & 13 show the surplus power from solar and wind respectively, after meeting the electrical demand. This surplus power is given to electrical boiler and in turn heat is stored in the heat storage tank which is further used to meet the difference in the DH production and the DH demand.

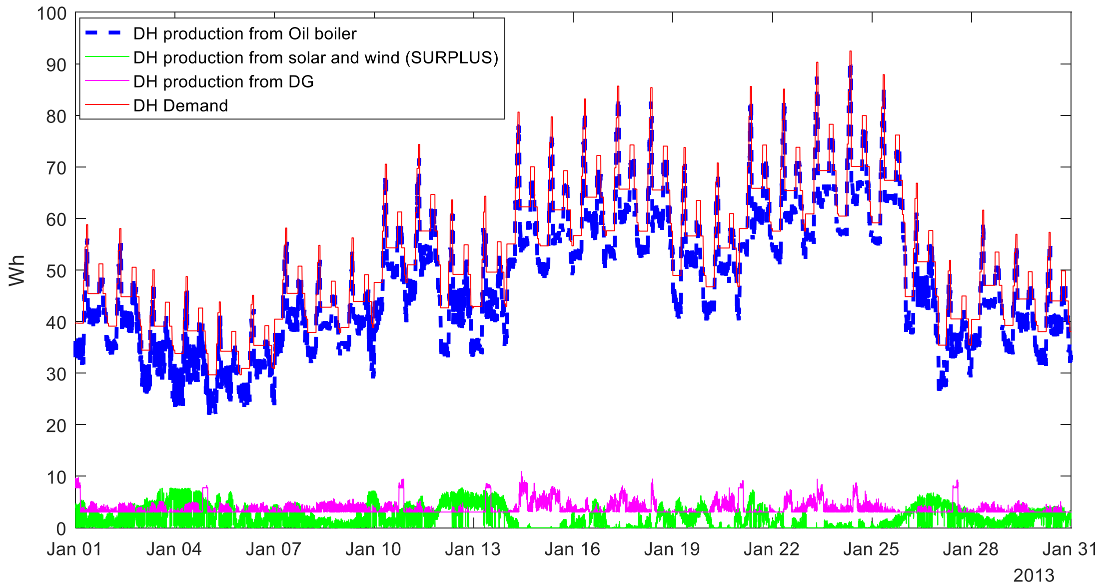

Figure 11. Detailed shares of thermal production for January month[BBJ2]

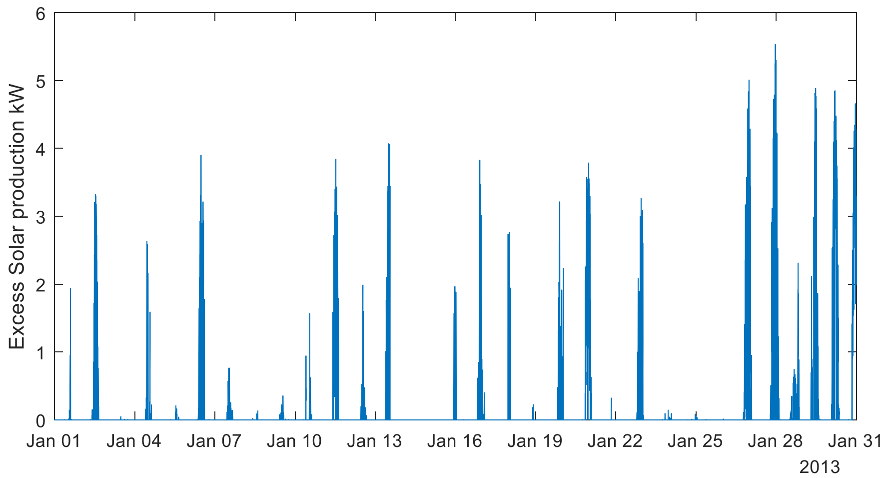

Figure 12. Surplus energy from solar for January

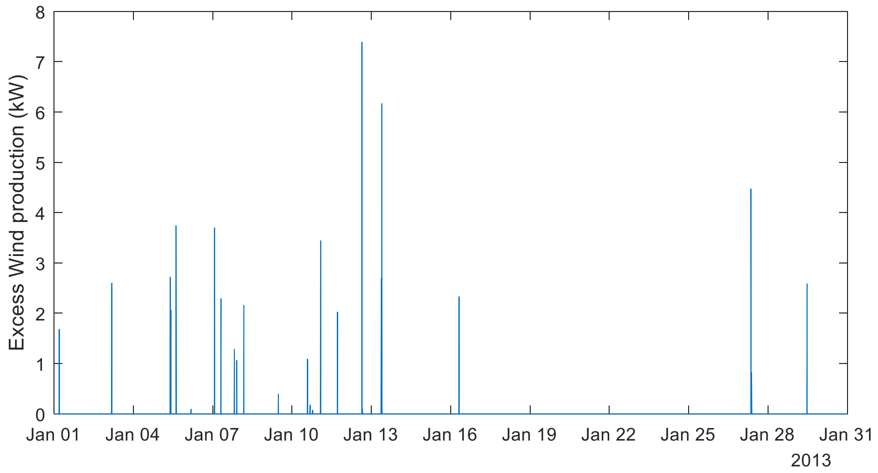

Figure 13. Surplus energy from Wind for January

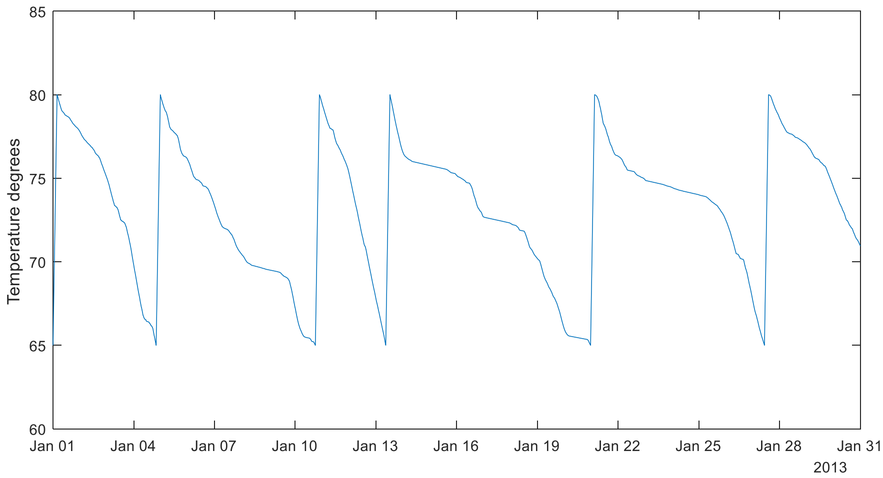

Figure 14(a). Temperature gradient in heat storage tank for January month

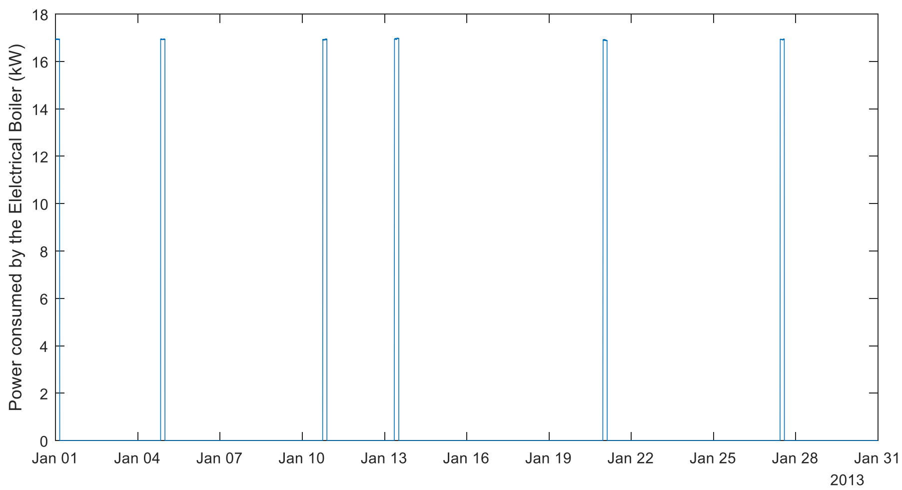

Figure 14(b). Production from DG to meet temperature range in HST for the January month

