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Hosting Capacity When Considering Controlled Aggregate DER

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SUMMARY

This paper describes a methodology to determine the hosting capacity for additional photovoltaic (PV) resources at a demonstration site considering the existing installation of an aggregate resource subject to various control strategies. The control strategies leverage metered and forecasted data to manage a group of distributed energy resources (DER). Metered and simulated data define the characteristics of the aggregate resource which include a mix of photovoltaic (PV), controllable load, and storage. The characteristics of the aggregate resource influence the impact on the feeder and resultant hosting capacity for a given scenario. The methodology has been implemented for a demonstration site in Pensacola, FL.

The Pensacola, FL demonstration site consists of two single-family residential buildings, each with 5 kW (AC Nameplate) rooftop PV installations and a shared 14 kW, 40 kWh battery energy storage system (BESS). Each residence also contains a controllable pool pump, water-heater, and HVAC units that are all constrained to meet a set of operating requirements. A model predictive control (MPC) strategy was developed to manage the group of DERs at the demonstration site. The goal of the control strategy is to calculate the optimal set-points for each resource to accomplish various targets. Two different control loops are used to dispatch the controllable loads at different time intervals. One loop operates on longer time scale and is used to offset the predicted gradual PV variation; another loop is used minimize the rapid fluctuations in the PV power production that occur on a short time scale. The combination of the two control loops effectively forms the local controller.

The hosting capacity for additional PV resources is calculated at the feeder-level and for the demonstration site for over-voltage, and voltage deviation issues. The analysis considers two characteristics for the aggregate resource: the percent output change influencing over-voltage and issues, and the percent output change influencing voltage deviation issues. The feeder's loading, and the size and location of existing DERs influence the ability to accommodate additional DER due to thermal issues, however, it is assumed that the feeder loading and existing DER size do not change under various control schemes.

Measured data is available at 1-second intervals for the Pensacola, FL demonstration site; this data includes the PV production (kW-AC), the demand of each of the controllable loads (kW-AC), and the total net power demand from each house. Data for the net loading on the transformer that serves the demonstration site is also available at 1-second intervals, which includes the two residences in the

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demonstration site, the shared storage system, as well as two additional residences not effected by the local controller.

The hosting capacity for a group of DERs is defined by the cumulative impacts of all resources in the group. To address the impact of the aggregate DER under various control schemes, simulated data is produced to reflect the response of the aggregate DER to the control schemes. The characteristics of the simulated aggregate DER response are then used to determine the aggregate DER hosting capacity of each local controller scheme.

KEYWORDS

Hosting Capacity Analysis
Aggregate Distributed Energy Resource
Model Predictive Control
Local Controller

A distribution feeder's ability to accommodate DER is influenced by the physical characteristics of the feeder, the loading on the feeder, and the existing DER on the feeder. Hosting capacity is the amount of DER that can be accommodated without adversely impacting power quality or reliability with the current configuration and infrastructure. The baseline hosting capacity is static when considering fixed topology, equipment, and power demand, while the remaining hosting capacity is effected by the size, type, and location of existing DER installations on the feeder.

The procedure to determine the remaining hosting capacity when considering separate co-located heterogeneous DER installations has been established [1], however, the impact of heterogeneous resources under common control, or aggregate DER, requires further investigation. It is thought that aggregate DER can mitigate the impacts associated with PV installations on the feeder depending on the type of control strategy implemented [2]. This paper describes a methodology for determining the remaining hosting capacity on a distribution feeder when aggregate DER installations are present.

A demonstration site in Pensacola, Florida is used to examine the effect of various control strategies for aggregate DER on the feeder hosting capacity. Connected to a 12.47 kV distribution feeder, the demonstration site consists of two single-family residential buildings with aggregate DER installation. There are two additional single-family residential buildings that share a service transformer with the demonstration site, but that do not contain aggregate DER and are unaffected by any outside control.

The distribution feeder hosting the demonstration site is operated by Gulf Power Company and delivers 11.4 MW at peak loading and 4 MW during peak PV production hours, which is considered to be the minimum loading of interest. There are five rooftop PV installations of the feeder, not including the demonstration site, with a combined nameplate capacity of 22.1 kW. A model of the distribution feeder was converted from CYME into OpenDSS, and contains the primary conductors, capacitor banks, switches, voltage regulators, service transformers, and service conductors. The OpenDSS model was validated against the CYME model to ensure that the conversion process was not a source of error in the distribution feeder model. A schematic of the distribution feeder model is shown in Figure 1.

