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Manajit Sengupta and Jamie Keller

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PV Ramping in a Distributed Generation Environment: A Study Using Solar Measurements

Manajit Sengupta[1], Jamie Keller[1]

[1]National Renewable Energy Laboratory, Golden, CO

Abstract — **Variability in Photovoltaic (PV) generation resulting from variability in the solar radiation over the PV arrays is a topic of continuing concern for those involved with integrating renewables onto existing electrical grids. The island of Lanai, Hawaii is an extreme example of the challenges that integrators will face due to the fact that it is a small standalone grid. One way to study this problem is to take high-resolution solar measurements in multiple locations and model simultaneous PV production for various sizes at those locations. The National Renewable Energy Laboratory (NREL) collected high-resolution solar data at four locations on the island where proposed PV plants will be deployed in the near future (Fig. 1). This data set provides unique insight into how the solar radiation may vary between points that are proximal in distance, but diverse in weather, due to the formation of orographic clouds in the center of the island. Using information about each proposed PV plant size, power output was created at high resolution. The team analyzed this output to understand power production ramps at individual locations and the effects of aggregating the production from all four locations. Hawaii is a unique environment, with extremely variable events occurring on a daily basis. This study provided an excellent opportunity for understanding potential worst-case scenarios for PV ramping. This paper provides an introduction to the datasets that NREL collected over a year and a comprehensive analysis of PV variability in a distributed generation scenario.**

I. Introduction

The Maui Electric Company (MECO) owns and operates the island of Lanai's electric power system. The electric power system is small in comparison to mainland grids. The system energy is produced by a set of diesel generators located at the main power plant. One or two generators (depending on system load requirements) provide system frequency regulation using isochronous frequency control. The total capacity of the diesel generators is around 3.2 MW. The minimum and peak loads are approximately 2 MW and 5 MW. There are also two large distributed generation systems in addition to the main powerplant. A large central station PV installation (1.2MW) owned and named "La Ola" by Castle & Cooke (C&C) is installed near the main diesel power plant. This provides power to the grid through a purchase power agreement (PPA). Only recently, has the La Ola PV system begun to generate power at full capacity, due to a PPA agreement requiring that the system incorporate a battery energy storage system. This was to help mitigate ramping rates associated with the La Ola PV system. The second large generation is a combined heat and power (CHP) 0.9 MW generator, also located near the end of the distribution circuit.

A team led by the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory and MECO is working with local developers on the island of Lanai to assess the economic and technical feasibility of increasing the contribution of renewable energy sources on the island of Lanai, with a stated goal of reaching 100% renewable energy as part of the Hawaii Clean Energy Initiative (HCEI). For MECO, enabling the reliable deployment (and determining the technical requirements associated with the reliable installation) of additional renewable resources such as PV systems onto the electric power system is one way to help increase the renewable energy penetration on Lanai.

The NREL team, with input from interested PV system installers, has been working to create and evaluate viable scenarios to assess the amount of PV that can be installed on Lanai cost effectively without reducing power quality, causing system instability, or increasing equipment failure. NREL installed equipment to measure the variability of the solar resource at several locations on the island. For over one year, NREL has been capturing 3-second time synchronized solar radiation data at four locations on Lanai that would represent some of the possible locations for additional PV systems. Fig. 1 shows the locations of the 3-second solar irradiance data collection points and some of the existing generation and load centers on Lanai. This data is available to help understand site resources and variability among sites, however, appropriate system simulation models and assumptions are still needed. In this paper, we present simulated PV output from the available solar measurements and investigate the variability in PV output for individual systems in terms of ramp rates, as well as the total output from all systems. The goal of this study is to investigate whether significant smoothing in aggregate ramps is achieved even in a case where there is a large plant with a few smaller plants within short geographic distance of the large plant especially in a location that is strongly influenced by the microclimate.

