Market Trends That Will Drive the Next Evolution of Operational Load Forecasting Models: The Operational Forecasting Challenges of Virtual Power Plants

Grid operators schedule and dispatch generation resources to meet demand in as cost-effective manner as possible. In a perfect world, the least costly solution would be to schedule and dispatch generation where the supply stack of generation exactly crosses the demand curve. With perfect foresight, generation would exactly offset demand. Because grid operators do not have perfect foresight of demand and there is always the possibility that a failure will occur somewhere within the electric grid, operators schedule an excess level of generation in the form of spinning reserves. This type of risk-adverse scheduling is common practice throughout the industry. In fact, most grid operators are held to a regulatory-prescribed minimum operating reserve margin. These operating reserve margins are accepted as a reasonably societal cost for avoiding generation shortages.

Growth of Grid-Connected Renewable Generation. In the 2000's, these operating guidelines were tested with the growing penetration of grid-connected solar and wind generation. Traditional generation resources such as nuclear power, gas-fired, oil-fired, and coal-fired generation provided reliable generation output and ramping capability. The only uncertainty associated with traditional generation resources was an unplanned outage. In contrast, solar and wind generation output is subject to meteorological events that are hard to forecast. As a result, the growing penetration of solar and wind generation led to an ever-widening of the reserve margin carried by grid operators.

To ease the pressure on carrying a higher reserve margin, grid operators invested in short-term forecasts of grid-connected solar and wind generation. In most cases, the forecasts were sourced by third-party vendors that specialized in the meteorological modeling that drives the irradiance and wind speed forecasts at the heart of the generation forecasts. While the forecast performance of these third-party forecasts is strong, recent changes to energy market designs provide renewable generation resource owners the option to submit their own generation forecasts for the grid operator to work against. With the correct market signals, it is expected that the individual resource owners are incented to be as accurate as possible.

Deep Penetration of Rooftop Solar PV. Starting in the mid-2000's, what grid operators measured as demand for electricity services became more uncertain with the mass adoption of solar photovoltaics (PV). On-premise solar PV generation leads to a gap between the demand for electricity services and what is measured as electricity consumption. Further, the volatility of solar PV generation translates directly into increased measured load volatility. As a result, the accuracy of most operational load forecast models that relied on measured load started to degrade as more and more households and businesses installed solar PV. The net result is grid operators are facing added pressure to increase the reserve margin to cover a growing load forecast error.

Prior to 2017, most solar PV installations were not paired with battery storage, nor were they necessarily tied to traditional demand response program participation or time-of-use rates. Further, there was little to no market mechanism for sharing excess generation across households and businesses. Instead, any excess generation simply flowed into the grid. As a result, the operational forecasting problem focused on how to incorporate forecasts of on-premise solar PV generation into the load forecast. Several solutions have been explored as part of a study funded by the California Energy Commission[1]. The solutions identified by the California Energy Commission study have been implemented by the independent system operators in Australia and North America—all of which faced the same degradation of forecast performance arising from the penetration of solar PV.

The Rise of On-Premise Battery Storage. From an operational load forecasting perspective, a potential game changer is the mass deployment of battery storage which further masks, from the perspective of the grid operator, demand for electricity services. To help fix ideas, consider the demand for electricity services for a residential home on a typical spring day with no space heating or space cooling activity. The following cases walk through a series of stylized examples of how measurements of load could be impacted by the introduction of controllable DER technologies.

- In the first case, no solar PV or storage installed. In this case, the demand for electricity services is completely met by electricity pulled from the grid (i.e., demand for electricity services equals measured load). This is the situation presented in Figure 1.
- In the second case, solar PV has been installed. In this case, measured load is the demand for electricity services less generation from the installed solar PV panels. This is the gap grid operators started to experience starting in the late 2000s. This is the situation presented in Figure 2. If the operational load forecast model was developed using measured load data prior to the installation of the solar PV, the forecast would over forecast loads during the daylight hours.
- Case three is the same as case two, but because of a thick cloud cover the output of the solar PV panels is reduced. In this case, the demand for electricity services is partially met by the solar PV generation, but more power is required from the grid to cover the short fall. This is the situation presented in Figure 3.
- In the fourth case, on-site storage is introduced. In this case, the storage utilization strategy is to charge the battery with the electricity generated by the solar PV panels. The stored power is then used to offset the evening hours demand for electricity services. This is the situation presented in Figure 4. In this case, the operation load forecast model that was developed using measured load data prior to the installation of the solar PV and storage will over forecast the evening hours load.