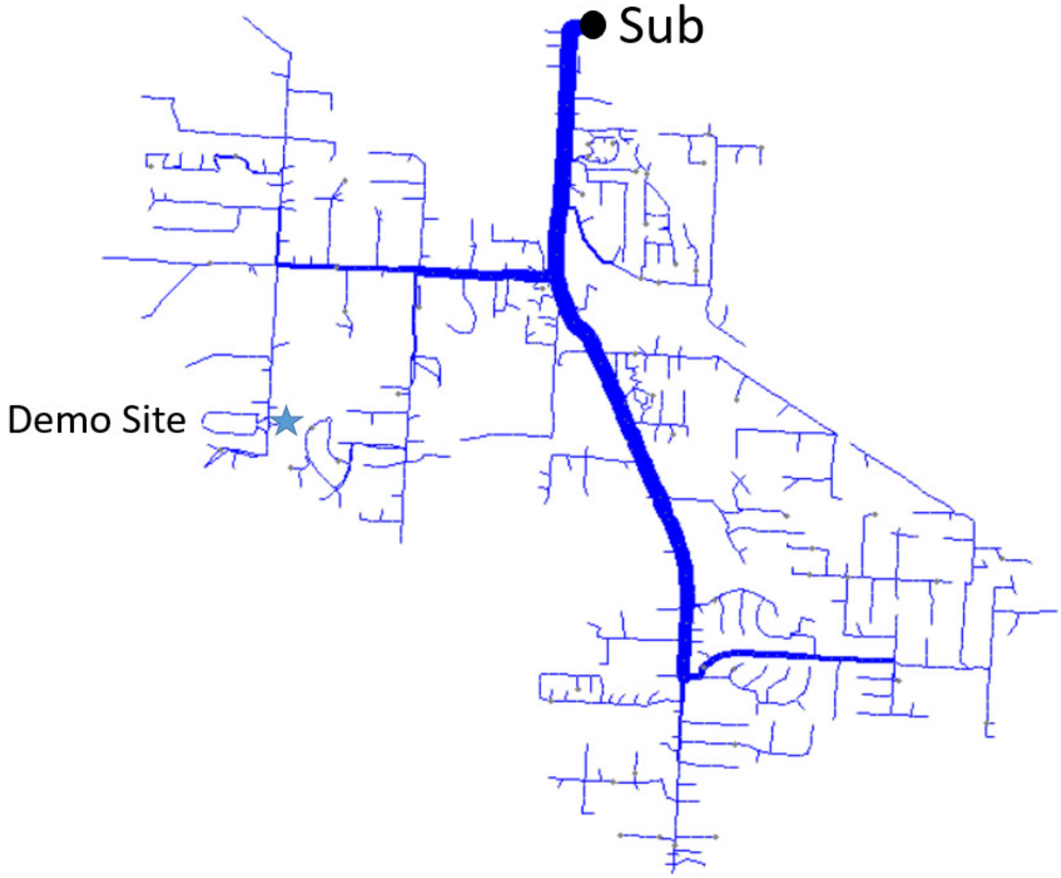

Figure 1 The feeder schematic

The aggregate DER at the demonstration site includes both generation and load based resources. The power generating resources consist of rooftop PV, while the load based resources are the controllable loads subject to commands from a controller; the BESS is considered to be both a generation source and load sink. Each PV system has a nameplate rating of 5 kW-AC, and the BESS has a rating of 14 kW-AC, 40 kWh. The controllable loads at each house are HVAC compressor and evaporator (outdoor unit), HVAC air handler (indoor unit), water heater, and pool pump.

The size of each of the controllable loads was characterized by the measurement data collected from the demonstration site. The 1-second interval data is sufficient for capturing the quasi-static-time-series (QSTS) behavior of each of the loads, but does not adequately capture the transient behavior. The measured data was analyzed to determine a nameplate size for each of the controllable loads based on the maximum QSTS demand. The results of the data analysis showing the size of each of the controllable loads is shown in Table 1. Note that every resource except for the water heater has the same size in each of the two homes.

Table 1

Resource	Size in Home 1 (kW)	Size in Home 2 (kW)	Total Size (kW)
Pool Pump	1.125*	1.125	2.25
HVAC Outdoor Unit	3	3	6

HVAC Indoor Unit	0.5	0.5	1
Water Heater	4.5	5	9.5
Total	**9.125**	**9.625**	**18.75**

*Measurement data from the pool pump in Home 1 was insufficient to determine the nameplate rating. Data from the pool pump in Home 2 was substituted for the purpose of this analysis.