Figure 14(a) show the temperature gradient in the tank. It is considered that the initial temperature inside the tank is 65 deg. The minimum and maximum limits on the temperature are 65 and 80 in degrees. Figure 14(b) shows the power consumed by the EB in order to maintain the temperature limits. Important point to notice here is that the electric boiler output is set to minimum 17 kW for all the simulations due to the fact that for maintaining temperature limits the EB model requires minimum 17 kW. This electrical power produced by the DG towards lifting the temperature in the tank will also corresponds to heat generation which is 5.3968 Wh. This can be seen from Figure 11 'magenta color waveform'[BBJ3][PP4] with peaks[BBJ5]. The cable loadings and the bus voltages are shown in Figures 15 & 16. Due to the presence of excess solar and wind production, there exists a voltage rise during soma periods of time. The excess energy from solar and wind is used to meet thermal demand which can be seen in Figure 11 green color waveform.

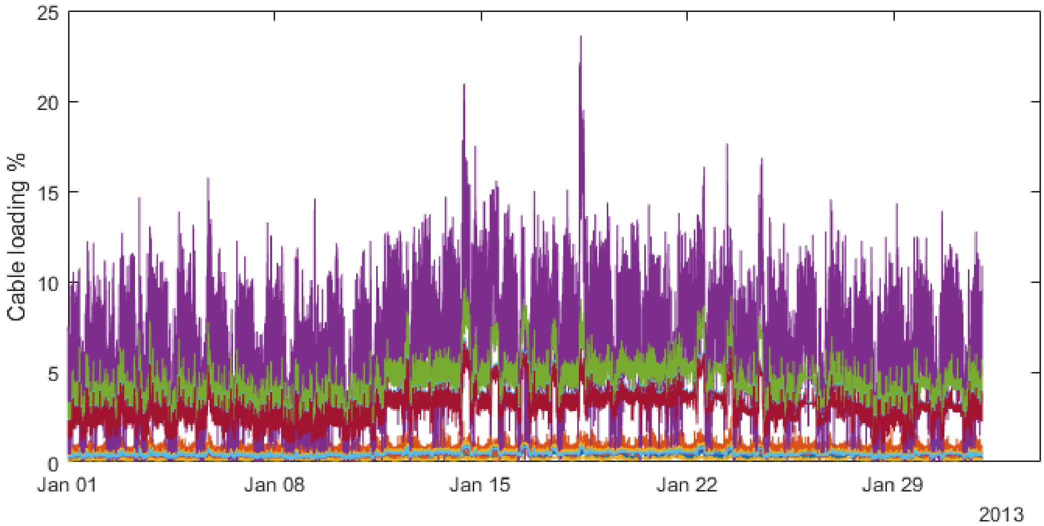

Figure 15. Cable loadings for January month

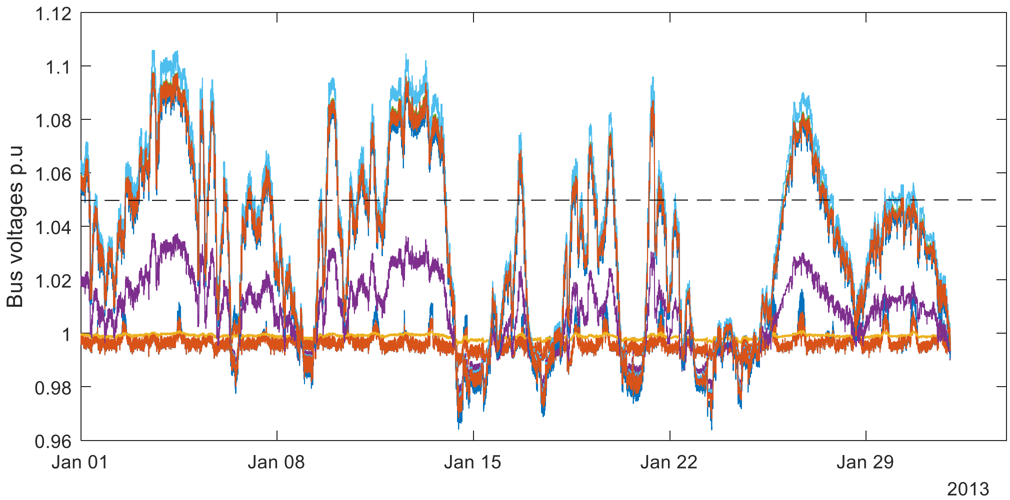

Figure 16. Bus voltages for January month

In January month, electrical demand is low, thermal demand is low, solar production is low and wind production is high. In order to meet thermal demand, the oil burner is sharing a larger part than the DG or solar/wind surplus. Due to high wind production there is rise in voltage profiles at the buses near wind installation.

Scenario – 2: April month

Figure 17 shows the electrical demand, solar production in the Figure 18 and wind production profile in the Figure 19 for the April month.

Electrical Demand

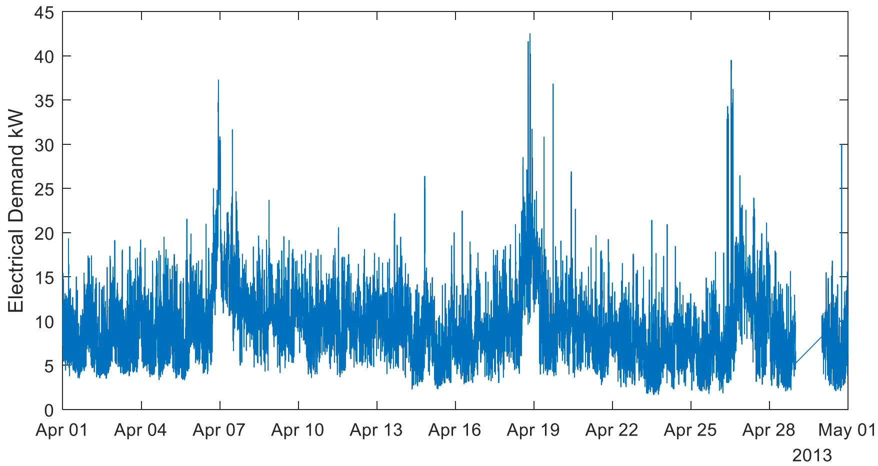

Figure 17. Electrical demand for April month without electrical boiler consumption

