DER FLEXIBLE INTERCONNECTION FRAMEWORK AND CASE STUDY

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ABSTRACT

Active power management can increase the amount of PV that a system can accommodate by reducing the output of that PV system when distribution grid conditions are unfavorable. This reduction of output is known as curtailment and will reduce the production of a solar power plant. This option may be preferable to utilities and plant developers that want to deploy systems at scales that exceed the grid's hosting capacity. Active power management and the systems that support it could be considered "non-wires" alternatives to traditional "wires" upgrades. The full suite of wires and non-wires solutions provide utilities and PV developers with flexible interconnection options. This paper focuses on quantifying the impact that various active power management control schemes have on PV production and curtailment.

INTRODUCTION

Conventional distributed energy resource (DER) interconnection analyses on the distribution system assume that DER will operate in a free-running unconstrained way – potentially producing full power at any time, according to their design and owner's discretion. In doing so, the distribution grid has a limited ability to accommodate these resources. Alternatively, if DER could be managed in a reliable way, potentially more DER could be accommodated on the grid. For example, the illustration in Figure 1 shows managed DER output at a specific location. The managed DER output is constrained within the time-varying hosting capacity (HC) limit to prevent grid violations from occurring. The result, however, is curtailment. The value of management is evident on the second day when the DER is allowed to produce at its full capacity. Without active power management as an option during interconnection, the DER size that could have been accommodated would have been significantly less. A smaller DER size would avoid curtailment on day one but would miss the opportunity for higher production on day two. The less hosting capacity varies with time, the less opportunity associated with active power management.

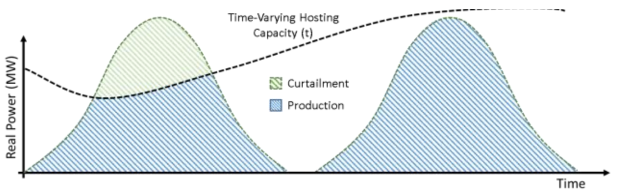

Figure 1. Example Real-Power Management Scenario

The term "Flexible Interconnection" refers to the breadth of options that are available for connecting new DER to the grid [1]. In addition to the options of limiting DER size or upgrading the grid infrastructure, larger plant sizes might be permissible at more locations through managed operation of the DER's active power. Figure 2 illustrates this idea.

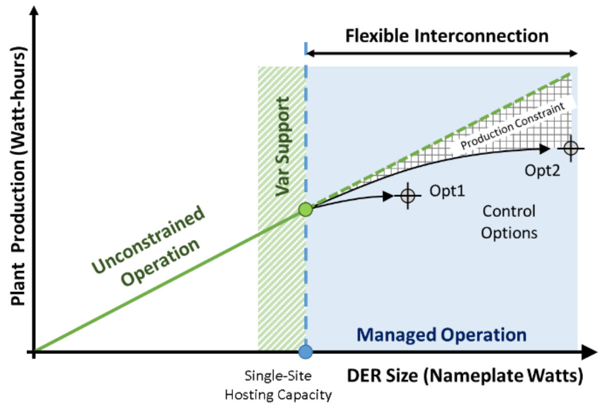

Figure 2. Illustrative Options of Active Power Management

The horizontal axis represents the scale (Watts) of a proposed plant, at a given location of interest. The vertical axis represents the productivity that might be expected from the plant, such as annual PV energy output. In the "Unconstrained Operation" area, the plant can run at its full capability, never being constrained, and no power system violations occur. Unconstrained operation is only possible up to the lowest hosting capacity for the location (vertical dashed blue line). The "Managed Operation" area considers control options that enable larger plants to interconnect without the need for immediate infrastructure upgrades, albeit with reductions in annualized plant productivity. Although energy reductions are not ideal, the opportunity to deploy a larger plant may be attractive to the entity considering the deployment. In Figure 2, the dashed green line represents the ideal plant production that would result if there were no hosting capacity limitations. As illustrated by the example control options, each possible control strategy results in a different estimated "plant productivity curve" that drops below the ideal line as the plant size is increased above the hosting capacity limit.

The difference between the ideal line and the plant productivity curve is of critical business importance to a plant developer that may have multiple locations and multiple control options to choose from. To estimate these differences involves forward-looking estimations of weather (e.g. solar irradiance), the feeder model, load profile, existing or new DER, and distribution system control specifics.