1 See the California Energy Commission, CEC-EPC-14-001, *Improving Short-Term Load Forecasts by Incorporating Solar PV Generation*, September 2016 for solutions to improve load forecast performance in the face of wide spread penetration of solar PV.

- The fifth case is the same as case four, but like case three a thick cloud cover reduced the battery charging levels and as a result some of the evening load is met by pulling power from the grid. This is the situation presented in Figure 5. In this simple case, the volatility of the solar PV generation is mirrored in the evening hours due to the varying levels of charging.

Finally, we depict in Figure 6 what the grid operator sees in the control room for each of the five cases. This figure illustrates why the operational load forecasting problem must evolve from a forecast of the demand for electricity services to include a forecast of solar PV generation and battery utilization strategies.

The fact that solar PV and storage has been installed does not necessarily mean the resulting measured load cannot be accurately forecasted. If the solar PV and storage profiles followed predictable patterns an accurate operational load forecasts are still possible. The challenge arises when DER technologies do not follow predictable patterns.

Virtual Power Plants. Today, Virtual Power Plants (VPP) represent another wrinkle to operational load forecasting. The most visible of these is the partnership between South Australia and Tesla that will lead to the world's largest deployment of residential solar + storage[2]. VPPs introduce a centrally dispatched "market" for sharing excess generation across participating households and businesses. A VPP can leverage all elements of the available DER portfolio including on-premise generation, demand response, and battery storage (potentially in the form of stand-alone batteries and electric vehicle batteries) to balance loads not only across the "market" participants, but also across hours of the day. Any excess energy that is not required by the "market" participants is automatically dispatched to the grid.

The distinguishing feature of a VPP is that a decision rule dispatches the utilization of the available DER technologies across market participants. Widespread installation of solar PV systems does not in itself form a VPP because weather conditions and not a decision rule govern when the generated electricity is "dispatched". The examples presented above where batteries are used to "dispatch" power in the evening hours is a form of a VPP, albeit with a single market participant.

From an operational load forecasting perspective this means the load forecast models need to account for the following three intermingled activities:

1. Calendar and weather conditions that drive the demand for electricity services,
2. Weather conditions that drive solar PV and other weather driven distributed generation, and
3. VPP DER dispatch strategies that spread power across market participants and across hours of the day.