Solar Production

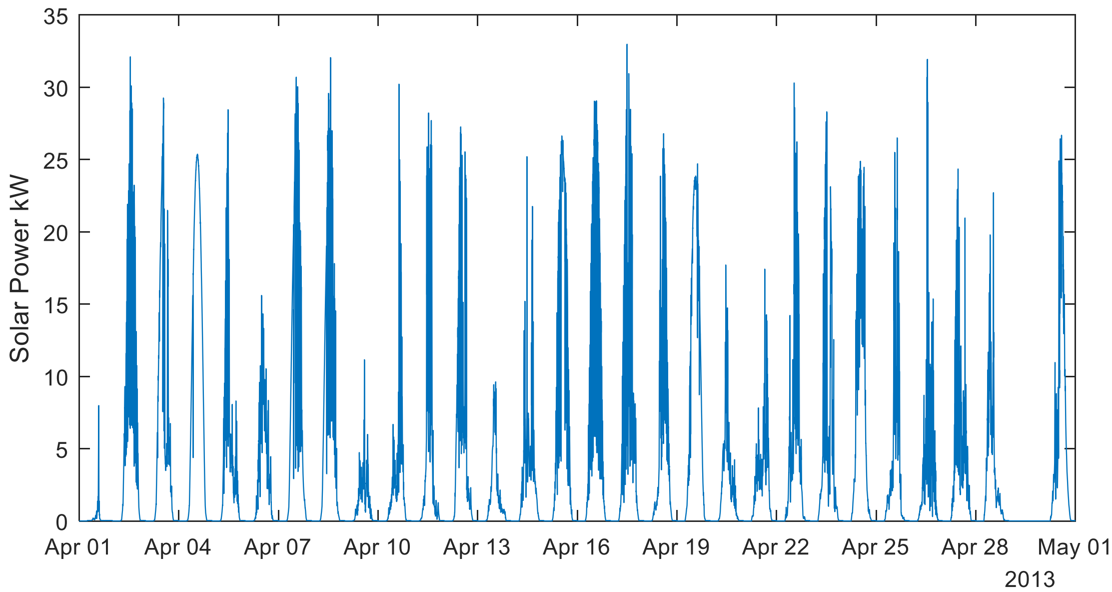

Figure 18. Solar production for April month

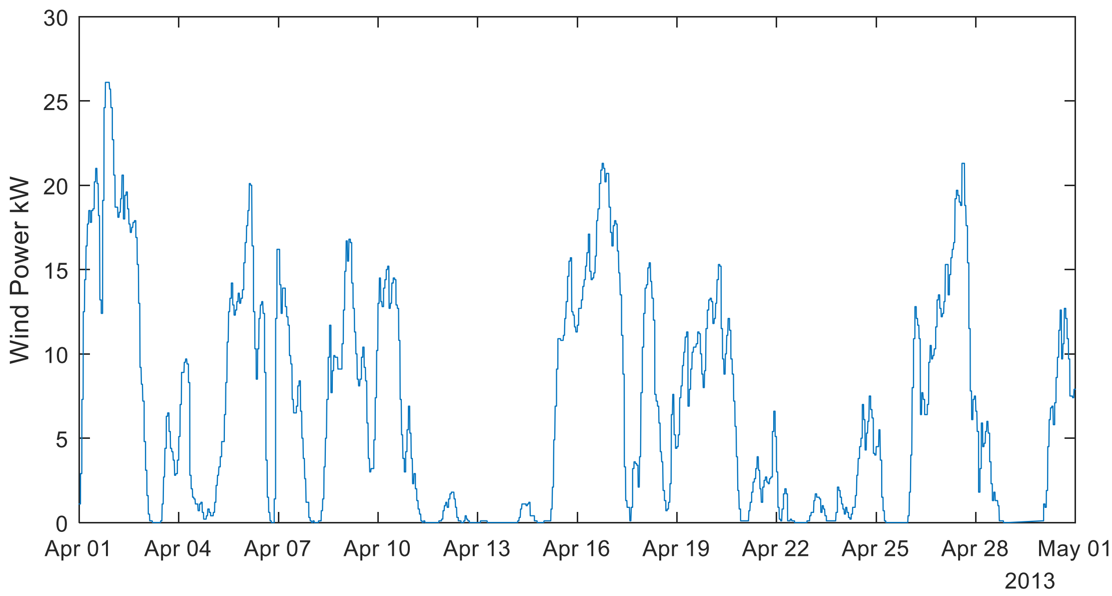

Figure 19. Wind production for April month

Diesel Production

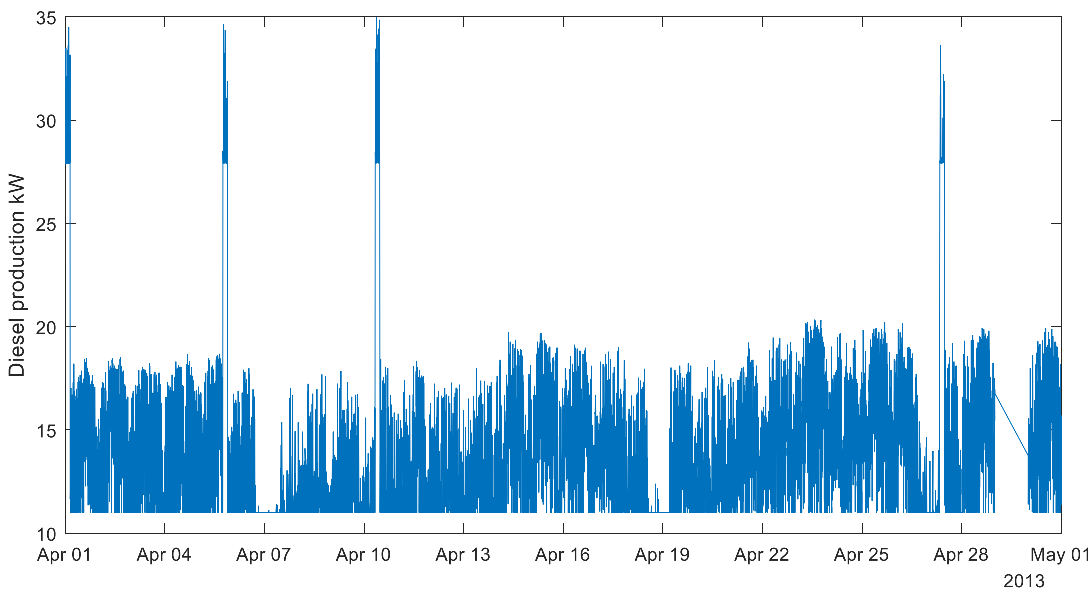

Figure 20. Production from DG for April month including DG generation to heat storage tank via the electrical boiler

Figure 20 shows the diesel production for April month. Figure 21 shows the thermal power shared by various thermal energy sources[BBJ6]. This is to show the details about the thermal energy produced by oil boiler, surplus energy from RES and heat from DG. The peaks in the heat production from DG are corresponding to the power produced by the DG to maintain temperature in the HST. Figures 22 & 23 show the surplus power from solar and wind, respectively which is used to meet thermal demand and can be seen in Figure 21 green color (Wh) waveform.

