The Role of Concentrating Solar Power in Integrating Solar and Wind Energy

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The Role of Concentrating Solar Power in Integrating Solar and Wind Energy

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Abstract— **As wind and solar photovoltaics (PV) increase in penetration it is increasingly important to examine enabling technologies that can help integrate these resources at large scale. Concentrating solar power (CSP) when deployed with thermal energy storage (TES) can provide multiple services that can help integrate variable generation (VG) resources such as wind and PV. CSP with TES can provide firm, highly flexible capacity, reducing minimum generation constraints which limit penetration and results in curtailment. By acting as an enabling technology, CSP can complement PV and wind, substantially increasing their penetration in locations with adequate solar resource.**

Keywords-solar; concentrating solar power; thermal energy storage; grid flexibility

I. INTRODUCTION

The Southwestern United States has an excellent solar resource for both photovoltaics and concentrating solar power (CSP). Significant deployment of both technologies is occurring, particularly in California, which has aggressive goals for reduction in carbon emissions as well as renewable energy deployment [1]. However because PV has a lower levelized cost than CSP, and is expected to continue declining in cost, it is expected to see a large and growing fraction of future solar deployment [2]. It is therefore important for CSP developers to explore the potential array of high value services that CSP can provide. The most significant difference between the operational characteristics of PV and CSP is the potential use of thermal storage (TES) with CSP, creating a dispatchable resource [3]. With TES, CSP can provide high capacity value, the ability to shift energy production to periods of high value, and also a variety of ancillary services. Previous analysis has demonstrated that these properties create an increase in value relative to non-dispatchable resources [1,4,5]. However another source of potential value is the role of CSP with TES as an enabling technology, providing a source of low-carbon grid flexibility. This can act to enable further deployment of wind and PV by reducing the grid's dependence on less flexible sources of capacity and operating reserves [6].

In this paper we examine the ability of CSP with TES to act as a renewable enabling technology. Section II demonstrates the importance of grid flexibility in avoiding curtailment at high penetration of renewable energy. It shows how the need for conventional thermal capacity to provide operating reserves and peak demand creates minimum generation constraints that may limit the ultimate penetration of wind and PV. Section III examines the ability of CSP to provide grid flexibility including capacity value, ramping, and energy shifting value. It uses examples from the Western Wind and Solar Integration Study Phase 2 (WWSIS-2) [7] study to demonstrate the flexibility requirements of CSP in high renewable scenarios. Section IV demonstrates the impact of CSP flexibility on renewable penetration. It uses a grid simulation model to demonstrate the ability of CSP to lower system-wide minimum generation constraints and increase penetration of PV and wind.

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II. THE IMPORTANCE OF GRID FLEXIBILITY

Large scale deployment of variable generation sources such as wind and solar depends on the flexibility of the remaining generation fleet to accommodate their variability and uncertainty. The economic limit to the penetration of renewable energy is created by the mismatch of wind and solar supply with normal demand [8]. Wind and solar generation can exceed the fraction of the demand that can be accommodated by variable resources. When the supply of variable generation exceeds what can be accommodated by the grid, generation is curtailed, and zero marginal cost and carbon free energy must be curtailed. This reduces the economic benefits of wind and solar generation and ultimately limits its contribution to the grid.

The amount of wind and solar that can be accommodated is based on the flexibility of the power system. This flexibility largely reflects the ability of conventional generators to start, stop, and ramp in response to the net variability of load, wind, and solar generation. Flexibility is driven by the mix of generators and their characteristics, with a key parameter being the overall minimum generation level, or the amount of thermal generation needed to be run to provide reliable service.