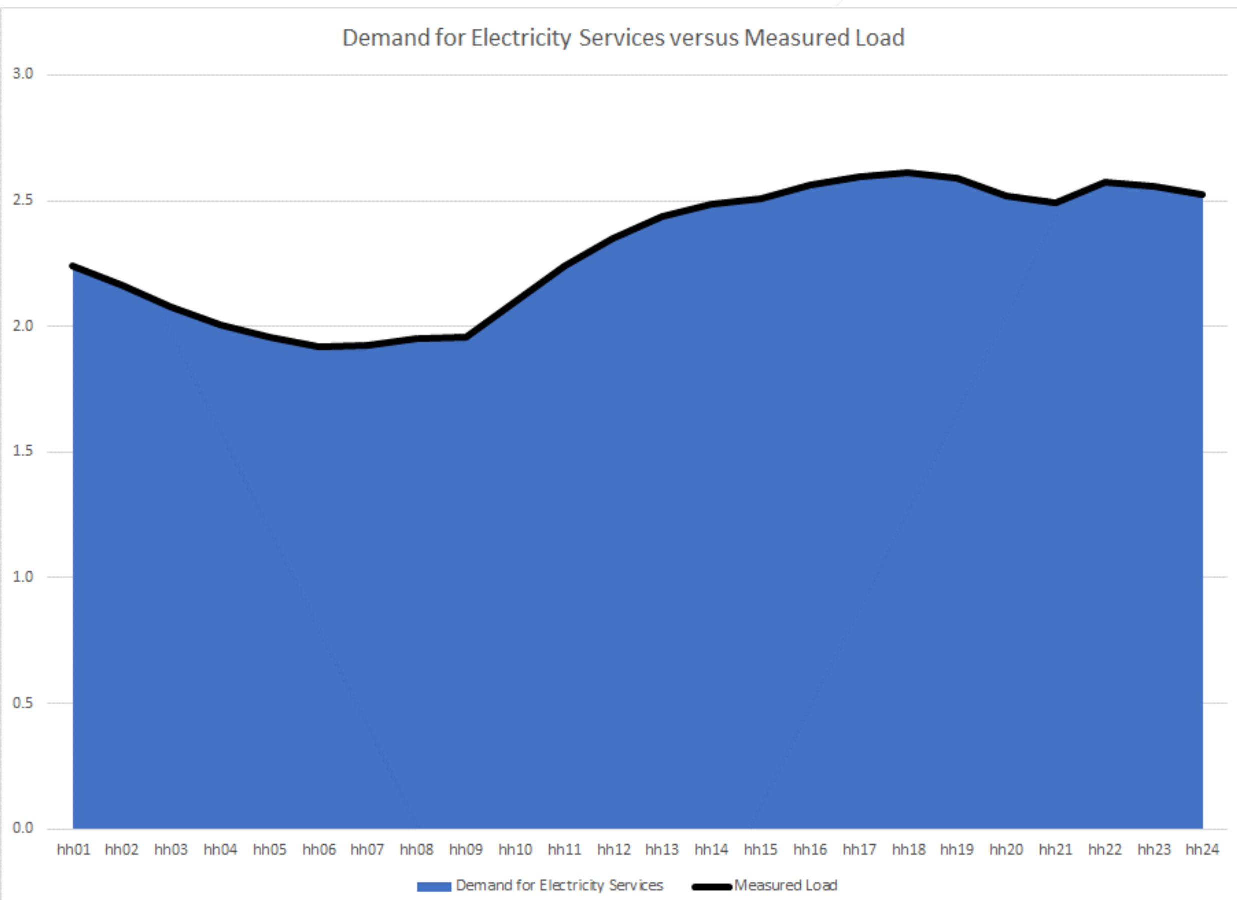
Activity one has been addressed by operational load forecast models that are designed to forecast the demand for electricity services based on well understood knowledge of how electricity is consumed.

[2] See the PV Magazine article of February 5, 2018 https://www.pv-magazine.com/2018/02/05/south-australia-tesla-partner-for-800-million-virtual-power-plant/

Activity two has been addressed over the past three to five years by the AEMO and most of the North American system operators facing significant solar PV penetrations.