This paper focuses on a quantifying the impact that various active power management control schemes have on production and curtailment. A feeder is examined with several candidate PV locations. Control is examined for each location for four DER sizes exceeding the hosting capacity.

METHODOLGY

Active power management schemes are an option to maintain power quality and reliability when interconnected DER exceeds the hosting capacity of a particular location. To examine the technical and economic impacts of such arrangements requires modeling and simulation analysis of each management option. Since management is a scheme that is applied over a time horizon, the modeling and simulation effort must also consider analyzing the corresponding time horizon.

Although it may not be possible to forecast the impact of active power management with precision due to the breadth of potential scenarios that could occur, it is possible to compute estimates that may be sufficient for supporting developer's business decisions. The range in scenarios that could occur is not only limited to the feeder and location of DER, but also the control of the feeder and the time-based variability of load and PV output. Because of this, the methodology in this analysis is constructed to derive the possible worst-case scenarios that could occur with sensitivities around the potential influencing factors.

The methodology consists of:

- Identifying the particular feeder and PV locations of interest
- Calculating the hosting capacity and developing the time-based HC profiles for each location
- Modeling the active power management methods used in each scenario
- Calculating the impacts and benefits of active power management for a range of DER sizes

The theoretical production and curtailment of PV output for each scenario is determined by placing PV into the OpenDSS [2] time-series analysis at and above the baseline hosting capacity (fixed power limit) for each particular location.

Feeder and Proposed PV Location

The analysis begins when a feeder and location for PV is selected. This could be any location on any feeder throughout any distribution system. For this particular study, two feeders from the Phase 3 California Solar Initiative Project [3] that have potential adverse voltage and thermal impacts due to DER have been selected. The feeders are shown in Figure 3 along with arrows identifying locations where analysis was performed. These locations are not arbitrarily chosen, but selected based on prior knowledge of the feeder such that the results from the PV locations will provide a range of impacts to draw observations. The hosting capacity at the chosen locations is ultimately limited by various constraints and depends on time of day as shown in Figure 4.

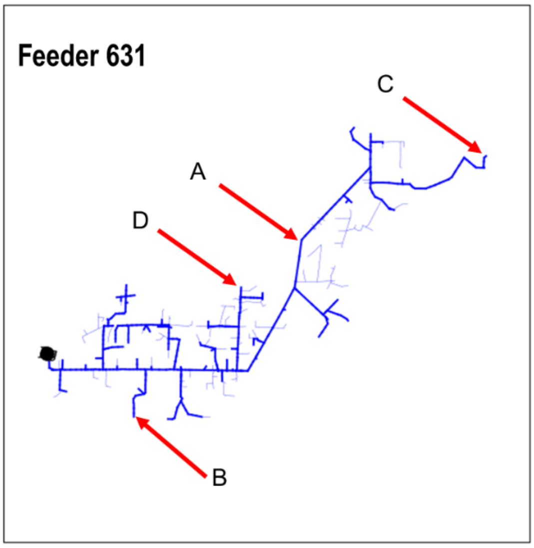

Figure 3. Feeders and PV Locations Chosen for Analysis

Hosting Capacity

Hosting capacity identifies the amount of DER that can be accommodated without infrastructure upgrades and without causing adverse issues. The hosting capacity value represents the threshold of DER deployment above which managed operation is required. As shown in Figure 4, hosting capacity is time varying as it depends on many impact factors such as load. These curves show overvoltage and thermal hosting capacity metrics but could also include additional voltage/protection metrics or could be analyzed to exclude either overvoltage or thermal. In this example, the thermal constraint dominates the overall hosting capacity for most of the period shown.

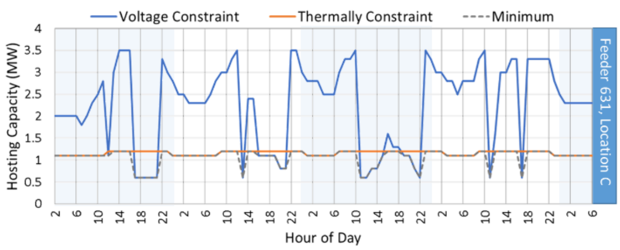

Figure 4. Example Hourly Hosting Capacity Curve

Control Methods Used

Although this project focused on active power management, it was recognized that the DER control options commonly employed by utilities include functions for both active and reactive power. To reflect this, the analysis was performed with the fixed power factor control function enabled for all DER, and set to 0.9 PF inductive, the limit defined by the IEEE 1547 standard. According to the definitions in this standard, full active power is available at 0.9 power factor, so PV systems do not need to curtail active power in relation to this setting.