Figs 1 and 2 illustrate the impact of grid flexibility on potential curtailment. They show the output of simulated wind and PV generators during two 48 hour periods. The simulated region is the Southwestern U.S. (California, Arizona, New Mexico and southern Nevada) using 2006 meteorological data. The ratio of solar to wind is 2:1 on an energy basis with a potential annual renewable penetration of about 30%. The simulation uses the REFlex dispatch model to simulate hourly operation of the thermal fleet in response to the load, wind, and solar generation profiles [6,8]. It also assumes that transmission is accessible to all generation sources on a short-term, non-firm basis. This "limiting case" allows for examination of the best technical case for wind and solar deployment without market barriers or transmission constraints. Fig 1 demonstrates the periods on May 12 and 13, where the potential penetration of wind and

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solar is about 46.6%. This is greater than the 30% annual energy penetration due to below average load. The grid reflects the generation fleet based on the Western Wind and Solar Integration Phase 2 study, with significant use of less flexible coal and nuclear generators.

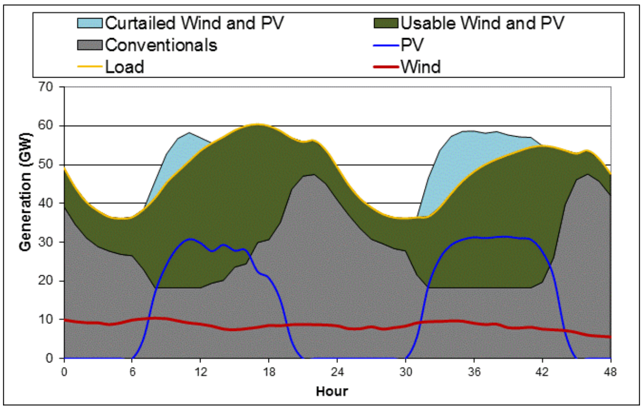

Figure 1. Simulated system dispatch in the southwestern U.S. on May 12-13 at current level of system flexibility

The figure demonstrates significant minimum generation constraints of the thermal fleet. Larger steam generators often have startup times that can prevent them being turned off during short periods of high renewable output, such as during the middle of the day. Furthermore, because of inherent variability and uncertainty in the power system, operators often must use partially loaded generators to provide a variety of operating reserves. There reserves are often provided by thermal generators, and their minimum generation levels also restricts the contribution of wind and solar. The need to keep thermal capacity online in Fig 1 is partially due to the ramping requirements that occur each day when the solar output begins to drop. Overall, during these 2 days, while the renewable potential is 46.6%, the actual contribution is 41.4%, and about 11% of potential renewable generation is curtailed.

Fig 2 demonstrates the impact of improving grid flexibility, replacing all of the less flexible generators (all nuclear and coal generators) with generators that can turn-off during short periods of high solar output, or have lower minimum generation points. In this case, penetration on these two days increases to 45.8%, and curtailment drops to about 2%.

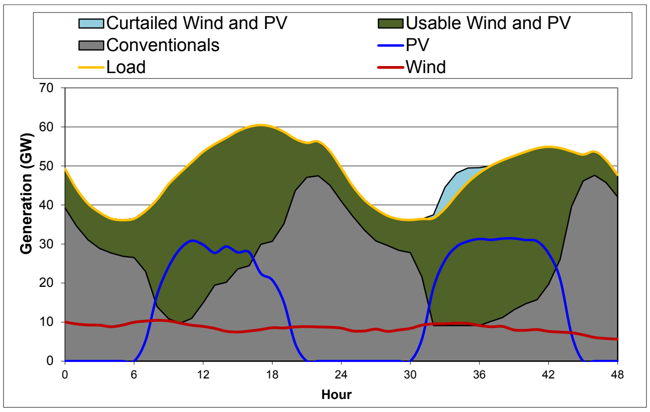

Figure 2. Simulated system dispatch in the southwestern U.S. on May 12-13 with enhanced of system flexibility

Grid flexibility creates the economic limit to renewable penetration as curtailment rates increase greatly as a function of penetration. Fig 3 demonstrates the marginal (incremental) curtailment rate of wind and solar in this system as a function of penetration for the two levels of system flexibility.