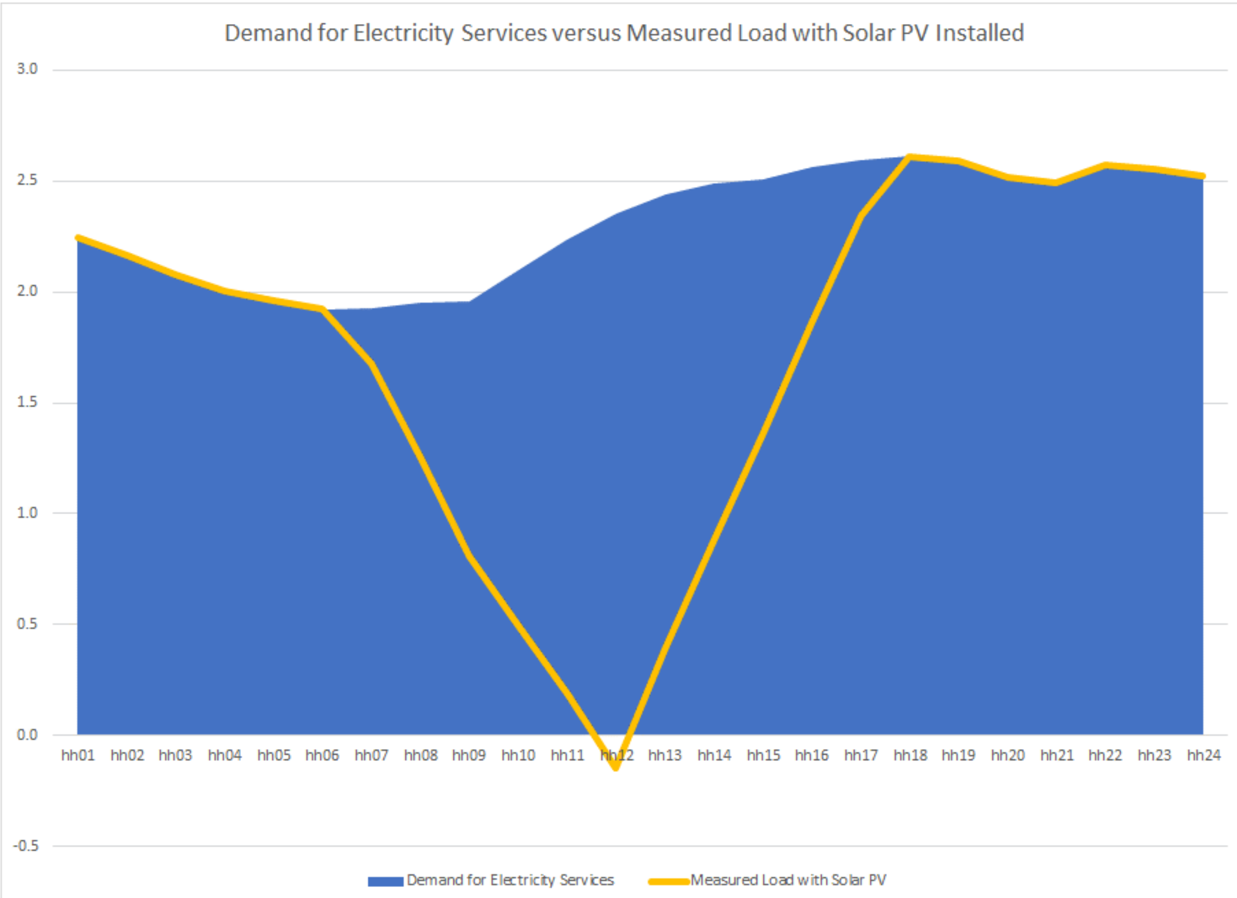
The new frontier of operational load forecasting is how to address the load impact of VPP DER activity. In cases where the VPP DER activity results in measured loads that follow predictable patterns traditional load forecasting tools can be utilized. The set of explanatory variables might have to change to capture the patterns exhibited by the VPP DER activity, but the basic statistical tools should still perform well. In cases where the VPP DER activity results in measured loads that do not follow predictable patterns traditional load forecasting tools may need to be replaced with other tools or algorithms. In this case, until a workable load forecast can be developed grid operators will feel the pressure to raise spinning reserve margins.