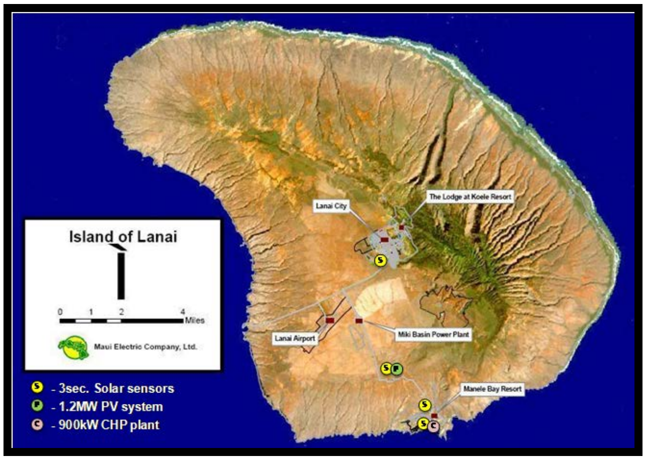

Fig. 1. Location of the four solar measurements marked in yellow.

II. METHODOLOGY

The team measured Global Horizontal Irradiance (GHI) at the four locations shown in Fig. 1. The four measurement locations are shown in Table 1, with the corresponding nameplate capacity of PV planned or deployed at each of these locations. Licor LI 200 silicon detectors were used at all four locations. The La Ola station also had meteorological measurement that included temperature and wind speed. Note that Lanai City is located inland while Waste Water and Challenge LP stations are close to Manele Bay.

TABLE 1: LOCATION OF SOLAR MEASUREMENTS AND THE NAMEPLATE CAPACITY OF MODELED PV.

Location	Nameplate capacity (MWac)
Lanai City	0.25
Waste Water	0.25
Challenge LP	0.25
La Ola	1.25

NREL's PVWatts was used to model PV output using the 3-second GHI measurements. The temperature was also used as an input to the model. In this study, the PV arrays were treated as horizontally oriented.

The team's primary interest was to investigate the variability of power production from each power plant, as well as the variability in aggregate production. Using the 3-second power output, ramp rates or rates of change in power production per second were calculated.

III. RESULTS

The team analyzed data for a period of over one year, computing and comparing the ramp distributions on a monthly basis. Fig. 2 shows the power production for a day (August 1, 2011). As expected, La Ola has a dominant influence on the change in total power produced. Our goal though is to investigate whether the addition of the three 250 KW plants has any influence on the ramps in the total power production.

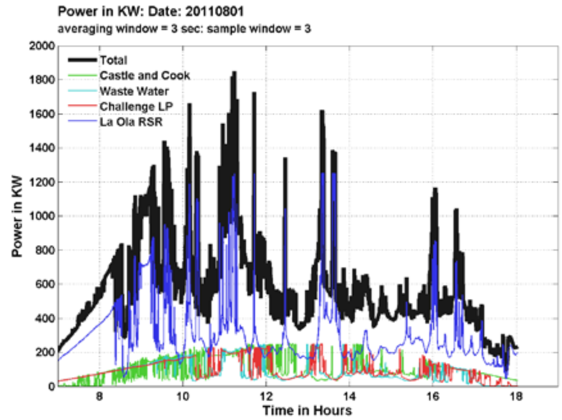

Fig. 2. Power production from the four plants and the total power output from the four plants in Table 1.

To estimate whether the power ramps produced by the La Ola plant is smoothed by distributing plants over the island, the team first estimated the 90th percentile values of the ramp distribution for each of the 18 months we used in he study. Those 90th percentile values were calculated for the La Ola plant itself and for all the plants in aggregate. The results are shown in Table 2.

TABLE 2: MEAN RAMP FOR AGGREGATED OUTPUT, 90TH PERCENTILE RAMP FOR LA OLA (1.25 MW) PLANT AND 90TH PERCENTILE RAMP FOR AGGREGATED OUTPUT FOR 18 MONTHS OF DATA.