A model predictive control (MPC) strategy was developed to manage the group of DERs at the demonstration site. The MPC calculates the optimal set-points for each resource to accomplish various targets. A model of each resource is used by the MPC to create a baseline behavior for the aggregate DER. The models use previous load data as well as forecasted temperature data to simulate the uncontrolled behavior of the individual loads. Two different control loops are used to dispatch the controllable loads at different time intervals. One loop operates on longer time scale and is used to offset the predicted gradual PV variation; another loop is used minimize the rapid fluctuations in the PV power production that occur on a short time scale. The combination of the two control loops within the MPC effectively forms the local controller.

The local controller is intended to send commands to individual components of the aggregate DER in order to accomplish both local objectives and system level constraints sent from a central or system controller. The communication between the local controller and the loads is not physically implemented at the demonstration site, but a simulated response of the controllable loads is available. For this paper the response of the demonstration site was simulated under three distinct control scenarios in which the local controller does not enforce any system-level constraints, but solely optimizes the DER assets to pursue local objectives, such as minimizing energy costs, maximizing the life of the BESS, etc. The simulated data was analyzed to determine the impact of the local controller on the remaining PV hosting capacity.

In the first scenario (SC0) the controller does not act on any of the resources, and the controllable loads and BESS follows the behavior described in the MPC models. In the second scenario (SC1) the local controller acts on the controllable loads, but not the BESS. In the third scenario (SC2) the local controller acts on both the controllable loads and the BESS. The PV systems are simulated with measured data for all three control scenarios. Each control scenario was simulated for 243 days at 1-second intervals to encompass a large variety of loading and PV generation combinations. Figure 2 shows the simulated response of the aggregate DER to the three control scenarios for a single day in the data set. The aggregate DER includes the controllable loads and PV at each house, as well as the BESS.