FIGURE 1. DEMAND FOR ELECTRICITY SERVICES VERSUS MEASURED LOAD



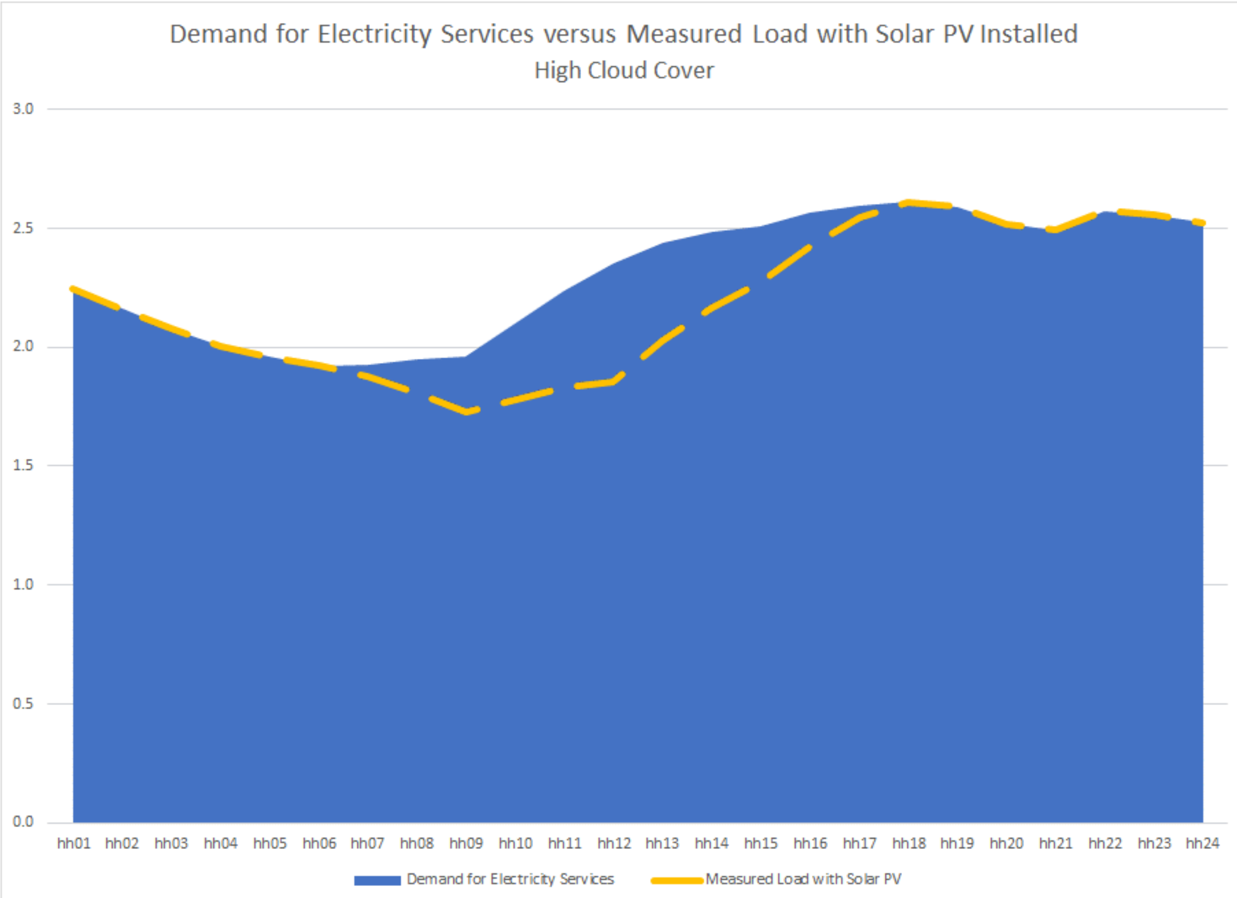
In Figure 1, the demand for electricity services is represented by the Blue shaded area. Measured load, which is what the grid operator sees, is represented by the Black line. In this case, demand for electricity services equals measured load.

