OBSERVED IMPACTS OF TRANSIENT CLOUDS ON UTILITY-SCALE PV FIELDS

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ABSTRACT

This paper illustrates the impact transient clouds have on the energy production at a recently commissioned 25 MW photovoltaic (PV) solar plant in central Florida. We analyze a day when clouds of varying scale influenced PV energy yield and also demonstrate how increasing the size of PV production can help dampen energy production ramp events triggered by the passage of transient clouds.

1. INTRODUCTION

Variability is perceived to be a major issue for utility-scale PV systems. The sudden change in PV energy production due to partly cloudy weather conditions is the primary concern. Because PV modules respond instantaneously to changes in solar irradiance, it has been speculated that PV fields (regardless of size) could have large and frequent ramp events that may create challenges for electric grid operators [1, 2].

The recent completion of Florida Power & Light Company's 25 MWac DeSoto Next Generation Solar Energy Center (henceforth referred to as DeSoto) near Arcadia, Florida (Figure 1), offers us a unique opportunity to observe the effects of transient cloud fields on utility-scale PV systems.

2. BACKGROUND

The DeSoto PV site is currently the largest PV solar facility in the country consisting of over 90,000 SunPower crystalline PV modules and covering 180 acres of land. To maximize energy production per acre the PV modules are mounted on SunPower T0 trackers which follow the sun throughout the day and increase the solar energy converted to power. The T0 trackers are single-axis and mounted with a tilt angle of 0 degrees oriented in north/south configuration while rotating east/west tracking the path of the sun as it travels the sky. These trackers also employ back tracking functionality to minimize the impacts of row-on-row shading during low sun angles. Commercial energy production commenced at DeSoto in October 2009.

Fig. 1: An aerial view of the recently commissioned DeSoto PV plant.

The site layout consists of 17 groupings of solar modules and inverter blocks referred to as containers (Figure 2). These containers range in size from 0.8-1.6 MW and have individual power meters. Additionally, several containers at DeSoto are also equipped with thermopile pyranometers measuring both global horizontal irradiance (GHI) and plane of array irradiance (POAI).

3. 13 DECEMBER 2009 CASE STUDY

GOES East visible satellite images from 13 Dec 2009 (Figures 3-5) illustrate the evolution of the cloud cover over

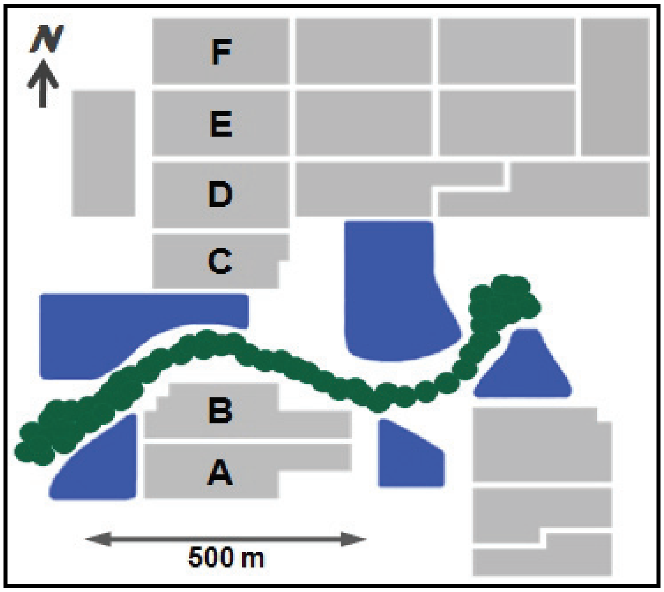

Fig. 2: DeSoto site inverter block container layout. Site water and tree coverage is denoted by blue and green shading, respectively.

