SOLAR THERMAL POWER GENERATION

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1. Introduction

Concentrating Solar Power (CSP) commonly is known to be used in huge, large-scale power plants, operating the solar thermal cycle at high temperatures to drive a turbine with the electrical output of the generator in the Megawatt range. The Parabolic Trough Collectors (PTCs) are large mirrors to be installed in long collector rows and with many rows in one collector field onto the ground. Using areas with good solar irradiation values e.g. in North Africa, a significant contribution to the electricity generation can be achieved.

Additionally to this concept, the SOLITEM light-weight PTCs, which are suitable for roof integration and already in operation for highly efficient solar cooling and steam generation, are used in a new concept for the local trigeneration: On Cyprus, the first Trigeneration Plant connected to concentrating PTCs, to be able to supply cooling, heating and electricity in one solar thermal plant and at the same time, has been set into operation.

Further R+D works are spent into the integration of solar seawater desalination. Once tested successfully, solar thermal energy will be able to cover all kinds of energies required and potable water. The new solar thermal energy concept will be used to increase the share of renewables even more than planned before.

As a novelty for Turkey, also the operation of a Solar Power plant with 10 MW electrical power output is planned to be installed in the South-East of Turkey. Turkey offers nearly similar boundary conditions as Spain, where the first Concentrating Solar Power Plants in Europe have been setup into operation. The solar irradiation in the South of Turkey also is excellent to operate CSP.

2. Solar Trigeneration

Parabolic Trough Collectors operated at about 180 °C can be used, as already done, for double-stage absorption cooling or steam generation, and the solar thermal energy can be used in an Organic Rankine Cycle (ORC) for the direct generation of electricity. Combining all applications in a trigeneration plant, the customer can benefit to use all required kinds if energy from one solar thermal plant, and at the same time, which is world-wide novelty.

Additionally, as the trigeneration plant is operated automatically, the operation mode can be set in that way to generate that kind of energy that is most expensive at the given time, to optimize the economics of the plant.

Fig. 1: The SOLTRIGEN Collector Field with SOLITEM PTC 1800 collectors

The first solar trigeneration plant is the SOLTRIGEN project, installed on Cyprus with an ORC engine with 15 up to 25 kW electrical power output. The plant has been set to operation, firstly to test the solar operation of the ORC process. The solar cooling components, a backup boiler, the optimizing of the single functional groups

and the combined trigeneration process and the optimization of the economical operation, generating the best savings on conventional energies at a given time, are further steps. The boundary conditions on Cyprus are excellent, as both the site shows very good values for the direct irradiation, and the conventional energies are expensive, as the island shows a strong dependency on the imports of fossil fuels.

The SOLTRIGEN plant includes the SOLITEM Online Monitoring System and operation control. In the future, several local trigeneration plants in different sizes can be operated in coordination, to cut the peaks of the electrical compression cooling, of the demand of electricity, and to integrate solar thermal energy in different ways into the existing energy supply structure. Here an Overall Energy Management System will be necessary.

The economy of scale, also concerning the ORC process, will be another task for the future. The type of Parabolic Trough Collector and the size of the collector field as well as the single functional groups can be adapted to the given conditions very exactly. Generally, the higher the capacity of a solar thermal plant is sized, the better the economics are given. With amortization times below 9 years already today, at the expected increase of the costs for conventional energies, the economics will be even improved.

The solar trigeneration reduces the energy supply of electricity from conventional energy sources both with solar cooling, to save electricity for compression cooling, and with the direct electricity generation. For this, besides the commonly used technologies such as hydro, wind or Photovoltaics, a new possibility to integrate renewable electricity into the energy supply structure is opened.

3. Renewable Electricity

The usage of renewable energy to generate electricity will be added by solar thermal trigeneration from sizes such as residential energy supply with several 10 kW up to the MW range, using CSP plants to be connected to the electrical grid. The small-scale trigeneration plant of the SOLTRIGEN project either can supply the energy demand at the customer directly, or with connection to the grid generate that kind of energy that offers the best economics at the given time. Both the solar cooling and the solar electricity generation cause a release in the load curve of the electrical grid, as the peaks in the demand are cut directly.