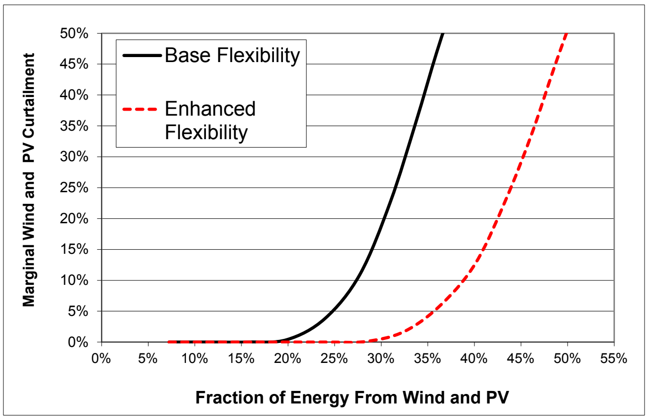

Figure 3. Marginal curtailment rates of wind and PV in the southwestern U.S. as a function of penetration

Curtailment of renewable resources has a direct impact on project economics – a plant with a 50% marginal curtailment rate would need to recover its costs on the 50% of energy actually placed on the grid, which doubles the levelized cost of energy for that project. As a result, increasing grid flexibility will be increasingly important as penetration of wind and solar increases, and will be essential to achieve very levels of penetration necessary for de-carbonized energy scenarios that depend on renewable resources.

III. Flexibility Services Provided by CSP with TES

Increased grid flexibility can be accomplished via two general mechanisms. The first, as illustrated in Section II, is to decrease the minimum generation constraints associated with thermal generation. This requires replacing less flexible generators with new generation that can ramp rapidly, and start and stop with minimal cost penalties. The second is to shift the timing of either renewable generation to better match load or the timing of demand to better match renewable supply. There are also many operational methods to achieve many options to achieve grid flexibility, however here we examine CSP with TES. While its ability to shift timing of supply is well understood, it also has the ability to address minimum generation constraints. This makes CSP somewhat unique among flexibility supply options. However its technical ability to provide grid flexibility must be examined in detail to ensure it can replace conventional capacity resource and provide the flexibility needed to act as a renewable enabling technology.

Replacing conventional, less flexible generation with CSP requires the plant to provide reliable capacity with sufficient flexibility to respond to the additional variability created by wind and solar.

PV, or CSP without storage has limited capacity value due to the mismatch of peak demand with solar generation. In the southwestern U.S. peak demand typically occurs at about 4-6 p.m. Previous studies have found that at low penetration, capacity value of PV can exceed 50% [9]. However as penetration increases, the peak demand shifts to

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later in the day when the solar resource drops, and the capacity value of solar drops rapidly.

Several studies demonstrate the ability of CSP with storage to provide very high capacity value [1,10, 11]. Fig 4 shows an example of CSP dispatch from the WWSIS-2 study [12]. The CSP plants have 6 hours of storage capacity at rated discharge, with the output of the plants aggregated in this figure. It shows the high solar scenario, where PV and CSP provide about 25% of the system's annual energy requirement. The top curve shows the net load after the contribution from wind and PV on July 24-26. The bottom green curve show the inflow of thermal energy from a CSP solar field. This represents the output from the aggregated fleet of CSP plants if they were deployed without energy storage. This curve demonstrates how the net demand for energy has been shifted by the PV, and how solar energy is no longer coincident with demand. The purple curve shows the dispatched CSP output, demonstrating how a large fraction of solar energy needs to be shifted to ensure output during the periods of peak demand.

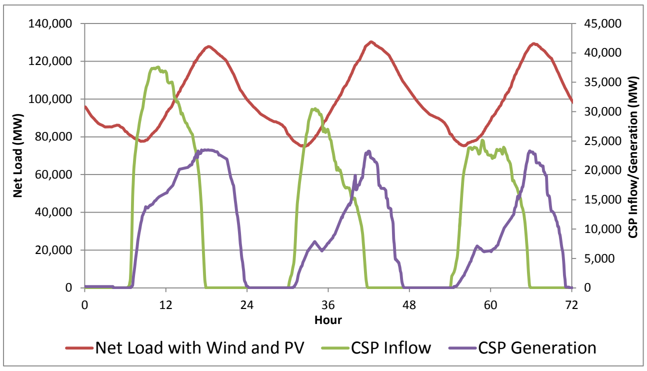

Figure 4. Dispatch of CSP in the WWSIS-2 high solar scenario on July 24-26

Application of reliability-based capacity credit methods find high capacity value for CSP plants with at least 4 hours of storage, depending on reasonably accurate forecast of load and solar resource. An example is illustrated in Fig 5, the capacity credit of a CSP plant in Southern California [11]. This result is at low penetration, but additional analysis has found that even at high penetration CSP with at least 4 hours of storage can retain high capacity value [1].

