next-CSP

High Temperature concentrated solar thermal power plant with particle receiver and direct thermal storage

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Deliverable *D6.4*

WP6 – Assessment of the highly efficient thermodynamic cycles that can be combined with the high temperature solar loop

Deliverable D6.4 Report about power plant dynamic modelling

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Foreword

The report D6.4 aims at the selection of the best power plant layout and the sizing according to pre-established time-of-delivery strategies. Selection prioritizes the solar multiple (number of heliostat unitary fields) and amount of particles for energy storage (storage sizing) to fit a determined demand profile. In addition, the thermal losses of the belts conveyors, have been estimated taking into account the charging and discharging operation mode of the storages tanks.

The analysis performed in this report adopts as **reference case the specifications and sizing provided in deliverable D7.1**, and in order to evaluate the best configuration, the dynamic simulations to determine annual performance of the whole power plant were performed. A sensitivity analysis for different cases of the thermal energy storage related to solar power plants' arrangements has been carried. For each configuration, two dispatching models have been analyzed.

Introduction and Objectives

The new generation of concentrated solar power systems (CSP) must be flexible and easy to hybridize with other renewable energy systems, and more in particular with PV; this possibility would make the cost of the electricity lower and the CSP more competitive in relation to other generation systems [1].

In order to be integrated into the electricity mix, it is necessary that these systems could shift the delivery of the energy at different times than when they produced it. The way to make generated energy dispatchable is by the use of thermal energy storage, which also enables the electric stability of the grid [2].

The electricity-dispatching model also plays a fundamental role in order to ensure its effective release in the electricity grid, allowing for example the baseload, load-following, and peaking duty to deliver energy and capacity when needed based on reliability and profitability [3].

Based on these considerations, solar combined power cycles coupled with thermal energy storage are potential candidates for this role; some studies have been carried in order demonstrate that these plants represent a cost-effective baseload electricity generation and an alternative to speed up the transition to a sustainable energy economy [4].

The site also influences the feasibility of the project, due to the solar availability and the costs; in this regard, some studies demonstrated that this technology is an environmentally beneficial and economically attractive option for renewable power generation in the MENA region [5].

In this scenario, the NextCSP plant concept appears as a very interesting power plant option as it includes these characteristics. The system proposed in this technology is composed by a multi tower system, a combined power cycle, thermal energy storage based in particles, belt conveyors, and it is located in Ouarzazate (Morocco). Furthermore, the dispatching model that is required, makes it flexible and easy to integrate in hybrid grids.

Since it is a multi-tower system, the choice of the solar loops numbers, and then of the energy storage system dimensions, as well as the estimation of the thermal losses of the transport system, represent a fundamental starting point for the eventual feasibility of the project.

In this report, the dynamic modeling of the Next CSP system has been carried out for different arrangements in order to evaluate:

- Number of unitary solar fields;
- Energy stored; and
- Thermal losses of the belt conveyors system.

The consortium partners granted several technical and economic data, in order to make realistic and useful the results obtained.

Conclusions

In this report, a performance analysis of the optimal configurations for the multi tower system has been carried out. Two cases of energy dispatching were analyzed, and for each case, two solar field configurations, with seven and eight towers, have been investigated.

Furthermore, a sensitivity analysis on the energy to be stored has been made. The use of some Figures of merit, regarding the energy and economic analysis have been established. From their results, it was possible to choose the best configuration. Finally, an assessment of the thermal losses of the belts conveyors has been carried out.

In order to guarantee the choosing of the optimal configuration of the Next-CSP project and the assessment of the thermal losses of the belts conveyors, the results of the dynamic simulations have been used for different arrangements of the system. In accordance with the information granted by the project partners, it was possible to update the numerical model adapting it to the real needs of the consortium.

The increasing in the temperature of the particles leaving the receiver at 825 ° C, made it possible to obtain a new Turbine Inlet Temperature of 800 ° C. The modeling of a new heliostats field allowed gaining a receiver efficiency of about 80%. The whole system increased its efficiency up to 49.4% at nominal conditions, closer to the target of 50%.

The specific dispatching scenario made it necessary the use of new Figures of merit, as well as the usual ones, for the selection of the optimal configuration.

The results of the analysis showed that the best configurations are:

Case 1: 7 solar loops – 2 GWh of storage;

Case 2: 7 solar loops – 2.5 GWh of storage.

For these two configurations the annual thermal energy losses by the belts conveyors are:

Case 1: 429.07 GWh;

Case 2: 492.26 GWh.

The minimum LCoE values of the optimal arrangements are:

Case 1: 13.24 c€/kWh;

Case 2: 11.85 c€/kWh.

The uncertainty analysis of the costs of the heat exchangers and of the particle transport systems, show that the bigger LCoE value increasing at least for the Case 1 is up to 14.06 c€/kWh, and for Case 2 is up to 12.62 c€/kWh.

The belts conveyors costs influence the base LCoE, of the optimal configurations, more than the heat exchanger costs; respectively 6.2% versus 3.1% in Case 1, and 6.5% versus 3.5% in Case 2.

In addition, the LCoE of the Case 2 is more affected by the CAPEX cost variation of the heat exchanger and the belt conveyors systems, than the LCoE of the Case 1.

In conclusion Next CSP project appears as a very promising option as baseline power system or able to generate in hybrid grid with photovoltaic and wind generation systems. The LCoE analysis results indicate that the power plant is able to shift the production of electricity to sunset hours and with restrictions of dispatch hours and at the same time keeping competitive costs, with values comparable to the existing plants in North Africa of 13 c€/kWh [9].

References

[1] L.Crespo. Lateral Thinking on Storage. Getting the Most when it is Empty, SolarPACES 2019.

[2] J. Forrester. The value of CSP with thermal energy storage in providing grid stability, Energy Procedia 49 (2014) 1632 – 1641

[3] G.Zhu, C.Libby. Review and future perspective of central receiver design and performance AIP Conference Proceedings 1850, 030052 (2017);

[4] B. J.Alqahtani, D. Patiño-Echeverri. Integrated Solar Combined Cycle Power Plants: Paving the way for thermal solar Applied Energy 169 (2016) 927–936

[5] M. Horn, H.Fuhring, J.Rheinlander, Economic analysis of integrated solar combined cycle power plants A sample case: The economic feasibility of an ISCCS power plant in Egypt

[6] Pacheco, J. E. E, Kolb, G. J., Reilly, H. E., Showalter, S. H., Goods, R. W., Bradshaw, D. B., Dawson, S. A., Jones, M. J., Hale, R. L., Gilbert, M. R. P., and Jacobs, P. E., 2002, “Final Test and Evaluation Results From the Solar Two Project,” Sandia National Laboratories, Report No. SAND2002-0120, Albuquerque, NM, p. 40.

[7] C. K.Ho, B.D.Iverson. Review of high-temperature central receiver designs for concentrating solar power. Renewable and Sustainable Energy Reviews 29 (2014) 835–846

[8] J. Spelling, A. Gallo, M. Romero, J. González-Aguilar. A high-efficiency solar thermal power plant using a dense particle suspension as the heat transfer fluid. Energy Procedia 69 (2015) 1160 – 1170

[9] L. Zhao, W. Wang, L.Zhu, Y.Liu, A.Dubios. Economic analysis of solar energy development in North Africa. Global Energy Interconnection. Volume 1, Issue 1, January 2018, Pages 53-62