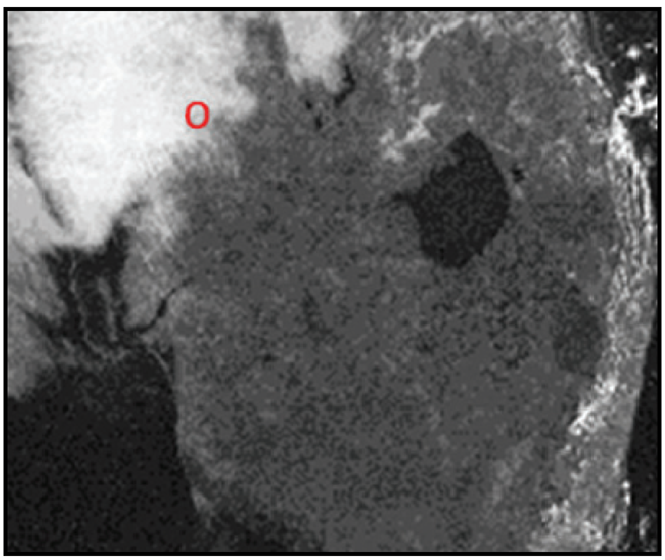

Fig. 3: 13 Dec 0915 LST GOES East visible satellite image. The approximate DeSoto PV site location is denoted by the red circle.

the DeSoto PV site. A dense morning stratus deck over DeSoto gave way to shallow fair weather cumulus clouds followed by the transition to a deeper cumulus field by mid-afternoon culminating in clearing skies near sunset. Figure 5 also illustrates cloud shadows being cast as the deepening and widening cumulus clouds coincide with the descending sun further amplifying the potential ramp-inducing effects of these clouds. The 00 UTC Tampa, FL National Weather Service rawinsonde (not shown) measured southerly winds at 5 m s^{-1} near 700mb.

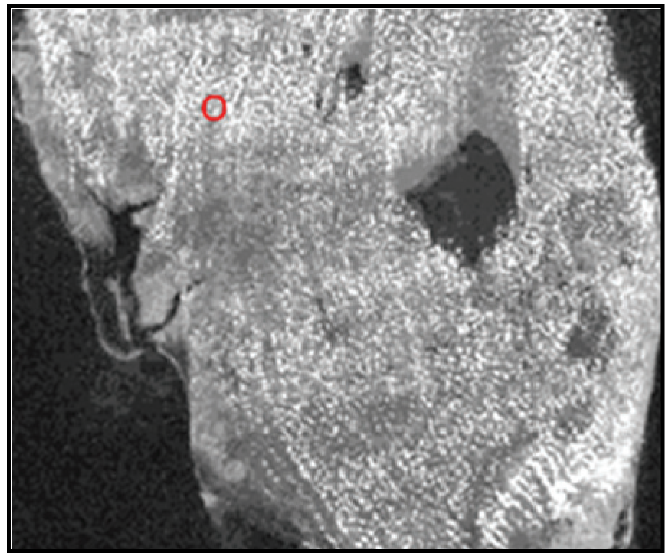

Fig. 4: Same as Fig. 3, but for 1215 LST.

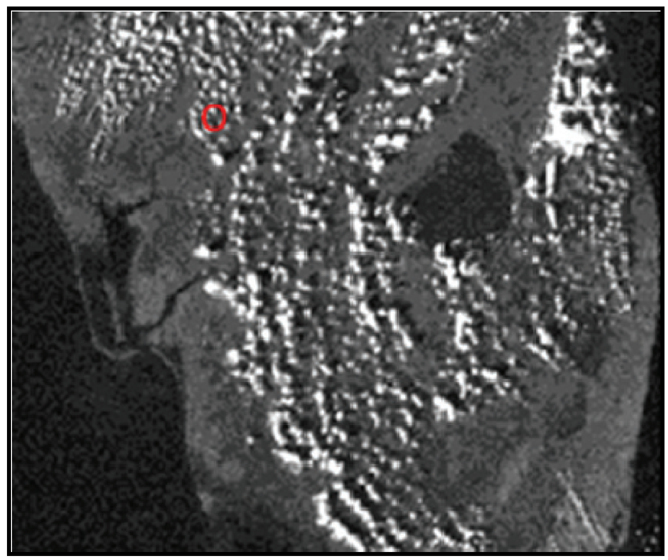

Fig. 5: Same as Fig. 3, but for 1515 LST.

