ANALYSIS OF BOREHOLE FIELD DESIGN FOR SEASONAL STORAGE OF RENEWABLE HEAT

Summary

As a part of complex energy system design, a sub-system combining a solar thermal system, an air-water heat pump using only electricity from the PV system and seasonal heat storage between summer and winter was modeled in the TRNSYS environment. To design the optimal configuration of the borehole field for seasonal storage, various variants were modeled: length of the boreholes, number of boreholes, borehole spacing for a defined ground massif and type of the boreholes (U-loop). The analysis has evaluated storage efficiency and usable heat supply to the low-temperature district heating system. General recommendations for the design of the borehole field were derived from the analysis: minimum total length of the boreholes, minimum volume of the borehole field, small spacing between boreholes and the resulting overall compactness of the field volume.

Keywords: seasonal storage, borehole field, solar thermal system, heat pump, photovoltaic system

Field of application for the findings: seasonal heat storage, design of energy systems

Addressed audience: designers, planners

1. Introduction

Complex energy system which is under preparation includes pilot systems for production, storage and supply of renewable heat for district heating purposes. The project combines a deep geothermal source of energy, use of waste heat from hydrogen electrolysis, solar thermal, photovoltaics and PVT systems in combination with heat pumps and underground heat storage. All the subsystems will be connected to a water circuit emulating a low temperature district heating system. Heat from this circuit will be transferred to conventional city district heating (DH) network at temperature 95 °C by means of high temperature heat pump.

The paper focuses on the design and analysis of two solar system concepts for fully renewable heat production: solar thermal system with photothermal collectors (SOL) and system combining photovoltaic modules and air-to-water heat pumps (PV-HP). Computer modeling has been used in the design and optimization of subsystem parameters. The paper shows an analysis of a seasonal heat storage design in the form of a field of ground boreholes.

2. Renewable heat production

Both solar systems use solar energy and ambient energy to convert it to heat supplied to low temperature DH system with seasonal heat storage. To compare the benefits of each solar system the same available collector area has been defined. The first source is a solar photothermal system (SOL system) with a solar thermal collector area of 1000 m^2, which produces heat by direct conversion of solar radiation. Solar high quality flat-plate collectors were considered with south orientation and slope 30°.

The second heat source is a combination of a photovoltaic system with a PV module area of 1000 m^2 (220 kWp), supplying electrical energy for the operation of high-temperature air-to-water heat pumps (PV-HP system). The production of usable heat by heat pump from the ambient air uses only renewable electrical energy by adjusting the heat pump power input to the PV system power output. The air-to-water heat pump was considered as a cascade of two units with a total heating output of 51 kW at A7/W30 at minimum speed (one unit) and a heating output of 623 kW at A20/W80 at maximum compressor speed (both units). Each unit has continuous power input control from 20 Hz to 120 Hz, resulting in the range of power control from 15 % to 100 %. Thus, the heat pump does not consume any electrical energy from the public grid during its operation and uses only renewable electricity to produce heat.

Both systems (SOL, PV-HP) supply the heat from spring to autumn (from April 30 to October 1) to a common seasonal heat storage formed by the field of ground boreholes. In the winter period, heat removal from the borehole field is considered directly to the low-temperature heating network with a temperature level of 35/25 °C. In the case of heat production by both sources in the winter, heat can be supplied directly to the low-temperature network as needed. Fig. 1 shows the simplified scheme of energy flows.

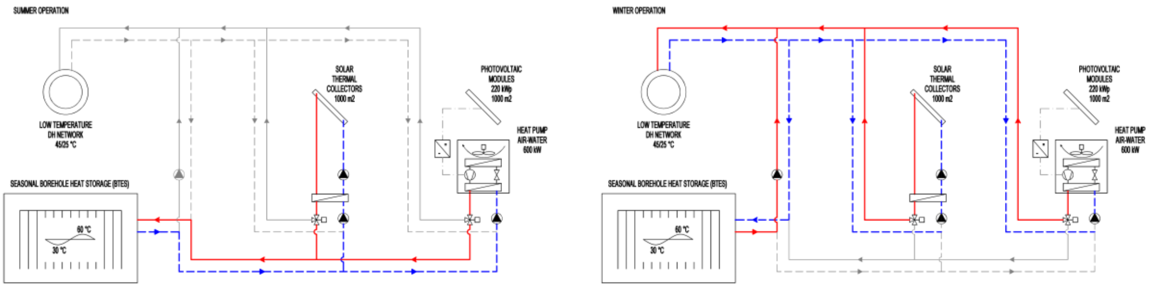

Fig. 1: Scheme of analyzed renewable heat system

3. Analysis of borehole field design

The analysis of the ground borehole field examined various variants of the ground borehole configuration: number of boreholes (20 to 100), depth (50 to 100 m) and spacing of boreholes (3 to 8 m) in the field for a given heat source in order to maximize usable heat recovered from the storage. The simulation of individual variants of the borehole field was carried out in TRNSYS 18 software. Due to the nature of the investigated system with seasonal storage, a period of 10 years was simulated to reach the stabilized conditions within the seasonal storage. The results presented are taken from the 10th year of the simulation, when steady-state operation is assumed.

