Solar Energy and Storage – Energy System Analysis on the use of energy storage coupled with solar technologies

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Overview

In countries with higher solar radiation compared to Europe, e.g. countries in Middle East and North Africa (MENA), solar technologies have become very competitive to other sources due to the falling costs. Some of these countries initiated national action plans to install high shares of photovolataics (PV) in relatively short time period, which consequently leads to integration challenges. Increasing share of renewable energy requires strategies to deal with highly fluctuating feed-in from renewables and subsequently novel operational strategies for the total system. Grid reinforcement and balancing of the fluctuating renewable resources are key topics.

This paper analyses the role of solar technologies and their interaction with energy storage to flatten or shift the electricity generation by using a fundamental electricity system modelling (ENTIGRIS, www.entigris.org). The capacity expansion and dispatch model is used to analyse the role of energy storage (chemical or thermal) in combination with PV or concentrated solar power (CSP). The analysis shows that battery prices have to be at the range of (50-100 $/kWh) to be considered as an option for storage coupled with PV in an optimized least-cost system of about 30-35% shares of renewables. If energy storage is required in an energy system, CSP coupled with a thermal storage proves to be a cheaper solution in the energy mix. The economic analysis also provides insight of the operation strategies of these energy storages.

Methods

The main objective of this study is to analyse the role of CSP and PV within an energy system with increasing renewable energy shares. This is achieved by modelling and optimizing a least cost expansion plan of the energy system with the model ENTIGRIS. The optimization model is formulated as a linear problem. The solver compares different electricity generation and transmission technology options while minimizing the system costs of the required technology mix and infrastructure for the electricity supply. The model optimizes the expansion and the unit-commitment in the overall power system by considering the grid constraints and geographical typology. The present hourly demand and long-term load projection has to be met at all times. As the design of energy storage in capacity and volume is also optimized, their roles in the electricity system together with the solar technologies can therefore be analyzed. A sensitivity analysis is conducted using several battery prices ranging from 500, 300, 200 to 100 and 50 $/kWh to test their economic feasibility. Furthermore, a sensitivity analysis is conducted with a variation of the weighted average cost of capital (WACC) to analyse the influence of government subsidies and incentive programmes on CSP in order to make it more competitive againt concventional power plants.

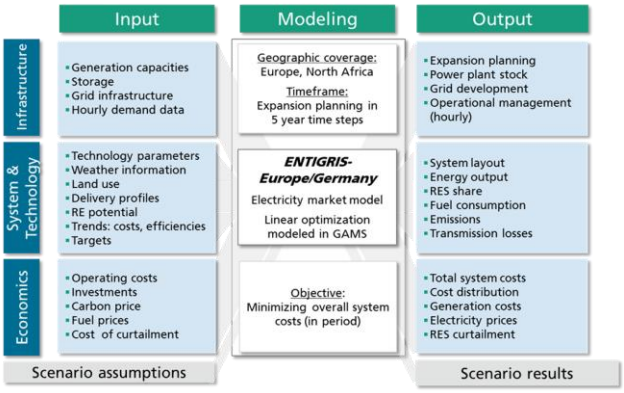

Figure 1: Input and output of the energy system optimization model ENTIGRIS

The applied version of the optimization model ENTIGRIS is a modification of the European version and covers the electricity system in detail [1, 2,3]. It optimizes the connection between the existing conventional power plant systems with a high resolution of renewable energy generation. Figure 1 shows the general input and output data of the optimization model which optimizes total cost for expansion planning and system operation over a specific time horizon (e.g. 20 years).

In the model, cost and technology assumptions are included with relevance to the specific electricity system. Current and future cost assumptions are included based on current market prices and learning curves to be able to estimate them to the future. Furthermore, all existing power plants are included with the installed capacity and geographical location in the energy system.

Results

Solar technologies contribute a significant share in the optimal result in the long-term expansion of electricity system in regions with high radiation such as in MENA. They are competitive to all other generation technologies, if world market prices of oil and natural gas are included in the analysis. This leads to strong increase of generation capacities on the renewable side. However, the model includes reserve margins and coverage of transmission grid which provides indepth results on specific power system how they can react on the conventional side on the high feed-in of renewables in the system. Based on the result, CSP with thermal energy storage is the more cost effective solution of a solar technology and energy storage compared to PV plus battery, as the former is preferred to be expanded by the model in all cases. The sensitivity analysis shows that batteries become economic feasible at prices lowers than 100$/kWh (if no other markets such as ancillary services, reserve or grid stability are requested and the focus is on energy shifting from day to night). A break-even levelized cost of electricity (LCOE) of 7.8 ct/kWh$_{el}$ is observed for CSP with a WACC of 4% and CCGT at a fuel price of 8 $ per Million BTU. A considerably lower LCOE of CSP is achieved by lowering the WACC further. This however would require a strong incentive programme in favour of CSP which could be achived by tax cuts or lower interest rates.
Figure 2 illustrates the impact of CSP and PV operations on the overall system. In this system, only a CSP is constructed with a 8h thermal storage. No batteries in addition to the PV system was built by the model. The CSP and PV feed-in during the day leads to a high flexibility capacity in the form of CCGT, as these power plants have to decrease their output during the day. CSP and thermal storage have their highest output share in the evening when PV is not producing.

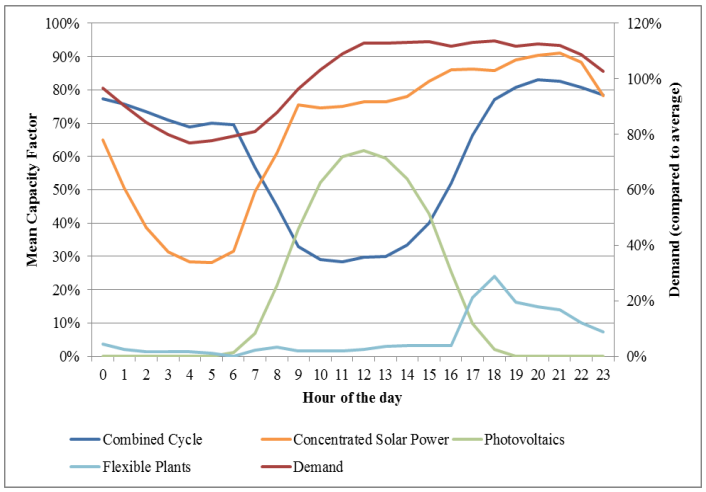

Fig. 1. Typical generation with PV and CSP plants in a system

Conclusions

Energy storage with solar technologies are an upcoming solution in energy systems. Electricity systems with CSP and PV generators will use increasing share of energy storage when renewable share are further increased. However, thermal energy storage is economic feasible already in the next years as integration cost in a CSP plant is lower compared to chemical energy storages such as battery stacks. However, battery storage might also play a role on ancillary services and other supportive operation in an electricity system.

References

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