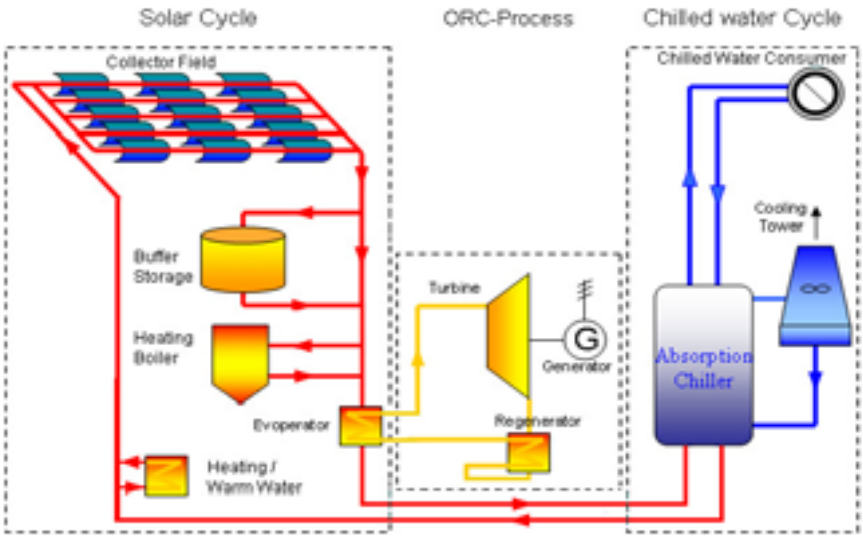

Fig. 2: Solar Trigeneration with Solar Cooling, Heating and Electricity Generation at the SOLTRIGEN project

The technologies of Solar Thermal Power Generation can be divided regarding the plant size:

- Residential energy supply, using ORC units adapted to the customers energy demand, usually also depending on the given installation possibilities. The direct electricity supply enables a much higher independency on the existing energy supply; especially places such as Cyprus where the SOLTRIGEN plant is installed, offering good solar irradiation data and suffering from a bad energy infrastructure, can benefit from this concept.

- District energy supply and electrical power up to the Megawatt range. The single functional group of the ORC unit and connected components can be designed the more economically, the higher the capacity is required. This economy of scale is given for each functional group as well as for the whole solar thermal

plant. ORC units from 500 kW up to 2 MW have better specific costs per kW electricity and are operated at better efficiencies.

- Solar Power Generation. Operating the thermal collectors at temperatures up to 390 °C, the concept with a steam engine for electricity generation can be used. This concept is applicable for plant sizes from about 2 Megawatt electrical power up to huge power plants. Below about 2 MW, it is more practicable to operate an ORC unit than a steam turbine. Actually, the setup of a 10 MW_e Solar Power Generation plant is planned for the South-East of Turkey.

All these paths of solar thermal energy supply will facilitate a significant contribution of renewable solar thermal energy besides commonly used technologies for renewable electricity.

4. Trigeneration technology

Each SOLITEM solution takes account of the conditions at the customer. The examination of the collector installation possibilities, with the option of roof integration due to the light-weight design, the option to choose the suiting type of PTC, and a special arrangement regarding the number of collectors per row and the number of rows in the field, allows to deploy the best possibilities in the supply with solar energy. Any single consumer may have a special energy consumption profile. A typical electricity consumption profile of a hotel is shown in figure 1.

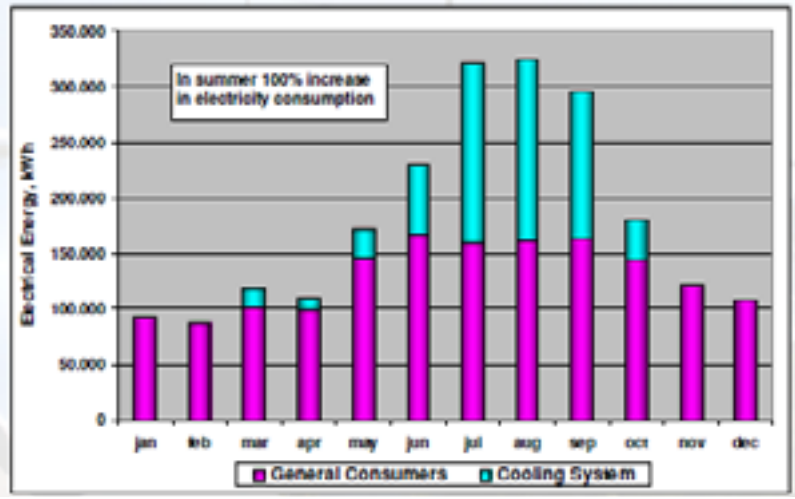

Fig. 3: Typical electricity consumption profile of a hotel

The example shows that in the summer season, the highly efficient solar cooling can be used to cut the demand for electricity for state-of-the-art compression cooling. The concentration of the solar energy, as done with Parabolic Trough Collectors, enables about 180 °C operation temperature of the solar hot water cycle. At this temperature level, which cannot be reached with conventional technologies, the operation of a double-stage absorption cooling process allows to generate about 1.4 units of cooling energy from 1 unit of solar thermal energy. Both the energy conversion in the solar collector and that one of the cooling process lead to an overall process efficiency that allows the economical operation; in best cases, such as calculated for a hotel planned to be installed on Cyprus, the static amortisation time is less than 9 years already today.