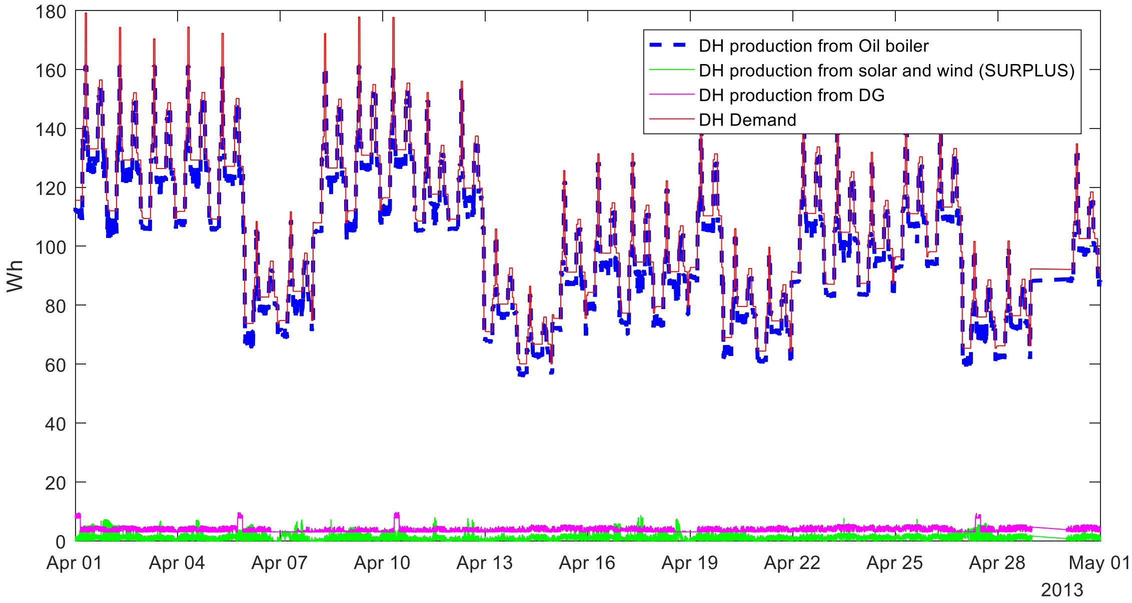

Figure 21. Detailed shares of thermal production for April month[BBJ7]