The modeling of the borehole field was performed using the type 557a model (Pahud D. et al., 1997), which represents a simplified model of boreholes with pipe U-loops. The field is specified by the number of boreholes, their depth and spacing, geometry and physical properties of materials (pipes, boreholes). The properties of the underground environment up to a depth of 500 m were based on the assumptions obtained from the geological survey in the given location. To simulate the operation of heat sources, hourly climate data for a relatively cold year with an average annual ambient air temperature of 7.7 °C and a horizontal solar irradiation of 1095 kWh/m^2 were used.

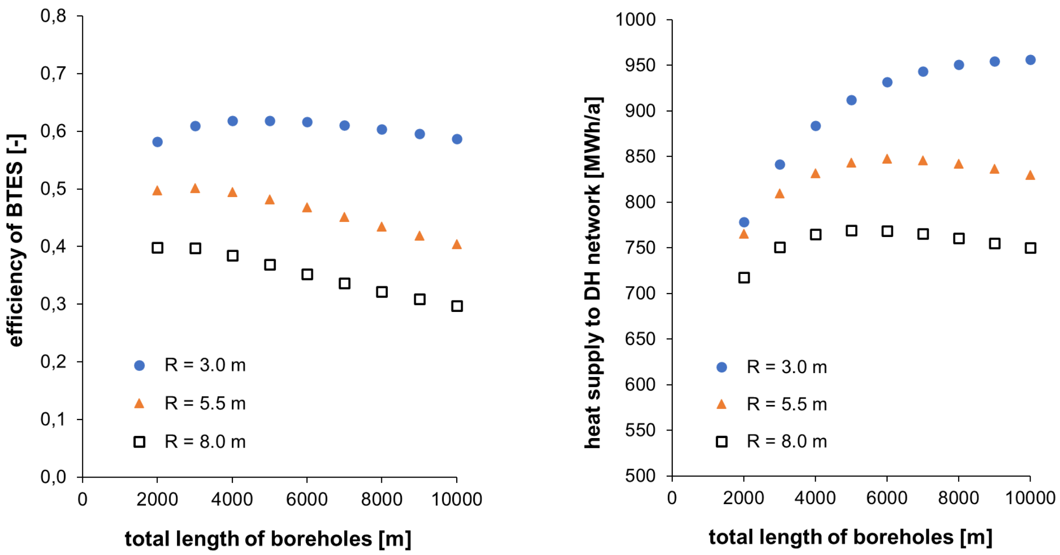

Fig. 2: Efficiency of seasonal storage and total energy supplied into low temperature network

The analysis monitored annual energy flows in the system. The aim was to investigate how the sizing and configuration of the borehole field can affect both the efficiency of the storage and the heat supplied from the sources to the low temperature network. Fig. 2 shows the dependance of both on total length of boreholes given by number and depth of boreholes. It is obvious that lower values for spacing of boreholes (R = 3 m) result in higher efficiency and heat supply. However, optimum design values for total length of boreholes differ for efficiency and heat supply. For efficiency the optimum 4 km can be found (62 %), while for heat supply the optimum is around 10 km (956 MWh/a).

Design decisions finally should consider practical issues, including economic view and feasibility. Due to typical achievable verticality for low-cost drilling about 5 % the distance R = 3 m is applicable only for low depth of boreholes. The flat optimum for heat supply for DH network leads to preference of lower total length of boreholes e.g. 6 km which results in cheaper installation and only 3 % lower heat supply compared to optimum at 10 km.

Comparison of both systems (SOL, PV-HP) results slightly better for PV driven heat pump system. The total annual heat production of heat pump delivered both to borehole field and directly to DH network exceeds the solar thermal system by approximately 14 % for the optimum case.

4. Conclusion

The simulation analysis of the borehole field for given system combining renewable heat sources sensitive to operation temperature results in several conclusions that should be considered when designing the seasonal heat storage:

- the total length of the boreholes, i.e. their heat exchange surface, must correspond to the performance parameters of the heat source to guarantee effective heat transfer to the ground mass without an excessive increase in the operation temperature (temperature difference between the liquid and the mass);
- the total volume of the borehole field must be chosen regarding the amount of stored heat, assuming also the usable temperature required in the reservoir (extraction of usable heat);
- need for low borehole spacings, which significantly increase both heat supply and the efficiency of using seasonal storage, however respecting that the sufficient total borehole length and storage volume are ensured;
- heat utilization and storage efficiency are influenced by the achieved temperature level of the storage – the optimum of these two main monitored parameters is then a compromise between a temperature level low enough for effective heat production by SOL and PV-HP sources (the lower the temperature, the higher the annual heat production of the sources) and a temperature level high enough for usable heat supply into the low-temperature network (the higher the temperature level reached in the storage, the higher the heat supply).

Analyses of complex energy systems, such as the presented renewable heat supply system with seasonal storage, must be carried out in sufficiently reliable simulation tools that allow for parametric analyses with low computational time requirements and with specific technical parameters of individual components (collector, heat pump, exchanger, drilling field, subsoil), as these can also significantly affect the result, or possibly trends in the entire analysis.

5. References

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