Implementation of solar energy at ESS for power supply and waste heat recycling

Abstract

The advanced research that is being carried out in different science fields today requires advanced technologies. The European Spallation Source, ESS, is a multidisciplinary research facility that is being built in Lund, Sweden. The facility, that will host the most intense pulsed neutron beams in the world, is a significant step forward in the science of everyday life. Even though ESS will contribute greatly to the future research, the facility will be a large power consumer increasing the total power consumption in Lund with almost 30 %. To reduce the environmental impact ESS is committed to an energy concept where the use of new efficient technologies, waste heat recycling and renewable energy will result in a carbon-neutral science facility. The paper presents an investigation to further investigate the utilization of solar energy as a source of renewables in two ways; collecting both thermal and photovoltaic energy. A prototype is presented as a module where both heat and electricity can be extracted simultaneously. The paper also proposes an electrical connection to ESS through the special power converters called modulators.

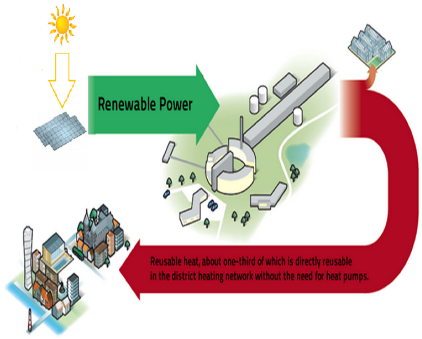
Energy concept

One of the main motivations for Sweden to host the project is the commitment of ESS to be the first carbon-neutral large scale science facility in the world. To reach this goal ESS is committed to an energy concept that could be summarized according to three cornerstones:

- **Waste heat recycling**
  The first cornerstone involves the investment in waste heat recycling, particularly waste heat from the new accelerator facility utilized in form of heated cooling water. It is anticipated that the total amount of surplus energy is 254 GWh annually. In order to optimize the utilization of this excess heat energy, the cooling system is calculated to operate at three temperature levels; 30°C, 55°C and 80°C.

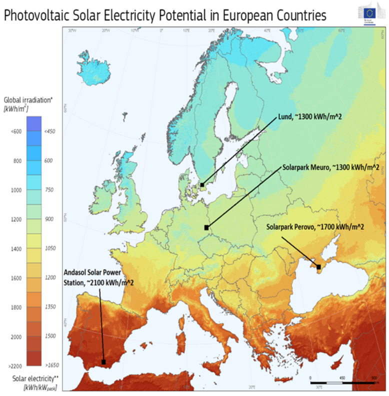
- **The use of new technologies**
  The second cornerstone of the energy concept is the choice of advanced energy efficient technologies for providing the ESS linear accelerator with power. With these technologies almost all of the energy supplied to the accelerating structures is transformed into beam power.

- **The use of renewable energy**
  The last cornerstone of the energy concept is the use of renewable energy. The amount of electrical energy required for the operation of ESS is approximately 270 GWh/year, this equates to an increased power consumption of 20-30% in Lund. Therefore ESS is committed to renewable power production to compensate for the increased energy consumption caused by the facility. One possible source of renewables is solar energy which is investigated in this thesis. The ESS energy concept is illustrated in the figure below.



Solar potential in Lund

Exploitation of solar energy in Sweden is commonly dismissed because of the high northern latitude. However, in spite of this, the solar potential in Lund is actually comparable to that of Solarpark Meuro in Germany, see figure below, which generates some 166 MW peak power. Comparing with southern Europe and North Africa, which have the highest irradiation levels in the world, the solar potential in Lund constitute some 60% of the available irradiation in these places.



Available land at the ESS site

The ESS site occupies 74.2 hectares of land north-east of Lund and, because of the nature of hazards present at the site such as radiation, most of this land remains unoccupied and serves the purpose as a barrier to the general public. This area can therefore not be used for agriculture or habitation; instead it could host a large solar field. The available land at the site, assuming utilization of all green space as well as building roofs and the accelerator shielding berm, is 41.2 hectares or 55% of the total site.

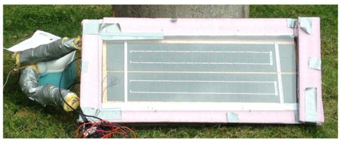
Because of the location of solar plants, either far from urban areas or in warm climates, most large scale solar plants do not try to capture the thermal energy. The greatest obstacle to using solar heat energy is the logistics of a distribution system for supplying heat. However, due to Sweden's commitment to reducing global warming and its climate, many cities in Sweden have adopted district heating systems to make substantial reductions in CO2 emissions. Due to the widespread use of municipal district heating systems close to the ESS, the capture of radiant heat from a solar field at ESS could be delivered to the local municipal district heating system and would outstrip the potential of many other solar facilities worldwide.