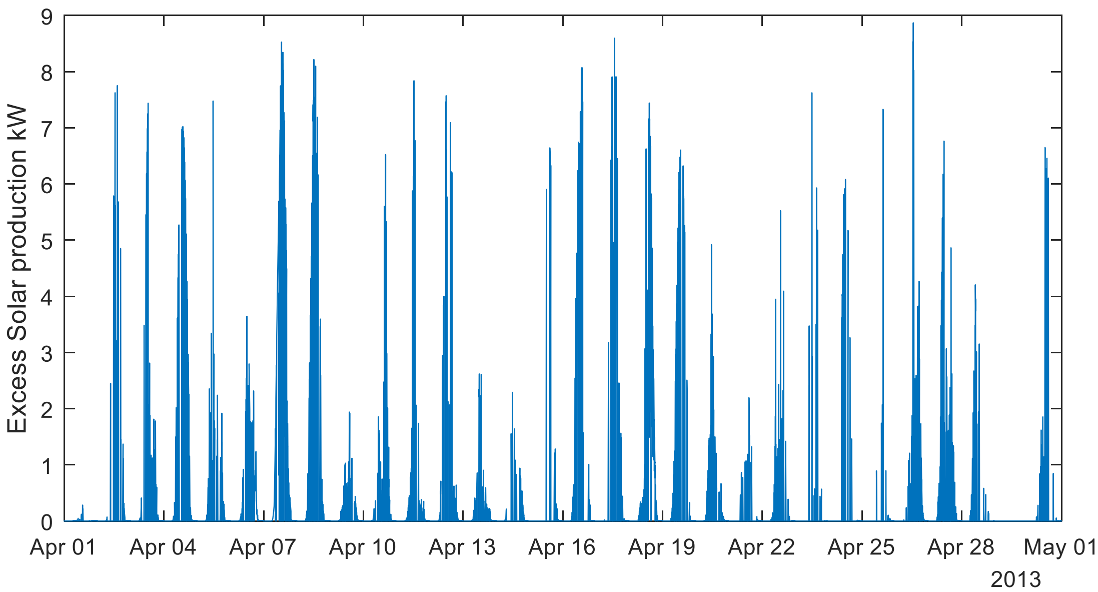

Figure 22. Surplus energy from solar for April

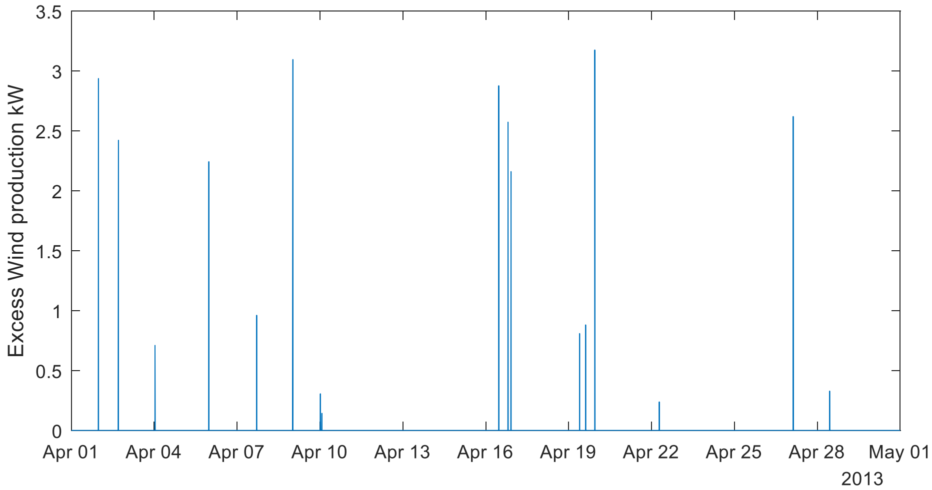

Figure 23. Surplus energy from Wind for April

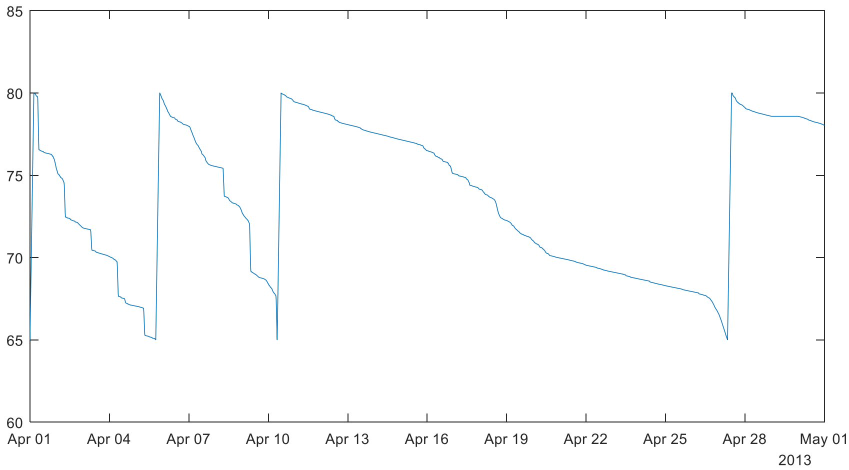

Figure 24(a). Temperature gradient in heat storage tank

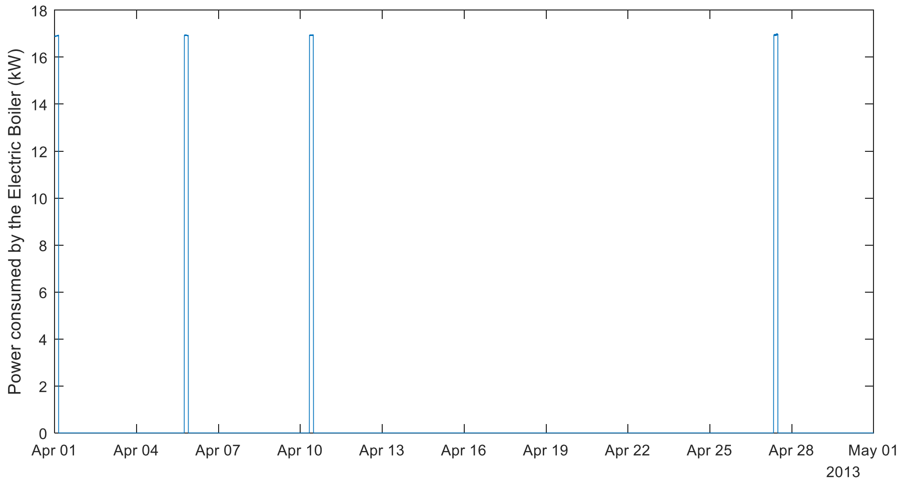

Figure 24(b). Power consumption for maintaining temperature in Heat storage tank for April month

Figures 24(a) & 24 (b) shows the HST temperature limits and the power consumption by the EB which is produced by the DG in order to raise the temperature in the HST, respectively. Figured 25 and 26 show the cable loadings and voltage profile in the grid.

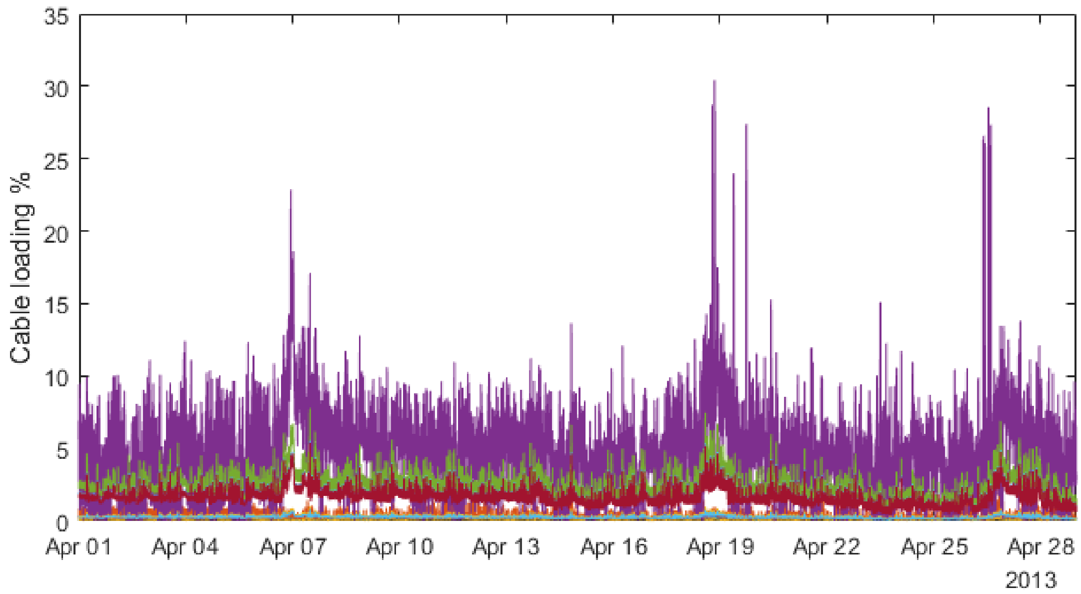

Figure 25. Cable loadings for April month

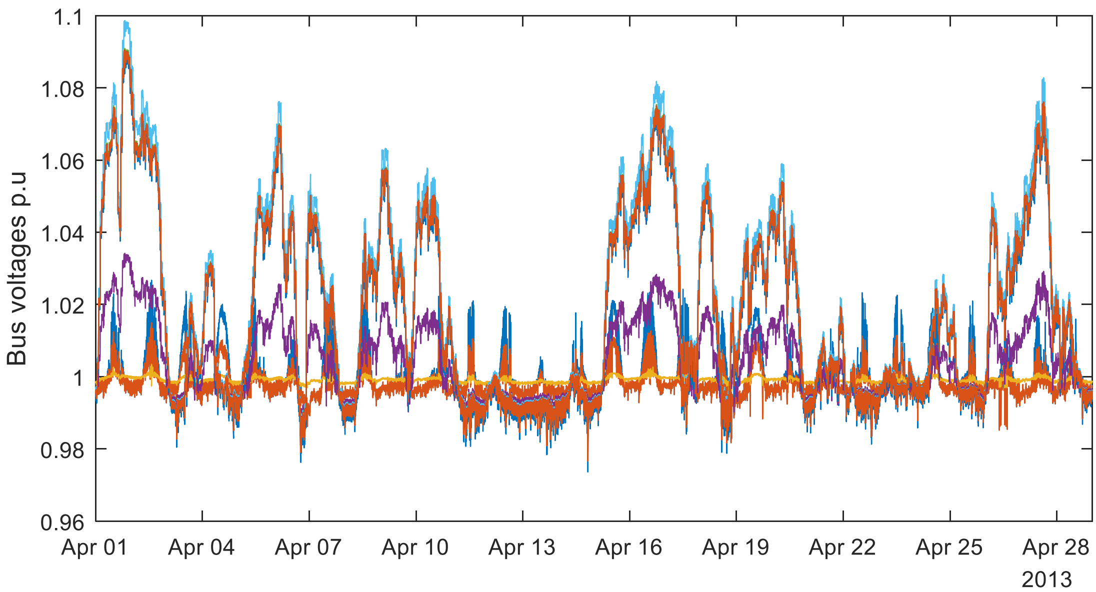

Figure 26. Bus voltages for April month

In April month, the electrical demand is low, thermal demand is high, solar production is high and wind production is nominal. There is again voltage rise at the buses near wind installation. Large part of thermal demand is met by the oil boiler for the considered conditions.

Scenario – 3

Simulations for July month

The electrical demand is high in July month due to summer and high tourists in the Livo island. Figure 27 shows the electrical demand. Figures 28 & 29 show the solar and wind production, respectively.