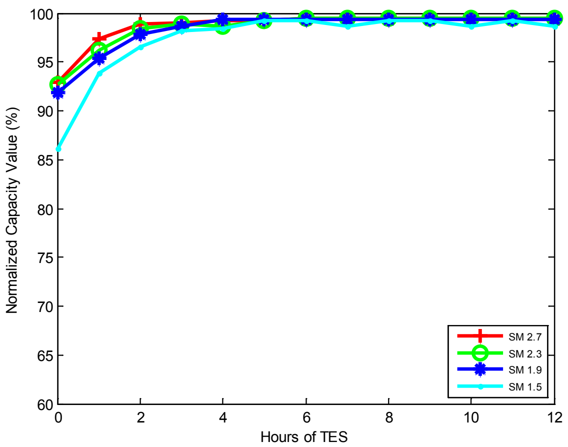

Figure 5. Capacity value of CSP plants in southern California

High capacity value alone is not sufficient to allow CSP to enable wind and solar. It must also have significant operational flexibility, operating with high ramp rate and range, and the ability to avoid generation during periods of high PV output. Fig 6 illustrates another period from the WWSIS-2 high solar scenario. As with Fig 4 it shows the net load after the contribution form wind and PV, but this period is on January 5-7. During these 3 days, PV creates short peaks in the early morning and early evening. In response, the generation fleet must ramp rapidly to avoid renewable curtailment. Also of note is the fact that during these periods essentially 100% of the incident solar energy is stored. This may require new modes of operation for CSP plants, requiring shut down in the middle of the day, and the ability to store most or all of the incident solar radiation. It may also require multiple starts per day and frequent part load operation. This also represents a divergence from renewable energy acquisition practices which are often based on generator levelized costs of energy as opposed to overall value [9]. CSP plants with the lowest overall cost tend to have higher capacity factors, with generation profiles that resemble baseload power plants [1,2]. This results in less operational flexibility to reduce output during periods of high PV generation [1]. Overall, the tradeoffs between CSP cost, flexibility, and overall value requires further analysis, and new market mechanisms may be needed to compensate CSP for provision of grid flexibility

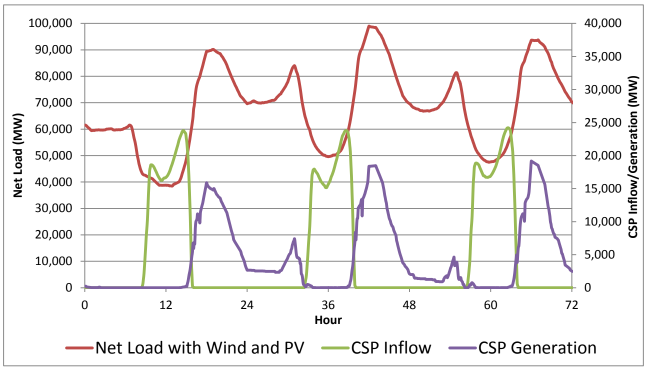

Figure 6. Dispatch of CSP in the WWSIS-2 high solar scenario on Januay 5-7

The impact of CSP deployment is to decrease the net ramping requirement of the system normally met by conventional generation. Fig 7 demonstrates this for the same period as Figure 6. This decreases ramping requirement reduces the need for partially loaded plants, and corresponds to a direct reduction in the minimum generation constraint.