YYMM	Mean KW/s Total	90 percentile KW/s La Ola	90 percentile KW/s Total
10-04	7.8	13.9	18.6
10-05	8.5	15.9	20.5
10-06	9.5	15.1	22.1
10-07	7.9	13.5	19.0
10-08	9.6	15.1	23.1
10-09	9.0	14.4	21.5
10-10	6.5	11.6	15.4
10-11	6.1	11.1	14.3
10-12	6.5	13.9	16.2
11-01	5.9	10.9	14.1
11-02	6.5	14.4	16.5
11-03	6.9	12.5	16.1
11-04	7.9	16.0	19.7
11-05	8.7	16.7	21.2
11-06	7.3	12.1	17.5
11-07	9.0	14.4	21.3
11-08	7.8	12.8	18.7
11-09	7.0	11.7	16.5

To estimate whether ramps were smoothed by aggregating the power produced by the four plants, we calculated the ratio of the 90th percentile ramps for the La Ola plant to the 90th percentile ramps total. We define this ratio as the ramp ratio. Note that La Ola is 62.5% of the total PV capacity. Therefore, if the ramp ratio is found to be higher than the 62.5% percent "capacity ratio," the aggregation produces a reduction in ramps through smoothing.

Fig. 3 shows that aggregation indeed produces a reduction in ramp rates, as the 90th percentile ramp ratio is always higher than 62.5% for all months. Some months have a higher ratio than others, the figure shows. As an example, the ramp ratio is nearly equal to the capacity ratio in the month of July and August the summer months. This indicates that aggregate ramps statistics are similar to the statistics of the individual plant. This implies that the solar resource at the various locations are correlated, which implies that the clouds are most probably stratus decks covering larger areas. On the other hand, the ramp ratio is much higher than the capacity ratio in the summer months. This implies that the summer months have more broken clouds and a low correlation between sites. Therefore, even though smoothing is a result of aggregation, all months do not have the same level of aggregation benefit.

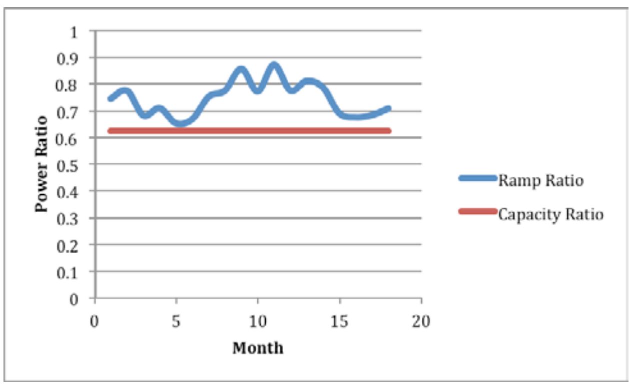

Fig. 3: 90th percentile ramp ratio of La Ola to total from Table 2 is shown in blue. The nameplate capacity ratio of La Ola to total is shown in red.

IV. Summary

Lanai is a small island, but environmental conditions over the island vary from coast to inland because of orographic effects that cause regular cloud formation in and around the island. Therefore, it is expected that there will be significant ramps in PV production that is distributed over the island. In this study, we find that small geographic separations, as seen in this case, can produce significant reduction in ramp rates, indicating that correlations decrease rapidly between locations. Even in a case in which one plant is sized to be much larger than others, significant ramp smoothing may be achieved through smaller distributed PV systems. In this case, we see that the smoothing is not uniform for all months. Winter months have large smoothing, indicating that local conditions vary significantly, even within short distances. The summer months have conditions that are more highly correlated, indicating that prevailing weather conditions cover the whole island. This finding is especially meaningful when we consider the fact that areas like Hawaii have significantly varying conditions that cause large ramping events to occur.

A well-planned distribution of PV over a small island such as Lanai can result in significant smoothing, indicating that larger smoothing can be achieved in some of the larger islands. Due to the high cost of fuel for diesel generators, the Hawaiian Islands seek to deploy renewables aggressively. This study shows that it is indeed possible to have significant deployment of solar if PV plants are properly distributed with advance planning.

While this paper shows just one example, it provides insights into how we can exploit the natural variability in resource through proper measurement, modeling and planning—especially in locations that have diversity in solar irradiance due to microclimate impacts.

V. Acknowledgements

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