EuroSun2026 ABSTRACT:

CRITICALITY OF MULTIPLE GW-HOURS OF THERMAL STORAGE IN ACHIEVING PRACTICAL & LOW-COST BASELOAD SOLAR ELECTRIC W/ CSP

Summary

Analytical tools, methods and hardware have been developed to enable CSP to deliver baseload solar electric, with an annual capacity factor of 95%. The paper demonstrates the techniques and rationale for achieving baseload solar power with CSP. System configuration and large-scale thermal storage are the enabling factors that make baseload solar practical, cost effective and ultimately able to bridge the last mile. The exact parabolic troughs & storage system that can achieve the results are identified. Finally, the capex implications and net levelized cost of electricity (LCOE) are surprisingly low. The optimization is illustrated with a Palmdale Ca. CSP case study, which has been optimized with 10 GW-hours of storage and 100MW electric output 24/7 that achieves a solar only LCOE of $0.046 per kW-hour. Though the solar and incentives are different, a CSP plant in Seville, Spain can achieve a net LCOE of €0.055 per kW-hour. This levelized CSP is a low-cost, practical and long-lived alternative to Lithium batteries, which can't cost-effectively achieve a high power factor.

Keywords: CSP, thermal storage, levelizing, baseload solar power, capacity factor
Field of application for the findings: CSP & Thermal Storage, Baseload Solar Power
Addressed audience: Grid operators, power producers, data centers power

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1. Preface

Clearly, the only way to realize a power grid where solar is ubiquitous, is to push solar to be a "baseload" power plant (i.e., 95% capacity factor), which is equivalent to coal and nuclear plants. This paper focuses on Concentrated Solar Power (CSP) and how CSP & sufficient storage configurations can achieve practical and cost-effective baseload solar power. This is not just an exercise in analytics, this paper identifies the exact, analytic tools, hardware & vendors that can deliver the results presented herein.

2. Thesis

With a sufficiently large thermal energy storage system (GW-hours) and properly optimized steam turbine sizing, CSP can easily operate exactly as a baseload power plant on a 24/7 basis. Baseload solar power via CSP in fact can replace existing coal-fired power plants. Finally, this optimization is more cost effective than an unoptimized system.

3. Overview

The paper guides the reader step-by-step through the logic and process of optimization, which is called "levelizing". This process is employed to determine the optimum configuration of a baseload CSP plant to achieve a 95% capacity factor. Net capex implications of storage required for optimization are detailed as well as net energy costs from a baseload CSP plant. The paper shows that a LCOE of $46/MW-hour is achieved for a case study Palmdale plant after implementing 10 GW-hours of storage. The method developed, called "Levelizing", is designed to force CSP plants to operate 24/7 by utilizing multiple GW-hours of thermal storage in conjunction with these new operating paradigms. This levelizing theorem is demonstrated in detail by use of two examples, Palmdale California, and Seville, Spain. Many factors affect the final optimum configuration including, insolation, local incentives, tax structure and carbon credits to name the most important.

4. Analytic Tools

Fundamentally new analytic modeling tools for CSP were developed, along with associated methods of optimization. These tools take into consideration over 300 variables to properly determine long-term and real-time system behavior. From this, a new paradigm for operating CSP plants was derived. The net result is an optimization process that forces CSP plants to be predictable, cost effective and with firm 24/7 output.

5. Impetus for this Work

Largescale solar without storage is becoming an issue in many regions due to over production, intermittence and displacement of baseload (inertial) sources. As the reader will be aware, in certain markets, PV is being curtailed (blocked) during peak production hours due to overproduction, grid saturation and limited storage. While battery storage is surging, the economics are far less than favorable and environmental concerns are substantial. Batteries are certainly not a viable long-term solution, because they require frequent replacement.