Special applications occur if the electricity supplier offers energy at high-tariff time in the evening, as done for example in Turkey. In this case, the usage of hot water storages to operate the absorption chiller after sunset can improve the economics additionally.

As it makes no sense first to convert conventional energy into electricity and than operating a compression cooling system with electricity, the efficient usage of solar energy as described above offers a better overall energy conversion efficiency. If electricity is required additionally, all common technologies, such as Photovoltaics or CSP, have the disadvantage that only on kind of energy is generated.

For this, the challenges of storing electricity, improving the grid, and the setup of an intelligent consumer structure (“smart grid”) that has the information when solar energy is offered and can be used, have to be solved. This implies time and additional investment. Especially the storing of huge amounts of electrical energy

won't be easy, but maybe answered with the integration of the traffic sector into the concept. Using electrical cars, the batteries of the cars will take over a significant share to store the energy.

The way to combine the energy conversion units for cooling and electricity generation directly enables the customer to use that kind of energy that either is required, following the load curve, or to use that one that is most expensive at the given time. For this, the combination of solar electricity generation with the complete concept has to be evaluated different to the PV or CSP technologies.

ORC processes for electricity generation are operated at several temperature levels. The level of 180 °C that is used in the described applications is sufficient for the ORC operation. While several customers have demand for electrical power in the range of about 150 kW, the specific electricity generation costs can be decreased with increased power. In spite, to customize the component size to a small-scale application, the SOLTRIGEN plant is designed for only 15 up to 25 kW electrical power. The SOLTRIGEN plant is the first step to combine the technologies. For any specified solar solution, the plant design and the sizing of the main components has to be adjusted to the demand structure, i.e. the single functional groups for cooling or electricity generation have to be chosen according to the given requirements. In general, the higher the capacity (thermal capacity of the collector field, cooling capacity of the chiller, electrical power output of the ORC), the better the economics.

Fig. 4: SOLITEM Online Monitoring System at SOLTRIGEN

The system is equipped with the SOLITEM Online Monitoring System, as shown in figure 4. The operation is full automatic. Using an Overall Energy Management System, the energy distribution can be arranged in that way that the best economical operation mode is switched on automatically, i.e. the Programmable Logic Controller PLC of the Switching Cabinet has the information which kind of energy at which point of time should be used directly by the customer, should be supplied by a conventional solution, or should be fed into a common grid.

5. Solar Power Generation

Above about 2 Megawatt electrical power, a conventional steam turbine offers better possibilities than the low temperature ORC process. The South of Turkey offers cities with a value of the Direct Normal Irradiation above 2.000 kWh per square meter and year. Actually, it is planned to install a 10 MW_e Solar Thermal Power Plant.

The collector field with the Parabolic Trough Collectors will be combined with a storage group, to be able to supply electricity for 24 hours. The total electrical efficiency is about 30%. For the huge thermal capacity to be installed, a bigger PTC model than the PTC 1800 will be used. The collector field is built up in a modular design, using thermal oil as heat transfer medium for 390 °C operation.

While the trigeneration and solar cooling plants regard the energy supply with solar thermal generated energy while the solar irradiation offers the best values, the operation of the solar power generation is different. Even at low irradiation values, the thermal operation start. The range between average and peak radiation values is used to store the thermal energy.

This concept for the direct electricity generation requires several new developments:

- Application of huge Parabolic Trough Collectors, using thermal oil at 390 °C for the heat transfer.

- Combining the functional groups collector field, storage group, and the power units to one whole solar power plant.

For huge thermal capacities and the solar thermal power generation, SOLITEM developed larger Parabolic Troughs. The PTC 1800 has 1,80 meter aperture width and offers about 4,5 kW thermal capacity at standard conditions. For the solar power generation, bigger PTCs with a larger aperture width will be used.

The combination of the collector field with the high temperature storage group is novelty. Several state-of-the-art possibilities are given. Actually, the best operation is the usage of molten salt for the 390 °C operation.

6. Conclusion

The described solar trigeneration, the integration of electricity into multi-functional solar thermal energy supply, and the setup of large-scale solar power generation plants offer several advantages:

- Easy integration of renewable energy systems.
- Application of the fitting technology for the given boundary conditions, concerning the PTC installation possibilities, the energy demand, and the total plant size.
- Increasing the technical potential of solar energy.
- Offering all kinds of required energies with on solar energy plant and at the same time.
- Using sustainable and zero-emission energy.
- Enabling the economical usage of solar energy already today.