The active power control methods analyzed include both autonomous and managed functions, but only managed functions are presented in this paper. The autonomous functions include volt-watt and a fixed power limit, while the managed functions examine annual, monthly, daily, and hourly dispatched active power limits.

Four managed control methods were analyzed:

- Annual active power limit: This control mode applied a single active power limit (% of nameplate) for the year. This limit was calculated to impose the minimum amount of PV constraint possible without causing violations, given that only one setting is used for the year. The power limit value is based on the lowest hosting capacity during the year at peak PV output times as illustrated in Figure 5. This is the most restrictive hosting capacity and what is commonly referenced when discussing a single value at a given location.
- Monthly active power limit: This control mode applied a tailored active power limit for each month of the year. Each limit was calculated to impose the minimum amount of constraint possible given that only one setting is used for the month. In the example of Figure 5, there were three months in which a power limit higher than the annual limit was possible.
- Daily active power limit: This control mode applied a tailored active power limit for each day of the year. Each limit was calculated to impose the minimum amount of constraint possible given that only one setting is used for each day. In the example of Figure 5, the daily variability in HC makes it possible for the average power limit (blue trace) to be substantially higher than the average monthly limit (orange trace).
- Hourly active power limit: This control mode applied a tailored active power limit for each hour. Each limit was calculated to impose the minimum amount of constraint possible for that hour. The data and analysis of this project is at hourly resolution, so for hourly management, the active power limit is adjusted for each analysis period.

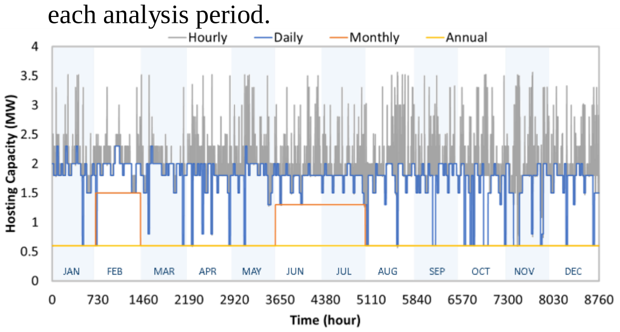

Figure 5. Example Managed Operation Schemes

The "Annual" method may be similar to a fixed, or set-and-forget, limit that is imposed at the time of plant construction as part of the agreement and rarely changed. The "Hourly" method may be similar to a real-time active power limit such as managed via an advanced DMS that adjusts the DER settings every calculation interval. Between these extremes, the "Monthly" and "Daily" methods may or may not have practical application, but are included in this study to better understand how the frequency of control calculation impacts results.

RESULTS

Analysis was performed for each location, control method, and PV size. For each, the measure of interest was the annualized production (kWh) relative to the uncurtailed case. As will be seen, results varied widely, with some scenarios having limited opportunity and others great opportunity for active power management.

The annual production loss (MWh) as a result of active power management for the two representative locations is shown in Figure 6 for a range of deployed system sizes above the baseline HC. At and below the baseline HC level there is no curtailment except in certain sensitivity analysis cases as described in [4].

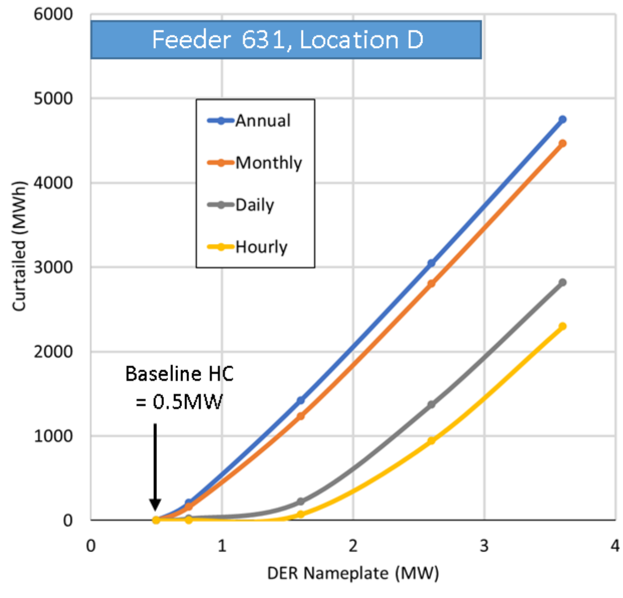

Figure 6. Annual PV Production Loss vs. DER Size

At location D on Feeder 631 (highly variable HC case), the four control methods produce significantly different outcomes, with daily and hourly control resulting in relatively little annual production loss out to ~3x the baseline HC. While curtailment losses increase as DER size exceeds the baseline HC, annual PV production also increases.