Electrical Demand

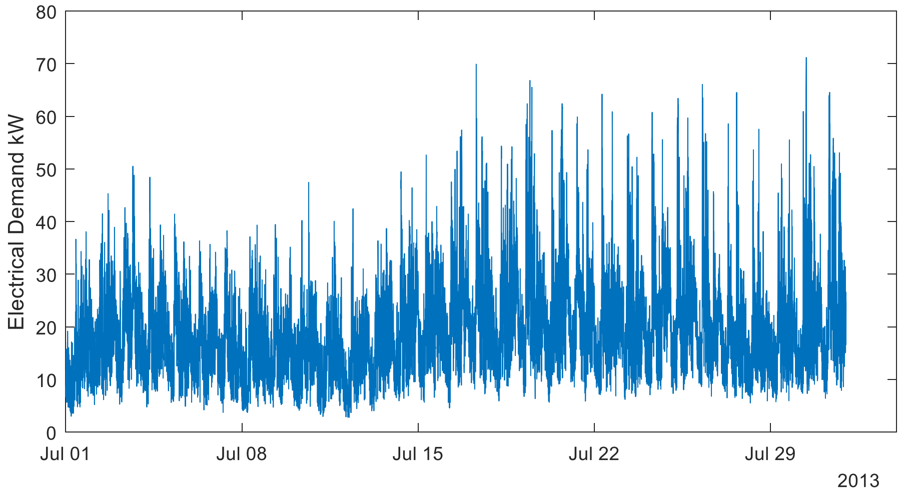

Figure 27. Electrical demand for July month without consumption of the electrical boiler

Solar Production

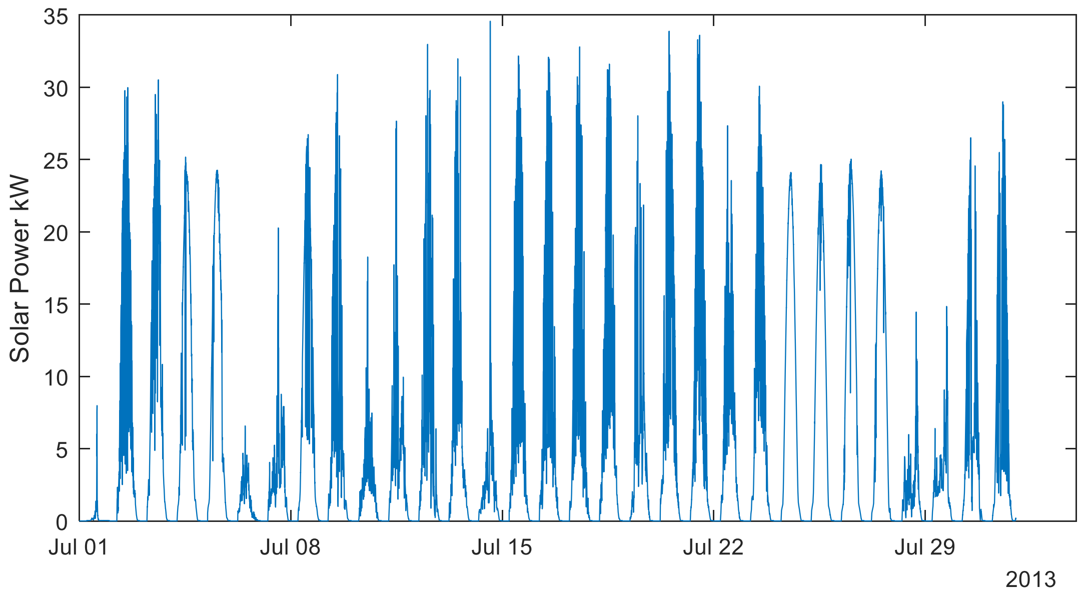

Figure 28. Solar production for July month

Wind Production

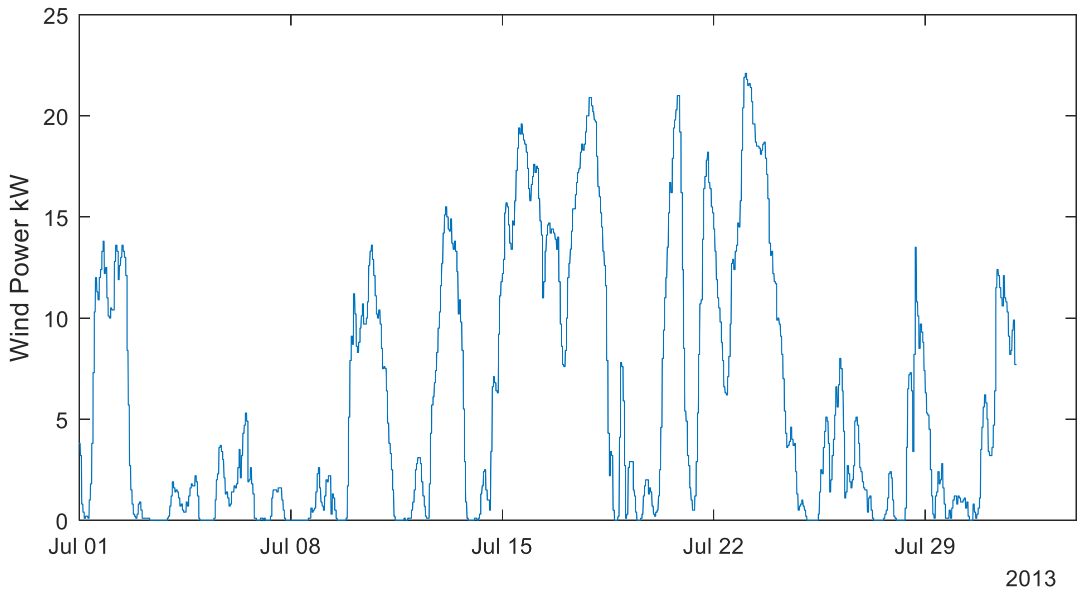

Figure 29. Wind production for July month

Diesel Production

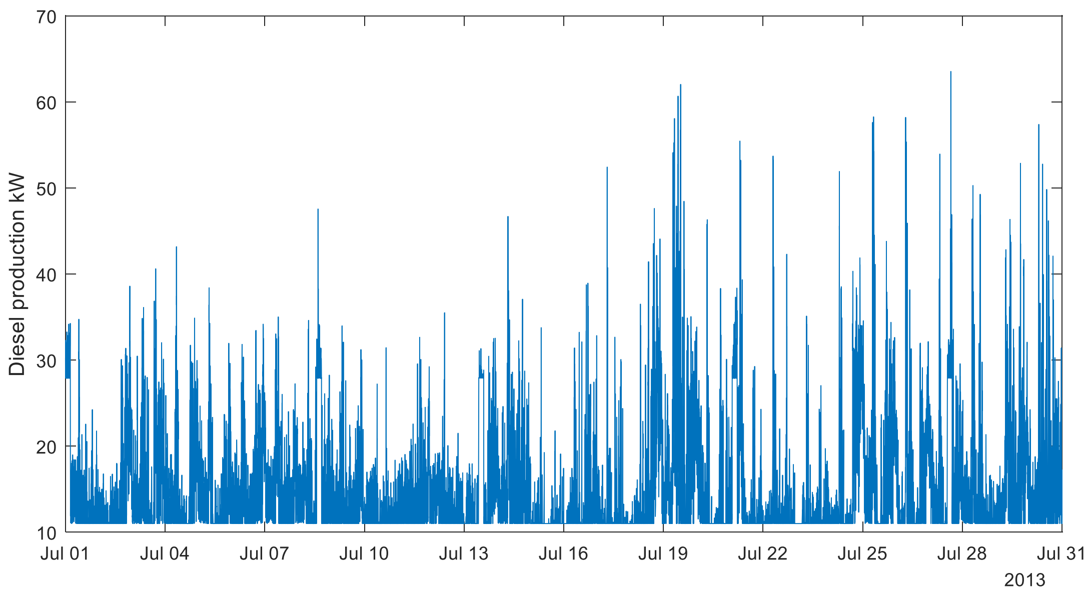

Figure 30. Production from DG for July month including generation for the electrical boiler.