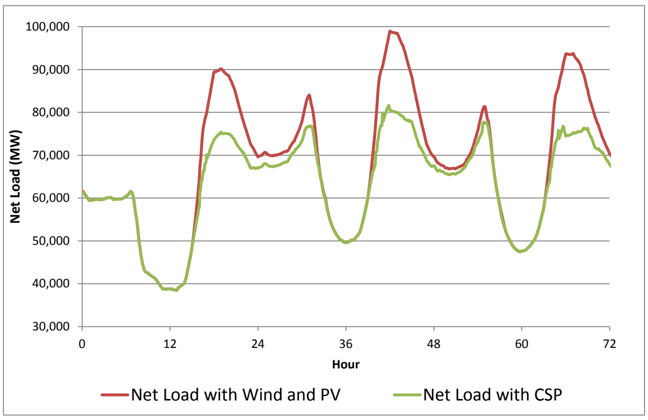

Figure 7. Decreased ramping requirements due to deployment of CSP in the WWSIS-2 high solar scenario on Januay 5-7

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IV. CSP as a Renewable Enabling Technology

As a result of high capacity value and high operational flexibility, CSP with TES can replace conventional thermal generation. As older, less flexible generators retire, or load grows, CSP provides an alternative to new generators. Many CSP plants, both existing and proposed, are essentially small steam (Rankine-cycle) plants with the capability of operating over 75% or more of their rated capacity, with only a 5% increase in heat rate at 50% load [6]. They are also designed for rapid starts. This can be compared to larger thermal plants that often operate over only 50% of their rated range and may require several hours to start.

The benefits of CSP in providing grid flexibility can be evaluated in terms of the increase in contribution of renewable energy resources. Returning to the simulations in Section II, we can examine how the addition of CSP can increase penetration of PV and wind, and significantly increase the overall penetration of renewable energy. Fig 8 provides an example of curtailment curves in scenarios where CSP provides flexibility benefits. The “Wind + PV” curve is identical to the base flexibility curve in Fig 3. We then repeat the same simulations, but add about 1 unit of CSP generation for each 4 units of wind and solar generation (so the final relative annual energy contribution of PV:wind:CSP is about 2.7:1.3:1). We also assume that each MW of CSP with TES allows for the retirement of 1 MW of conventional thermal generation with an operating range between 50% and 100%.

The blue curve shows the impact of additional flexibility due to CSP on the wind and PV generation. The reduction in conventional generation allows a greater contribution from wind and PV, even without the load shifting benefit of CSP. The green curve shows the total contribution from all three renewable energy sources. At 50% penetration, marginal curtailment is still relatively high at about 31%, indicating the likely need for additional flexibility options. Even at 50% penetration, there is still a substantially amount of less flexible generation, which could be replaced with more flexible generation, or other flexibility options [13]. These include a greater amount of CSP, other forms of energy storage, demand response, or greater interchange of energy with regions outside the southwestern U.S. It should also be emphasized that achieving high levels of wind and PV are not necessarily contingent on CSP deployment. However the results in Fig 8 do demonstrate the role of CSP as a potentially important source of flexibility in scenarios of very large deployment of renewable energy.

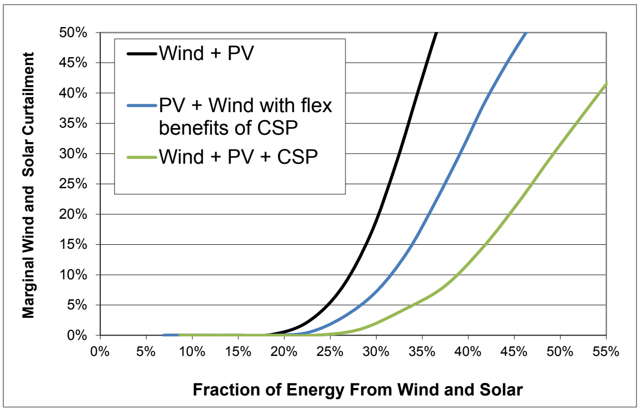

Figure 8. Impact of CSP flexibility on increased penetration of PV and wind

V. Conclusions

CSP with TES has the ability to be a complementary resource to PV and wind. CSP can act to shift load and also replace existing, less flexible conventional generation. To act as a source of flexibility, CSP plants will need to be designed and operated accordingly. CSP plants will need to have greater operation at part load, emphasizing capacity services as opposed to energy services typically valued in renewable power purchase agreement in the U.S.

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