Figure 7 shows the annual production for each site and control method, along with a reference line showing the theoretical production that would result if curtailment were not required. In this view, the gap between the reference line and the production curve for a given control strategy indicates the loss, with smaller gaps implying more feasible scenarios.

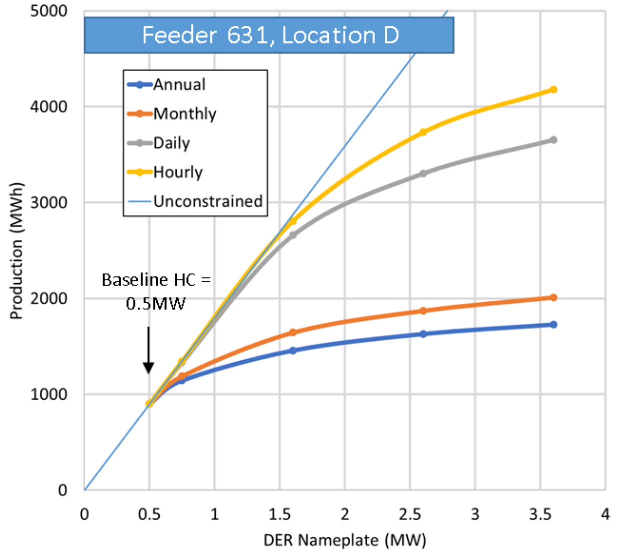

Figure 7. Annual Production (MWh) vs. DER Size

Figure 8 provides another view of the annual energy production for each scenario, with the vertical axis scaled as a percentage of uncurtailed production.

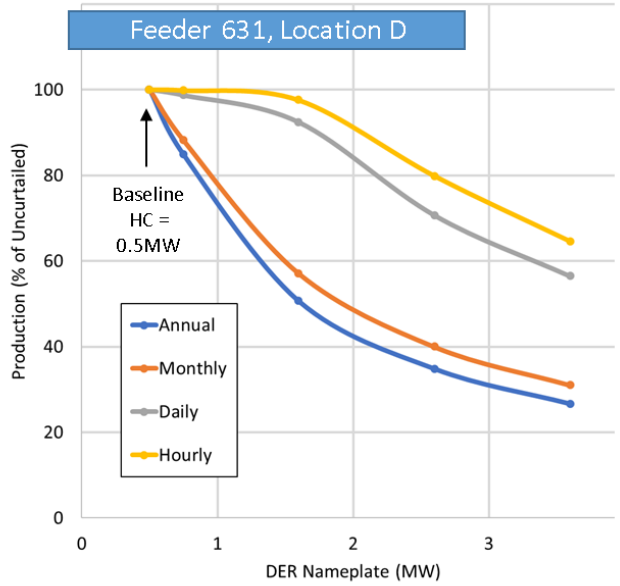

Figure 8. Annual Production (% of Uncurtailed) vs. DER Size

This view provides perhaps the clearest understanding of the situation for each site and control method. As expected, control methods that operate most often (hourly) are the best to reduce curtailment and improve production. At the Feeder 631, Location D site where variable HC exists, both hourly and daily control provide significant opportunity for larger PV plant size. For example, at 3x the baseline hosting capacity, daily control production is at 90% of uncurtailed and hourly control above 95%. For all scenarios, the level at which the production begins to drop off is dependent on the control scheme and the hosting capacity variability. This occurs because there is always an upper limit to the hosting capacity curve.

The benefit of more frequent control methods lies in their ability to more closely follow a time-varying HC curve, allowing more PV production during times when HC is higher. There are two factors that make this ability effective. First, the hosting capacity at the location must have significant variability. Second, the hosting capacity must be relatively high during the mid-day periods when high PV output is available.

For the Feeder 631, Location D scenario presented above, performance improved as the control method became more frequent. This improvement is due to by the increase in average and maximum hosting capacity setpoints as shown in Figure 9. As the control is adjusted more often, the average production over the year increases. Other locations simulated, however, did not improve as well, and some not at all. The better opportunities for applying active power management are scenarios with highly variable hosting capacity, including high capacity at times of day when solar production is high.