Figure 30 shows the electrical power production from the diesel generator. Figure 31 shows the thermal power shared by various thermal energy sources i.e. oil boiler, surplus energy from RES and heat produced by DG[BBJ8]. From which it is clear that the with the considered scenario, the oil boiler is producing more thermal energy. Figures 32 & 33 show the surplus power from solar and wind, respectively which is used to meet the thermal demand. Figure 34(a) shows the temperature in the HST. Figure 35 & 36 show the cable loadings and voltage profiles.

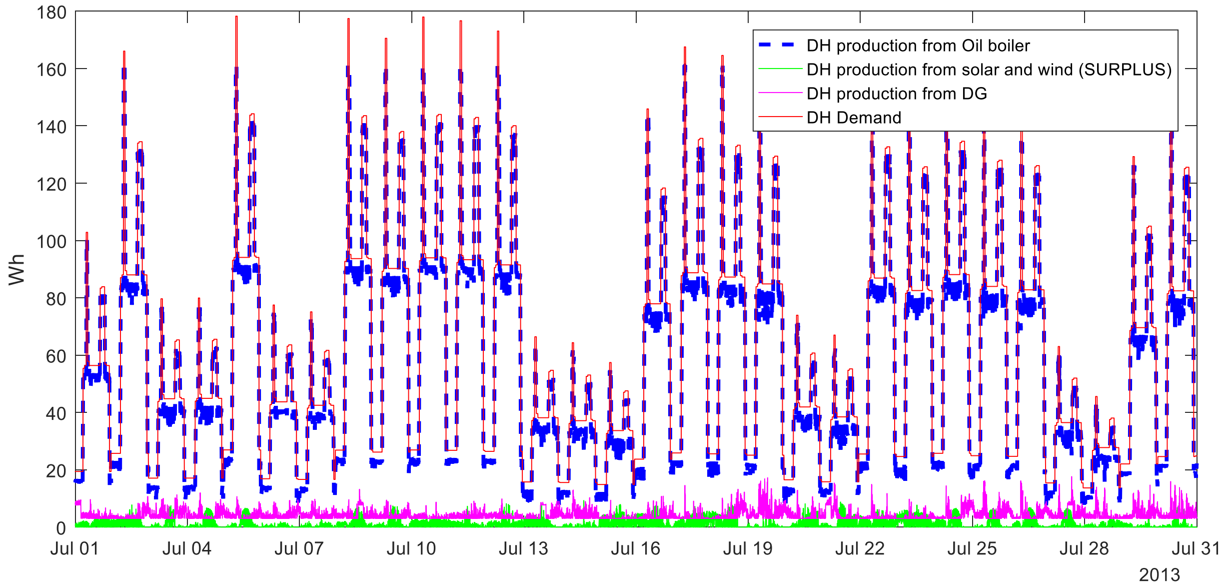

Figure 31. Detailed shares of thermal production for July month[BBJ9]