The evolution of cloud cover on this day can also be observed in DeSoto substation power and GHI traces (Figure 6). The stratus cloud cover dissipated between 09 and 10 Local Standard Time (LST) leading to a highly variable power production period lasting until after 13 LST. After this time we see a transition to lower frequency, larger amplitude fluctuations in the DeSoto energy production and GHI due to the passage of less frequent, deepening cumulus clouds. Finally, clearing skies allowed for smoother energy production through sunset. These profiles contrast sharply with the DeSoto energy production and GHI measured during clear sky conditions (denoted by the blue traces on Figure 6).

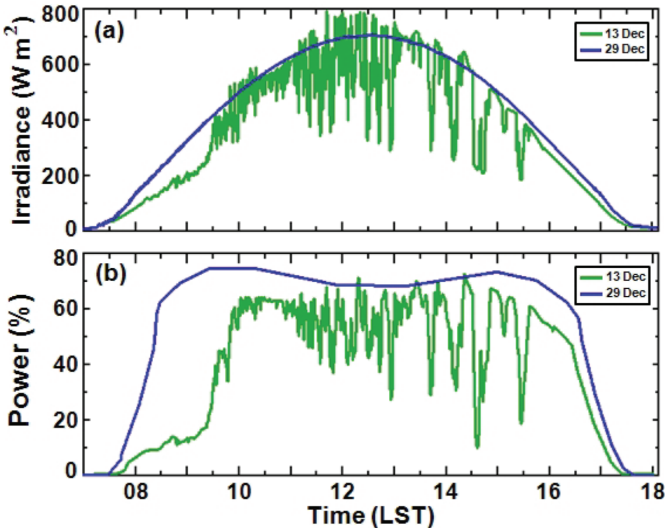

Fig. 6: (a) Ten second resolution GHI (site-averaged) measured at DeSoto on 13 Dec and clear sky reference from 29 Dec. (b) Ten second resolution DeSoto power production on 13 Dec and clear sky reference from 29 Dec.

4. TRANSIENT CLOUD IMPACTS

High spatial and temporal resolution data recorded at DeSoto allows us to visibly track the impacts transient clouds have on individual container as well as site power production.

Figure 7a depicts changes to individual container and substation power production during the passage of a small cloud along the western edge of the DeSoto PV site. This lone cloud passed over containers A,B,C,D,E and F (as identified in Figure 2) with no discernable impacts on any other site containers during this time frame. We observed a systematic decrease and then increase in power production from container to container as this cloud progresses north. A similar temporal progression was also observed in GHI measurements from containers B and E as illustrated in Figure 7b.

Interestingly, DeSoto substation power production during this time period actually ramps up slightly just as the cloud begins impacting the first container, and then slowly retreats back down as the cloud impacts more containers. This uptick in power production, attributed to cloud edge effects, has also been noted at other PV sites [1]. While individual containers have energy production deficits of nearly 60% (e.g., container B at 1054 LST), overall site power production decreases by only 5% during the cloud passage period effectively demonstrating the PV ramp dampening capabilities of the DeSoto PV site.