FIGURE 2. DEMAND FOR ELECTRICITY SERVICES VERSUS MEASURED LOAD WITH SOLAR PV INSTALLED



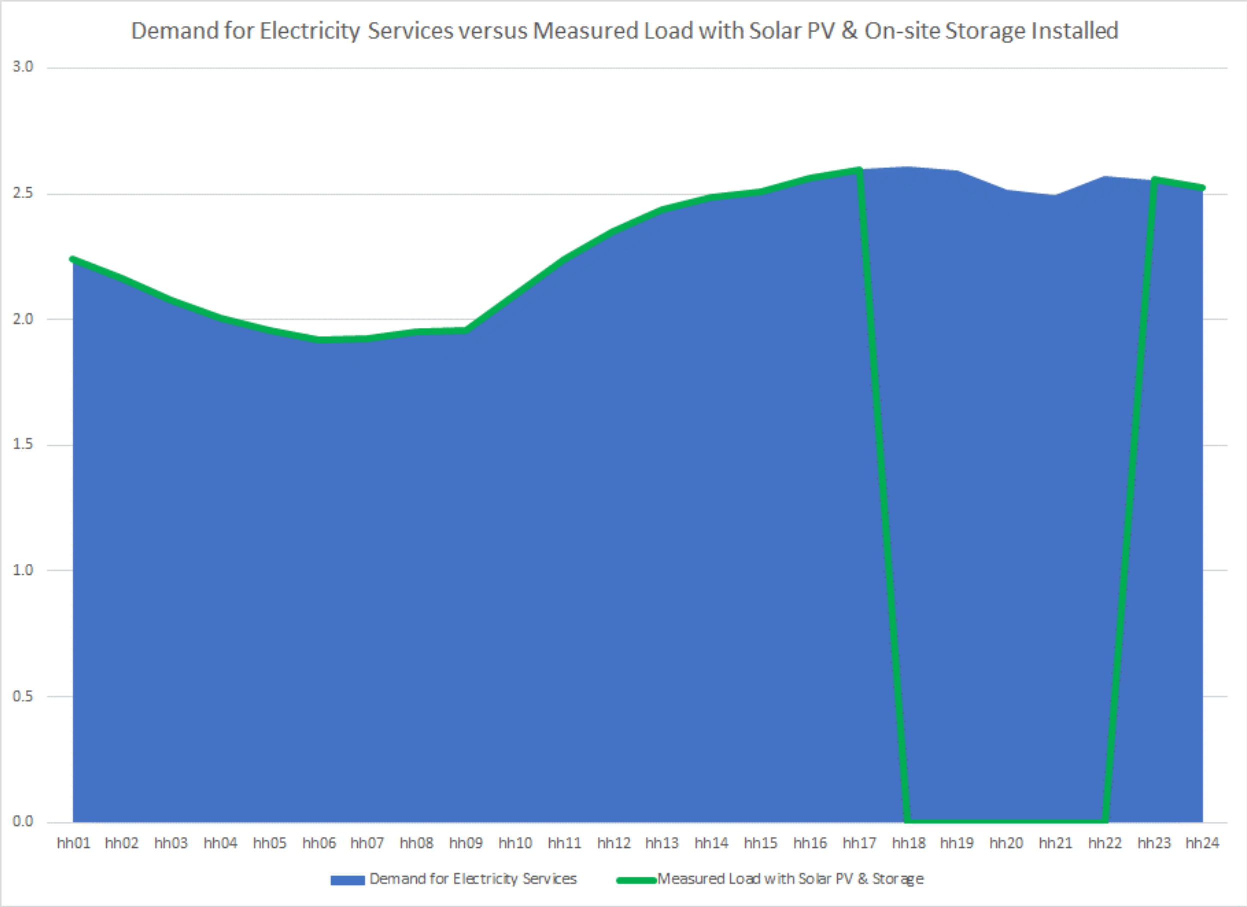
In Figure 2, the demand for electricity services is represented by the Blue shaded area. Measured load, which is demand or electricity services less solar PV generation, is represented by the Gold line. In this case, demand for electricity services does not equal measured load.