Estimation of the field

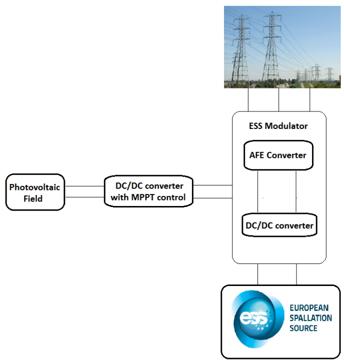
By connecting the ESS modulators to a photovoltaic facility, the electric power generated by the solar field is estimated to 3 MW-year annually, this is more than enough to compensate for the power supplied to the accelerator. In addition, it might be possible to utilize the radiant heat, estimated to exceed 6.4 MW-year annually, that is captured by the photovoltaic facility and not converted into electricity.

Prototype and connection

To test how the PV/T works in real implementations, a model of the system is created together with an electrical circuit. The PV/T model consists of two PV panels, Styrofoam insulation, a copper plate, a copper tube, a cover of glass, mineral wool, plastic tubes and three temperature sensors. Under the absorber plate water is circulated in a copper tube to extract the heat. The water, 2 liter, in the reservoir is circulated with a water pump with a flow rate of 2.2 liters/minute.

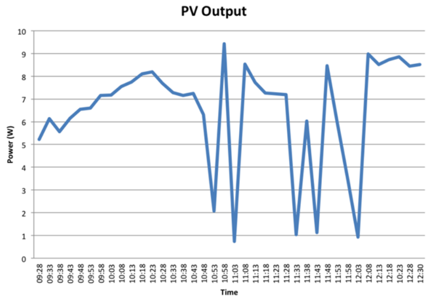


The electrical connection to the ESS modulators enabling power exchange between ESS, the solar field and the utility grid is shown in the figure below.

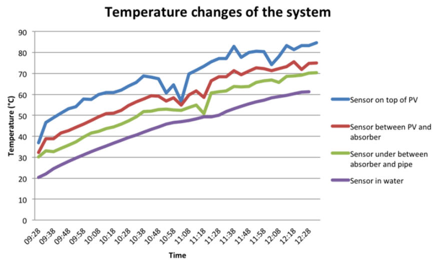


Results

The result of the power output from the PV after a 3 hour measurement in the sun can be seen in the figure below. The measurement was made August 9 with start at 09:28, it was a clear sky with some cumulus clouds and a temperature of 18°C. The panel was facing south with an inclination of roughly 40°C.



The change of temperature for the various sensors during a 3 hour measurement can be seen below. The measurement conditions are the same as that of the power output from the PV. The different colors represent the different sensors; blue is the temperature on top of the PV, red between the PV and absorber, green underneath the absorber and purple for the water temperature.



The calculations for the amount of thermal energy, in the form of heated water, extracted from the PV/T prototype is 352.8 kJ meaning a thermal power extraction of roughly 33 W. While the electrical output generated from the PV was around 7 W.

Conclusions

The work presents one possible way to implement a solar field of 25 hectares, which would compensate the required beam power at the ESS facility as well as proposes a possible connection enabling power exchange between ESS, the utility grid and the solar field. By connecting to the already existing power electronic topology, the photovoltaic energy can be used directly on-sight, meaning very small transmission losses. This distribution is therefore very advantageous compared to the common distribution of solar energy via the utility grid.

It has been established that, if 80°C water could be extracted from the PV/T panels, the water could be connected to the district heating system in Lund. If the water only reaches lower temperatures, as in the thesis, the water could still be utilized in food production systems. Regardless the application the utilization of thermal energy from the solar field would almost double the amount of energy extracted from waste heat recycling. Since the solar potential in Lund is quite high, the electric energy extracted from a solar field at ESS would constitute almost 60% of that of a similar field installed in North Africa. However, since the thermal energy also may be used in Lund, the total efficiency will increase by a substantial amount resulting in a much higher utilization of the available solar irradiation. Further work to the thesis should involve detailed analysis of different field configurations, development of an improved version of the PV/T prototype and a closer investigation of utilization and distribution of the collected hot water.