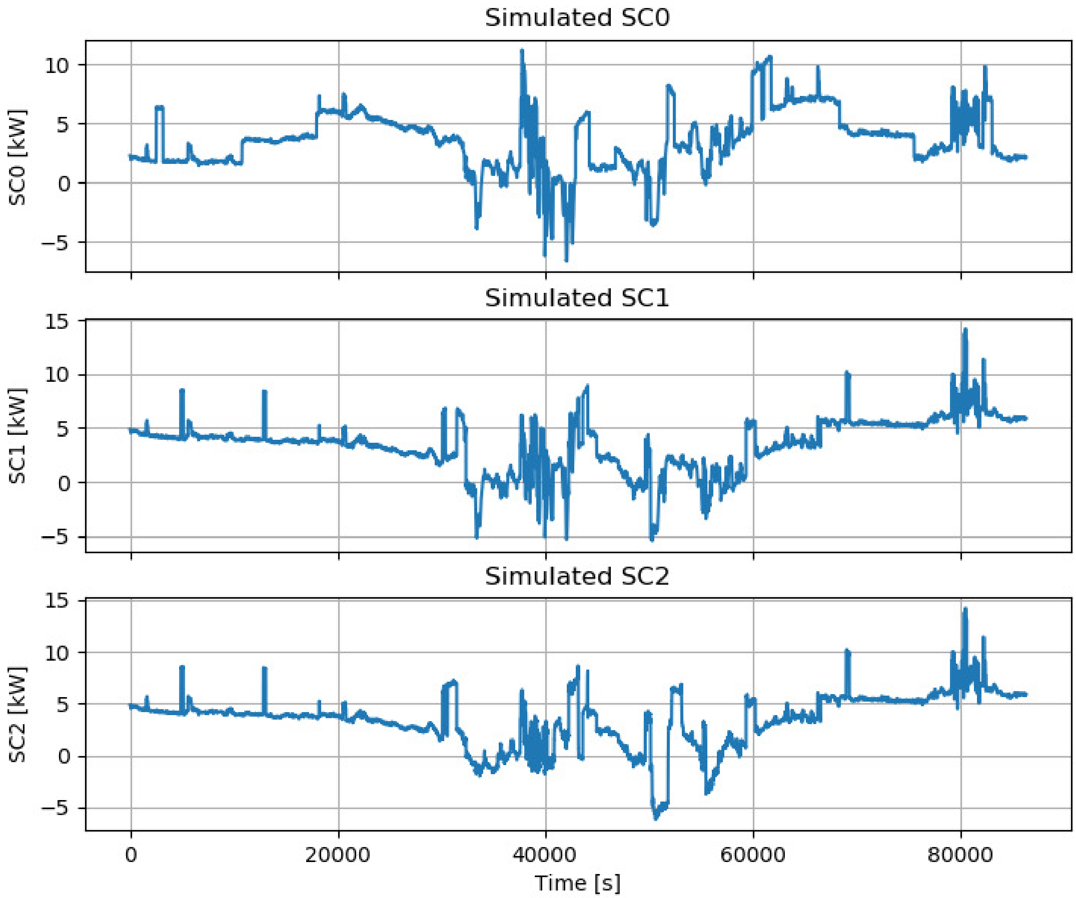

Figure 2 Simulated response of the aggregate DER to three control scenarios

The simulated data was analyzed to determine the pertinent characteristics describing the aggregate DER. The characteristics of the aggregate DER directly affect the remaining hosting capacity of the distribution feeder as well as the remaining hosting capacity of the demonstration site. For this analysis the hosting capacity was analyzed to determine the ability of the feeder to accommodate additional PV installations, however, alternative additional DER, including aggregate DERs, could be considered as well. EPRI's Distribution Resource Integration and Value Estimation (DRIVE) tool [1] was used to determine the remaining hosting capacity for PV on the feeder based on the characteristics of the aggregate DER.

The DRIVE tool calculates hosting capacity based on voltage, thermal, protection, and configuration metrics. The tool considers three characteristics of existing DER that impact hosting capacity metrics: the size of the DER, the location of the DER, and the type of DER. The size and location of the DER affect all hosting capacity metrics, while characteristics defining the type of DER impact certain subsets of the hosting capacity metrics. For the remaining PV hosting capacity the relevant voltage metrics are over-voltage issues and voltage deviation issues. Thermal and protection metrics are also relevant to PV hosting capacity, however those issues are primarily affected by the size of existing DER, which is fixed for the purpose of this analysis. The default thresholds for each metric considered are presented in Table 5.

The DER type characteristics that are impacted by the local controller, and therefore considered for the remaining PV hosting capacity analysis, are the percent output change influencing over-voltage and issues, and the percent output change influencing voltage deviation issues. The per-unit fault contribution of the DER impacts protection issues, however the fault contribution of the DER is not affected by the controller, and not considered in the analysis.

The DRIVE tool considers load based resources and generation based resources separately. The aggregate DER contains both load and generation resources, and the characteristics of each of those subsets of resources are unique. For this reason, the simulated data was analyzed to determine the characteristics for loading and generating separately. The size of the load resources is defined as the sum of the nameplates of the controllable loads and the BESS, while the size of the generation resources is defined as the sum of the nameplates of the PV and the BESS. Table 2 shows the size of the load resources and the size of the generation resources.

Table 2 The size of the load and generation resources

	Load Resources (Controllable Load + BESS)	Generation Resources (PV + BESS)
Resource Size	18.75 kW	24 kW

The positive (load) percent output change influencing over-voltage issues was determined by the maximum simulated load divided by the size of the load resources. The positive (load) percent output change influencing voltage deviation issues was determined by the maximum positive variation in a 5-minute moving window divided by the size of the load resources. Table 3 shows, for each control scenario, the maximum simulated loading, the maximum simulated loading variability, the percent output change influencing over-voltage issues, and the percent output change influencing voltage deviation issues.

Table 3 Load based resource characteristics

Load Resource Characteristics	SC0 (No Control)	SC1 (Control of Loads)	SC2 (Control of Loads and BESS)
Maximum Load	18.764 kW	17.751 kW	17.752 kW
Maximum Load Variability	16.741 kW	14.013 kW	17.480 kW
% Output Change for Over-Voltage	57.294%	54.200%	54.203%
% Output Change for Voltage Deviation	51.119%	42.787%	53.374%

Figure 3 shows the simulated response of the aggregate resource on the days resulting in the maximum load based resource variability.