FIGURE 3. DEMAND FOR ELECTRICITY SERVICES VERSUS MEASURED LOAD WITH SOLAR PV HIGH CLOUD COVER



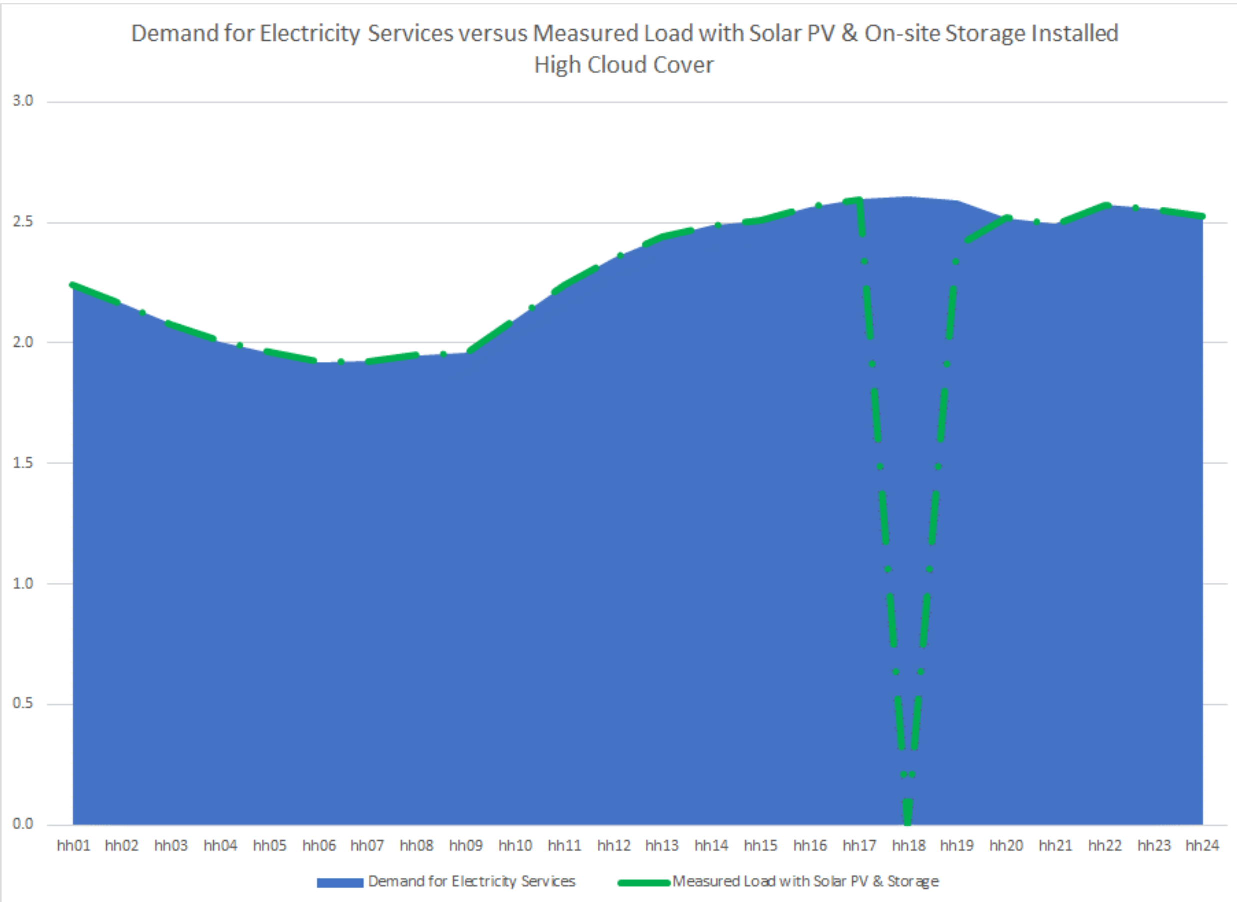
In Figure 3, the demand for electricity services is represented by the Blue shaded area. Measured load, which is demand or electricity services less solar PV generation, is represented by the Gold Dashed line. In this case, high cloud cover reduces solar PV generation which requires more power is drawn from the grid. The result is the demand for electricity services is closer to measured load.