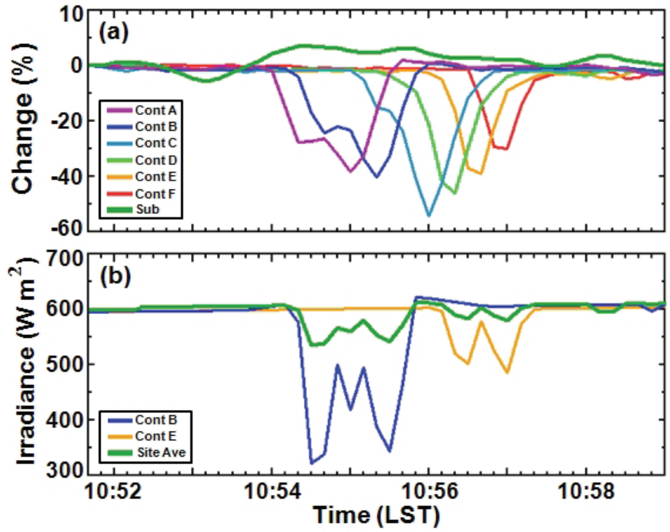

Fig. 7: Ten second resolution DeSoto power (a) and GHI (b) data depicting container-level response to the passage of a small cloud.

Zooming out, Figure 8 illustrates the impacts of passing clouds on the daily profile of energy production. Cloud-induced ramp rates are shown from ten second data for a variety of PV module groupings. While single containers (0.8 and 1.6 MW) show significant ramp rates throughout the day, the magnitude of ramp events on system production becomes increasingly dampened as more and more PV modules are grouped together. When we look at one minute resolution data (Figure 9) we see a similar reduction in the magnitude of ramp events when comparing a 1.6 MW container to full DeSoto capacity. This pattern of ramp magnitude reduction begins to falter when we transition to longer time averaging periods.

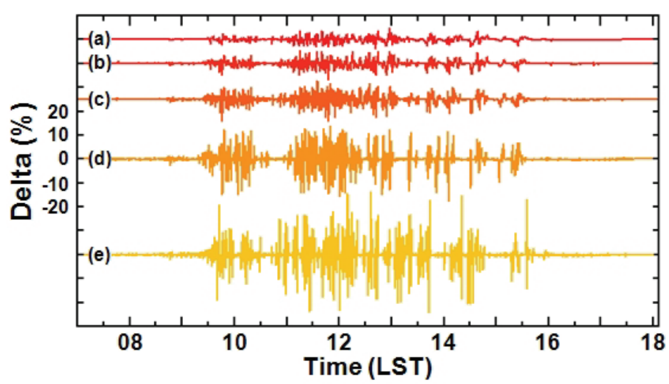

Fig. 8: Percent change (delta) in ten second power on 13 Dec for (a) all containers (25 MW) and subsequently smaller groupings of containers: (b) 16 MW, (c) 6.4 MW, (d) 1.6 MW and (e) 0.8 MW.

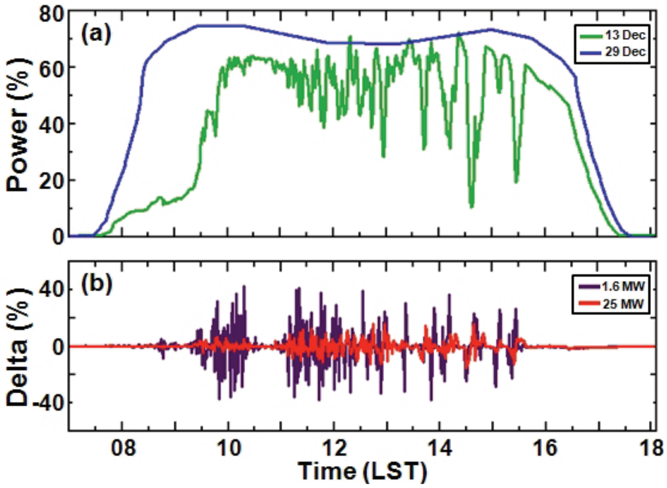

Fig. 9: (a) One minute averaged power production from 13 Dec and reference clear sky conditions on 29 Dec. (b) One minute averaged change in power (delta) on 13 Dec from a 1.6 MW container and DeSoto substation (25 MW).