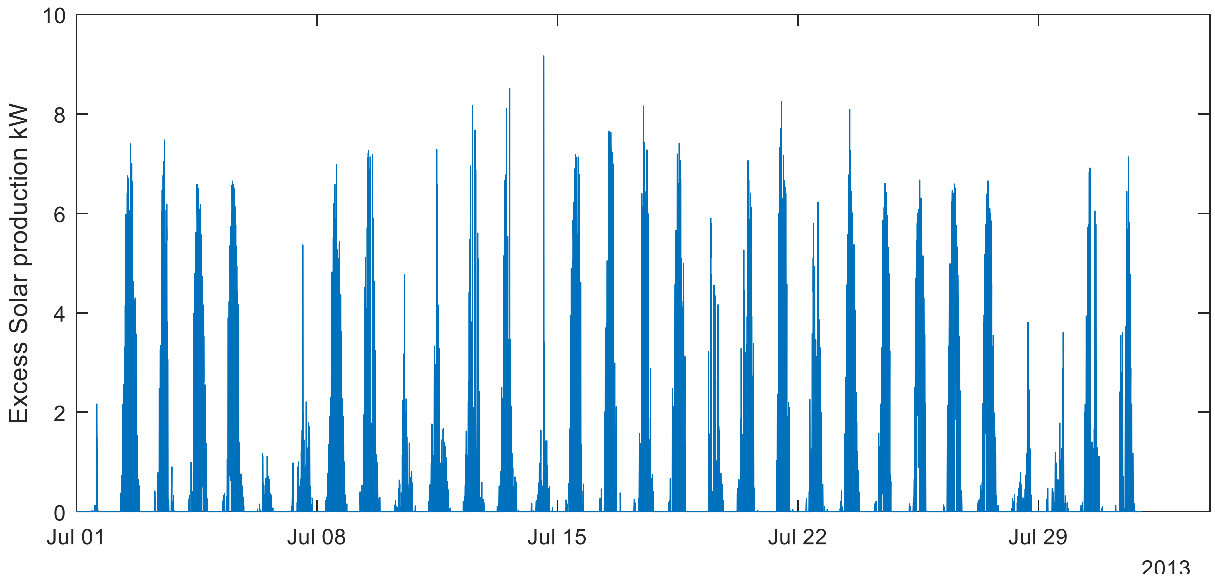

Figure 32. Surplus energy from solar for July

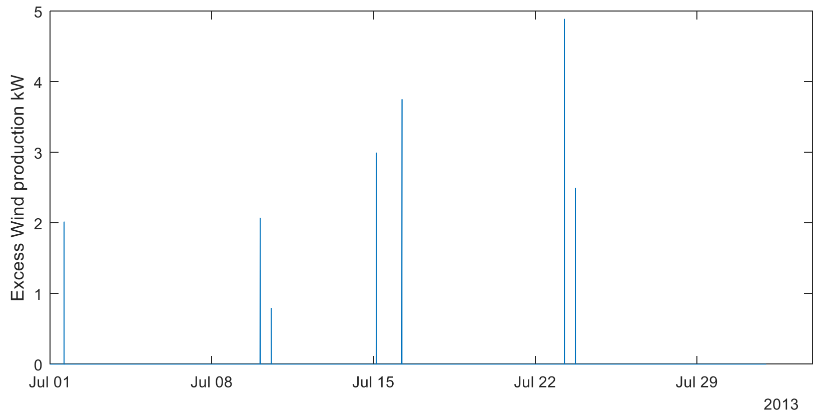

Figure 33. Surplus energy from wind for July

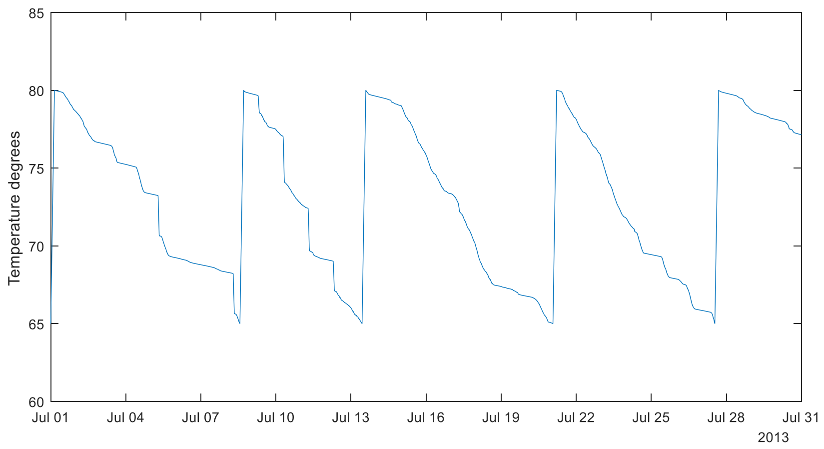

Figure 34(a). Temperature gradient in heat storage tank for July month

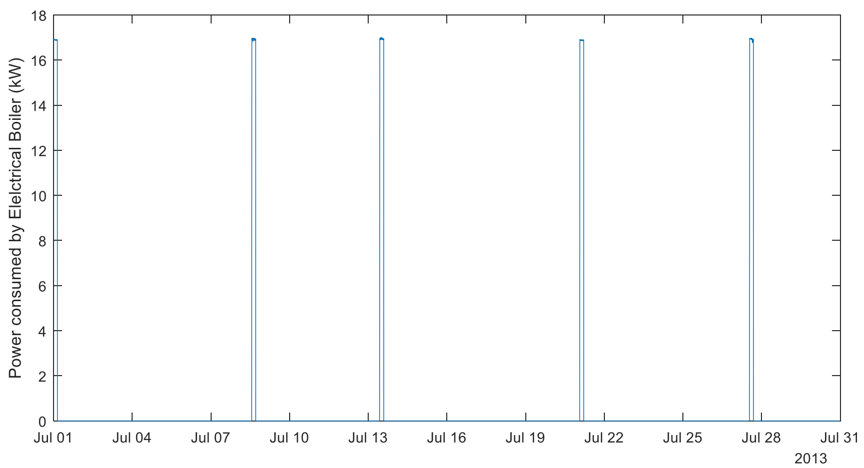

Figure 34(b). Power consumption for maintaining temperature in Heat storage tank for July month

From Figure 34(a) it can be observed that whenever temperature is falling below 65 deg it is lifted to 80 deg. Figure 34(b) shows the power produced by the DG (consumed by Electric boiler) in order to meet the thermal demand gap for maintaining temperature level within range 65 – 80 deg. The logic given in the electric boiler setup searches for surplus energy availability whenever temperature is falling to 65 deg, if surplus available the electrical boiler is fired and heat is supplied into the tank until temperature is lifted to 80 deg. There are times where surplus energy is not sufficient to maintain temperature limits in the HST, so the DG is used. Because of the combined effort of availability of surplus power and DG production, the HST temperature can maintain at 65 - 80 deg range.[BBJ10][PP11]

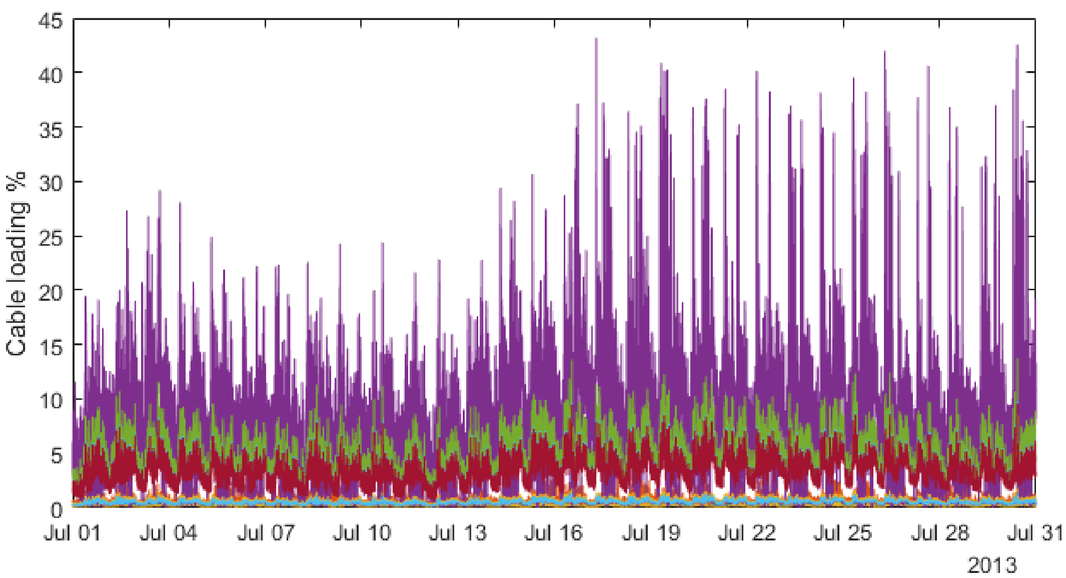

Figure 35. Cable loadings for July month

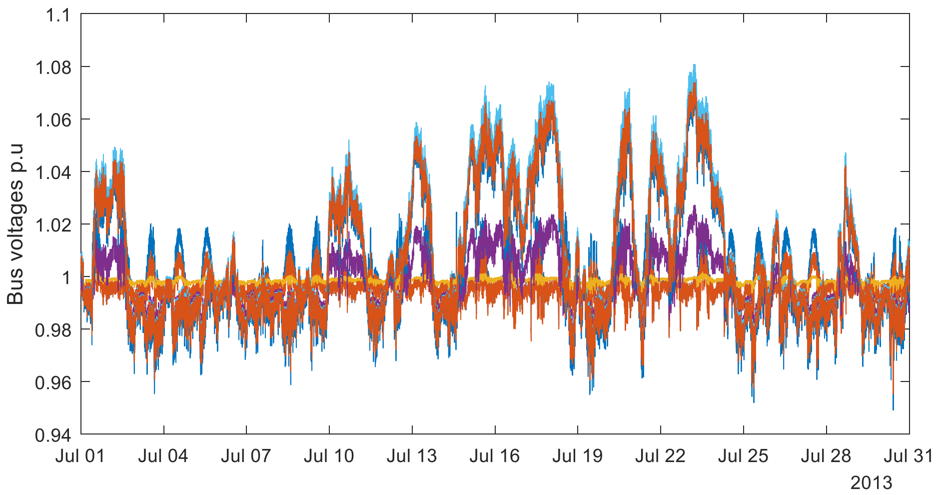

Figure 36. Bus voltages for July month

In the July month, there is high electrical demand and thermal demand. The diesel generator and some part of solar/wind are responsible for meeting the electrical demand. The thermal demand is met by the oil burner and HST.

Conclusions:

Simulations are carried out on the grid with DG (minimum limit 11 kW), Solar (33.3 kWp), Wind (25kW), Electric boiler and an Oil boiler. Diesel production is to meet electrical demand on the Livø along with thermal demand. Here in these simulations, the Electric boiler is fired in two cases. One is whenever there is surplus power from RES. Another is power from DG whenever the temperature in the heat storage tank falls below minimum temperature limit. EB needs consuming minimum 17 kW from the DG in order to maintain 65-80 deg temperature limit within the HST.

- The heat supply to the HST is from DG and surplus from Solar/Wind.
- The Electrical demand is met by DG and solar/wind (In priority wind followed by solar)
- Thermal demand is met by DH system (Oil boiler in these simulations) and if any gap by heat storage tank.
- Heat storage tank is good buffer to store the wind/solar surplus and also heat from DG.
- April and July months are having high thermal demand.
- In the July month, the electrical demand is high.
- The surplus energy availability makes it possible to provide thermal energy to meet the gap between DH production and DH demand.
- There could be times where either solar or wind need to be shut down as there exists voltage above acceptable limits.