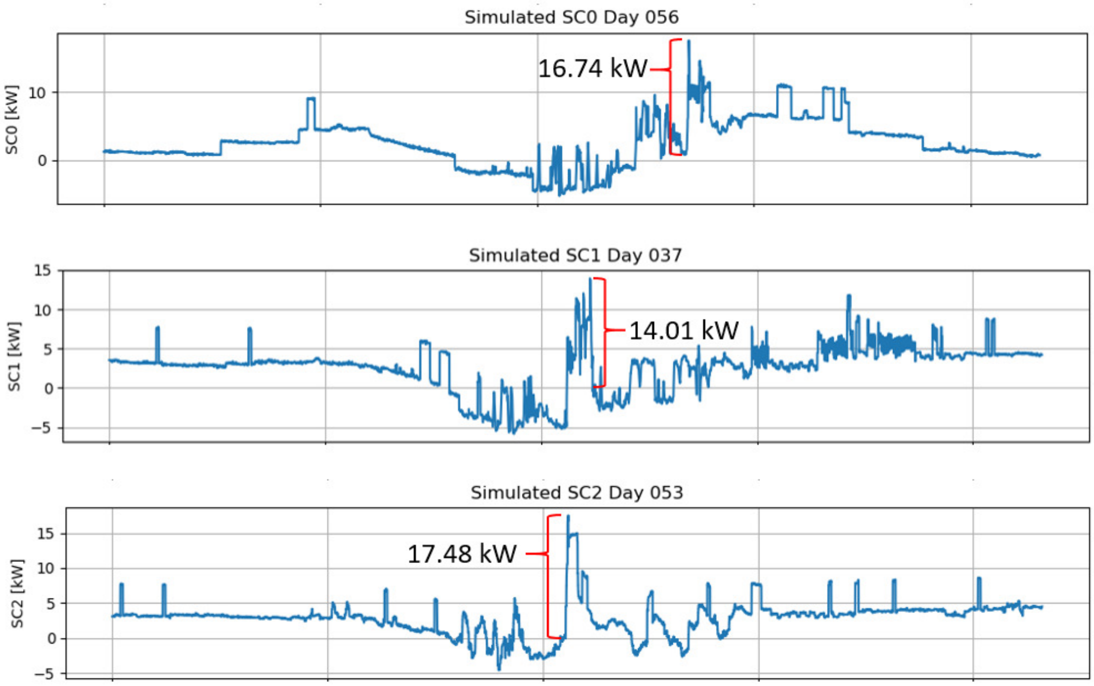

Figure 3 The maximum load based resource variation

The negative (generation) percent output change influencing over-voltage issues was determined by the maximum simulated generation (negative load) divided by the size of the generation resources. The negative (generation) percent output change influencing voltage-deviation issues was determined by the maximum negative variation in a 5-minute moving window divided by the size of the generation resources. Table 4 shows, for each control scenario, the maximum simulated generation, the maximum simulated generation variability, the percent output change influencing over-voltage issues, and the percent output change influencing voltage deviation issues.

Table 4 Generation based resource characteristics

Generation Resource Characteristics	SC0 (No Control)	SC1 (Control of Loads)	SC2 (Control of Loads and BESS)
Maximum Generation	11.028 kW	10.108 kW	11.792 kW
Maximum Generation Variability	10.505 kW	9.312 kW	11.685 kW
% Output Change for Over-Voltage	45.952%	42.115%	49.132%
% Output Change for Voltage Deviation	43.770%	38.800%	48.687%

Figure 4 shows the simulated response of the aggregate resource on the days resulting in the maximum generation based resource variability.