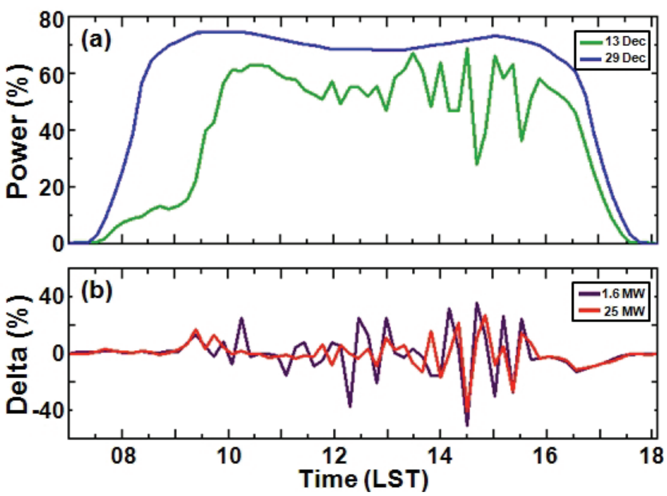

Fig. 10: Same as Fig. 9, but for ten minute averaged data.

While Figure 10 shows that a ten minute averaging time span smoothes out the higher frequency shallow cumulus cloud impacts on energy production, we see very little difference in the magnitude of ramps during the afternoon between 1.6 MW and 25 MW PV module groupings. This is due to both the speed and size of transient clouds impacting DeSoto energy production [3]. When we transition to hourly averaged data (Figure 11) we see almost all significant power production variability has been removed leaving only two major ramps associated with the morning stratus deck burn off and sunset periods.

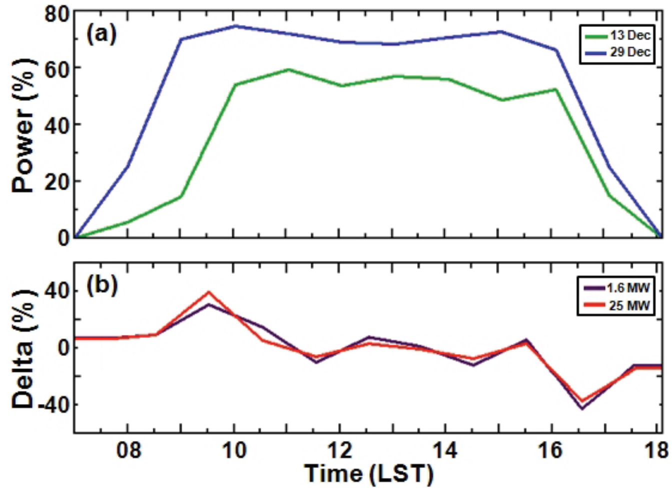

Fig. 11: Same as Fig. 9, but for hourly averaged data.

5. CONCLUSIONS

This work has only scratched the surface of what can be accomplished with a utility-scale PV facility such as DeSoto. We observed a significant reduction in the amplitude of power fluctuations induced by the passage of small clouds when we scale up from 0.8 MW to 25 MW in PV capacity. While larger clouds were shown to have differing impacts depending on the length of time averaging, these results are heavily influenced by the speed of the clouds impacting the site. Analyzing the impact of clouds of different sizes and traveling at different speeds will give us a more complete understanding of utility scale PV variability.

6. REFERENCES

1. Curtright, A., & Apt, J. (2008). The character of power output from utility-scale photovoltaic systems. Progress in Photovoltaics: Research and Applications, *16* (3), 241-247
2. North American Electric Reliability Corporation (NERC). 2009. Accommodating High Levels of Variable Generation. White Paper. April. http://www.nerc.com/files/IVGTF_Report_041609.pdf
3. Hoff, T. E., & Perez, R. (2009). Quantifying PV output variability. Draft, Clean Power Research, LLC.