6. Cost Implications of GW-hour of Storage

Critically, when the cost implications of GW-hours of storage are examined, the paper demonstrates that the net capex change is near zero (0 $/€). This is primarily due to the downscaling of the Balance of Plant (BOP) as a consequence of adding storage during levelizing. To clearly restate: unoptimized and optimized CSP power plants have nearly the same capex, with the very significant difference of how and when the power is delivered.

7. Before & After Conditions

Figures 1 & 2 below show the before and after conditions of the Levelizing Theorem applied to the Palmdale location. Figure 1 shows the unaltered solar power plant, without storage, i.e., the instantaneous electricity produced directly from the sun. Thus the power level is drastically different from hour-to-hour with even & night obviously being zero (0), while the peak power of 346MW happens for only a few hours in summer.

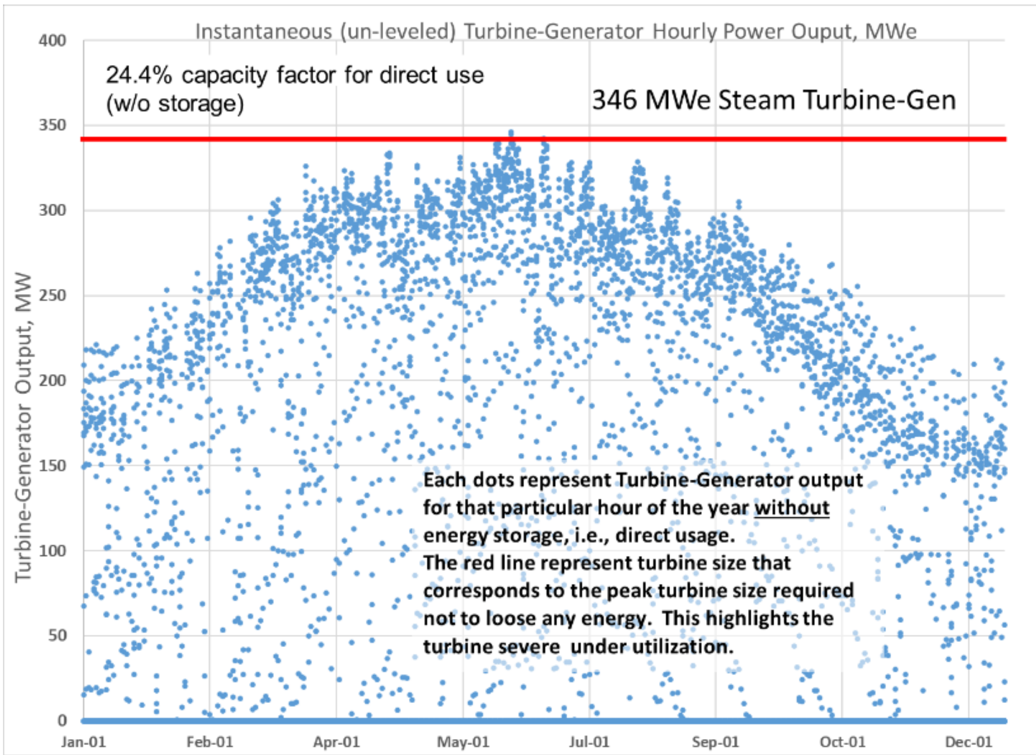

Figure 1 Unoptimized Solar Power Plant before i.e., no storage (each dot = 1 hour).

Whereas Figure 2 (following page) shows the full final result of levelizing with storage and associated balancing processes to achieve baseload solar power. The power levels are consistently 100MW, 24 hours per day and 351 days per year, allowing for a 2-week maintenance shutdown period at the end of the year. Notice that this particular optimized plant configuration has a 95% capacity factor, which is 80% solar with the addition of 15% makeup fuel, mostly in the wings of the winter period. However, it should be noted that there are alternative operating regimes, which have 95% solar only, requiring as little as 3% makeup fuel, typically to bridge long overcast periods. This small makeup number is minimized by the massive thermal storage.