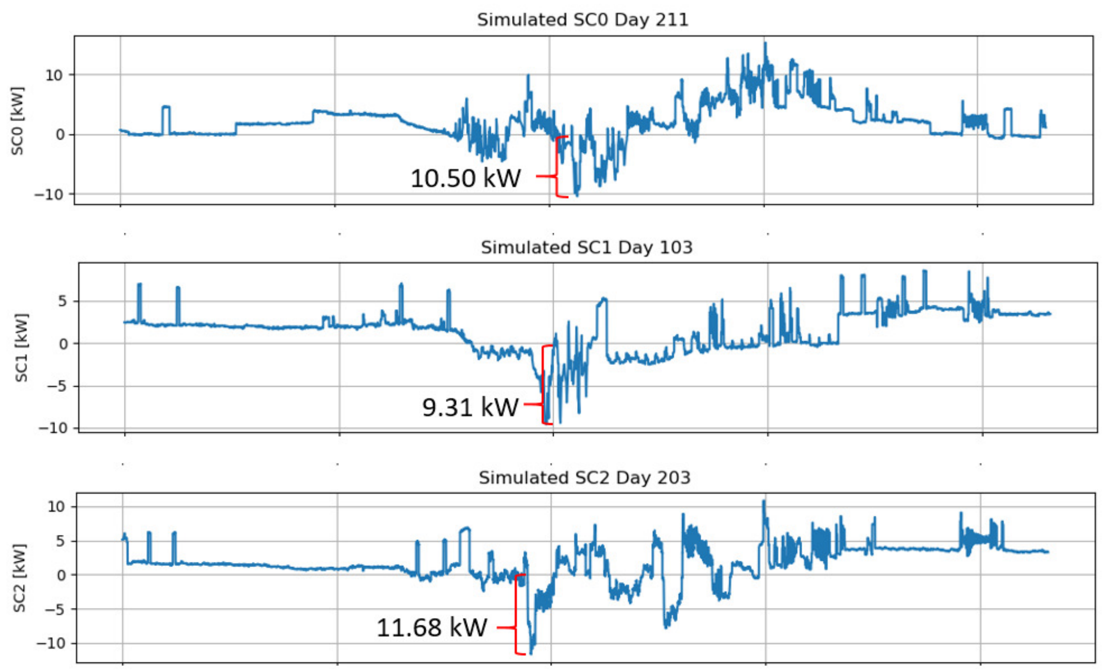

Figure 4 The maximum generation based resource variation

The remaining hosting capacity for additional PV resources was analyzed with the DRIVE tool for each scenario using the characteristics in Tables 3 and 4. The feeder level hosting capacity was analyzed with a model containing only primary conductors with loads modeled on the medium voltage (MV) side of the service transformers. The site specific hosting capacity was analyzed with a model containing all primary and secondary conductors with the loads at the service point on the end of the low-voltage secondary conductors. The difference between the two analyses highlights the effect of the impedance of secondary conductors and transformers on the remaining hosting capacity [3]. Because the aggregate DER is small relative to the total load on the feeder, a DER penetration interval of 0.001 MW was used to capture the effect of the local controller on the remaining PV hosting capacity. Similarly, a maximum DER penetration of 4 MW was used, which is significantly large enough to capture the remaining PV hosting capacity without reaching the maximum penetration.

To capture the differences realized from the high impedance secondary conductors the aggregate DER was split between each of the homes in the demonstration site. Although there is a slight difference in the size of the controllable loads due to the different sizes of the water heaters, the aggregate DER was evenly split between the two homes because the simulated data does not contain the response of individual resources. For the feeder level hosting capacity analysis, the entire aggregate DER was modeled at the MV side of the service transformer.

The results of the hosting capacity analyses are shown Table 5. The primary issues are measured at the MV side of the service transformer serving the demonstration site, while the secondary issues are measured at the most limited locations on the demonstration site secondary network, which are the individual conductors serving the homes at the demonstration site.

Table 5 The remaining hosting capacity for additional PV resources at the demonstration site

Scenario	**SC0**	**SC1**	**SC2**
Primary Overvoltage	0.2310 MW	0.2313 MW	0.2310 MW

Primary Voltage Deviation	0.8437 MW	0.8440 MW	0.8433 MW
Primary Regulator Voltage Deviation	1.2557 MW	1.2576 MW	1.2543 MW
Secondary Overvoltage	0.0173 MW	0.0173 MW	0.0170 MW
Secondary Voltage Deviation	0.0980 MW	0.0983 MW	0.0977 MW

The results presented in Table 5 show that the effect of the local controller on the aggregate DER does impact the remaining PV hosting capacity. Due to the small size of the aggregate DER relative to the feeder loading and the small changes in aggregate DER characteristics seen in Tables 3 and 4, it is not surprising that the impact of the local controller is also small. The scenario represented in SC1, when the local controller only acts on the controllable loads, shows slight decreases in both the load and generation base resources' characteristics influencing over-voltage and voltage deviation issues. These slight decreases result in increased remaining hosting capacity for most issues when compared to SC0. The scenario represented in SC2, in which the local controller acts on both the controllable loads and the BESS, shows slight increases in both the load and generation based resources' characteristics influencing over-voltage and voltage deviation. These slight increases result in decreased remaining hosting capacity when compared to SC0.

The work described in this paper is focused on a unique local controller at an existing demonstration site, but is applicable to a wide variety of aggregate DER, control scenarios, and distribution feeders. These results show that the methodology presented for determining the remaining hosting capacity when considering aggregate DER is practical. The results suggest that a greater change in hosting capacity may become more apparent with larger differences in the aggregate DER characteristics under various control scenarios, with larger aggregate DER size, or at different locations on a distribution feeder. Future work in this area will include studying additional scenarios where the local controller is provided with constraints on active power imports/exports that aim to increase the remaining PV hosting capacity. These constraints will be developed to address the factors limiting the hosting capacity at the demonstration site.

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