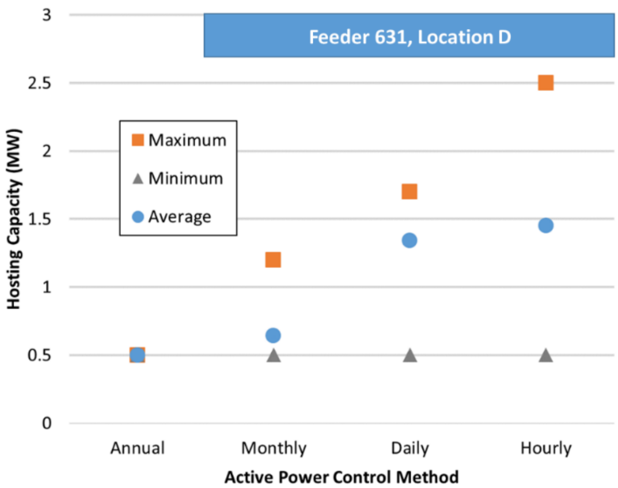

Figure 9. Annual Range in Applied Active Power Limit, by Control Method

Since the improvement using managed control is linked to hosting capacity, it is inherently related to the specific location on the feeder. Feeder 631, Locations C and D have wide ranges in time-based hosting capacity, while there is no variation in hosting capacity at Location B on the same feeder because a nearby thermal constraint is the limiting factor and remained the same for the entire year. Location A has a slight variation as its thermal constraint is relaxed as load fluctuates on the feeder.

Figure 10 compares the plant productivity for each location on Feeder 631 for the extreme control cases, annual and hourly. In these plots, data at the same location is plotted in like colors, with annual control plotted as a solid line and hourly control as a dashed line. The X-axis in the top frame is DER size in MW and is useful for seeing the difference made by control method at each site.

In the bottom frame, the X-axis is normalized. This view makes it evident that the impact of active power management is essentially the same at locations with little or no HC variability. At these locations, the result is driven by the annual load and solar profiles. As noted previously, at locations C and D where HC varies more significantly with time, the hourly control method results in good opportunity for active power management. The improvement represented with the x-axis as an increase in penetration above baseline hosting capacity shows that all scenarios, except hourly control at the PV Locations C and D, result in similar production impact.

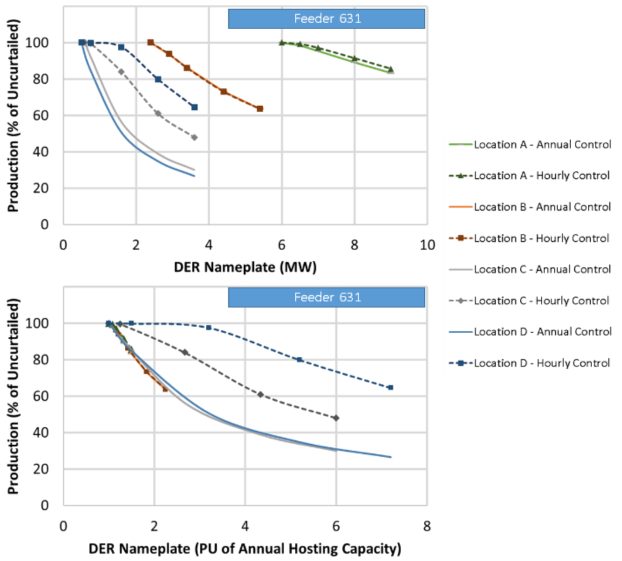

Figure 10. Production by Location for Feeder 631 Locations

CONCLUSION

Active power management can increase the amount of PV that a distribution system can accommodate by limiting the output of individual PV systems when distribution grid conditions are unfavorable. This limiting of output, or curtailment, will reduce the long-term production of a solar power plant. This option may still be favorable to PV developers that want to deploy plants that exceed the hosting capacity, accepting active power management as a "non-wires" option in lieu of traditional "wires" upgrades. The full suite of wires and non-wires solutions provide PV developers with flexible interconnection options.

Many aspects of active power management impact the production of PV systems. Several of these aspects are examined in this study such as feeder, site-specific PV location, load/PV profile, PV penetration level, and control scheme.

REFERENCES

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