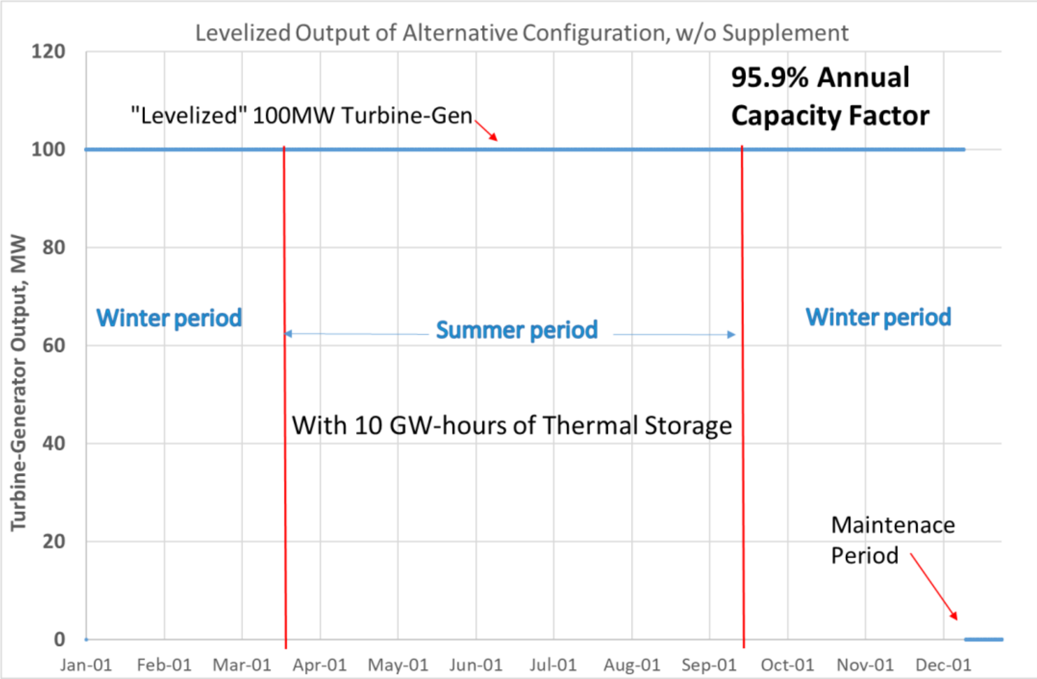

Figure 2 Optimized Solar Power Plant w/ 10 GW-hours storage and w/ Maintenance Period

8. Storage Utilization

Given the massive 10 GW-hour scale of the storage in the forgoing analysis, it is instructive to question how effectively this is used. Part of the key to optimizing economics is storage utilization. Storage utilization is the measure of the utility of storage compared to its maximum theoretical utilization. It is also a measure of its capex efficiency, i.e., how efficient the capital expenditure is being utilized in a productive capacity. The annual storage utilization associated with Figure 2 is 62%. Other configurations reach an annual storage utilization of greater than 80%. This is high and potentially near the point at which a larger storage volume should be investigated.

9. Conclusion

The proposed optimization method of levelizing CSP by employing massive GW-hour scale thermal storage yields the most cost-effective baseload solar power plant. Plants configured via the proposed levelizing method are twice as cost-effective as the alternative of using Lithium batteries to attain the 95% capacity factor. Perhaps equally important; the service life of an optimized CSP plant is a minimum 4x longer than Lithium batteries. Steam turbine generator (STG) is the most efficient means of converting solar heat to electricity. The key to using STGs is to never shut them off. Therefore CSP must be configured to run as a baseload plant, otherwise they have limited utility. This constantly on, constantly available, is a prime requisite of a baseload power plant of any kind. This has never before been achieved with CSP due to the excessive capex of previous systems configurations. Baseload solar power can solve many of the intermittency issues and contribute to grid stability as well as providing a long-term solution to functionally replacing coal fired power plants. This paper shows that baseload CSP can be both practical and cost-effective with the correct optimization techniques and hardware. Finally, the necessary tools have been developed to achieve all this.