FIGURE 4. DEMAND FOR ELECTRICITY SERVICES VERSUS MEASURED LOAD WITH SOLAR PV & STORAGE INSTALLED



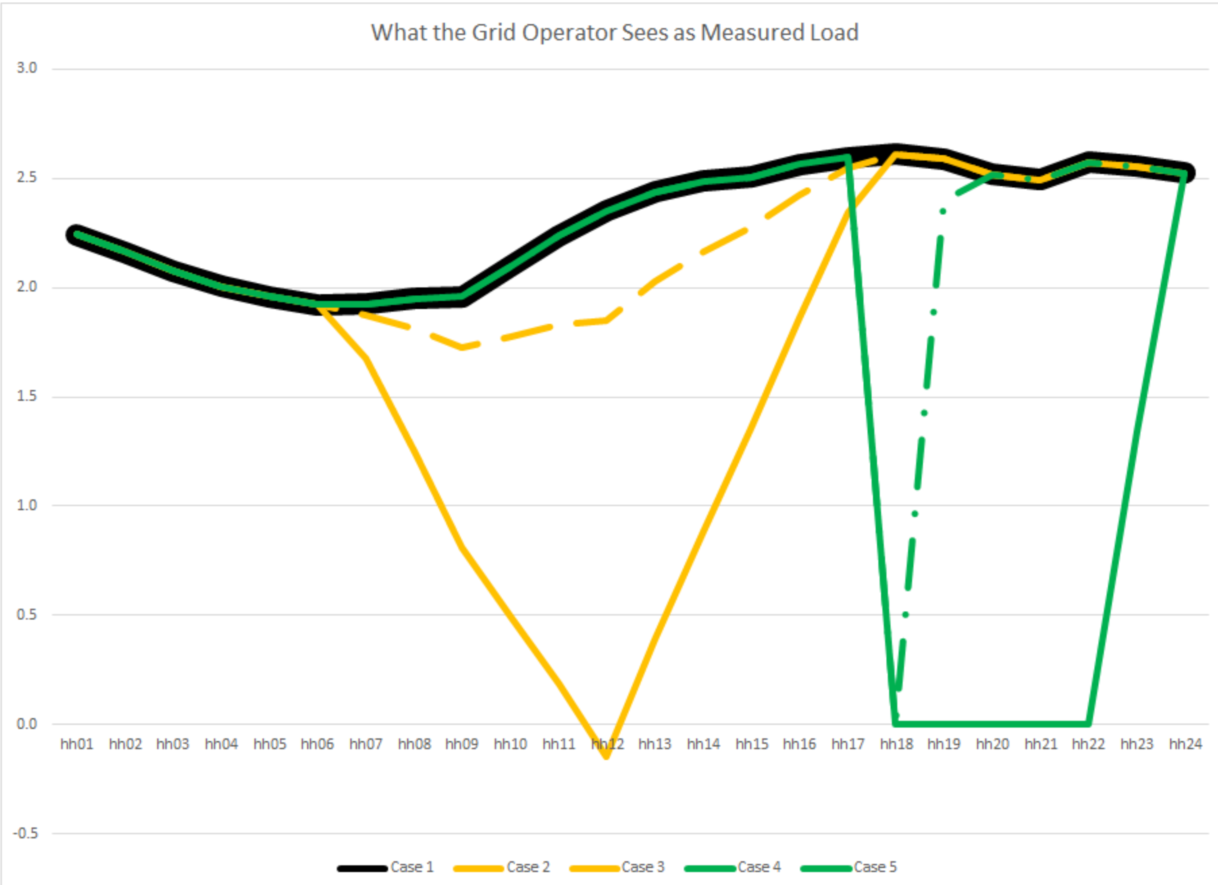
In Figure 4, the demand for electricity services is represented by the Blue shaded area. Measured load, which is demand or electricity services less solar PV generation and battery storage, is represented by the Green line. In this case, battery storage is used to shift the electricity generated by the solar PV panels to the evening hours. This creates a gap between the evening hours demand for electricity services and measured load.

FIGURE 5. DEMAND FOR ELECTRICITY SERVICES VERSUS MEASURED LOAD WITH SOLAR PV & STORAGE HIGH CLOUD COVER



In Figure 5, the demand for electricity services is represented by the Blue shaded area. Measured load, which is demand or electricity services less solar PV generation and battery storage, is represented by the Green Dashed line. In this case, battery storage is used to shift the electricity generated by the solar PV panels to the evening hours. Because of the high cloud cover there is less battery storage available to offset the evening hour demand.

FIGURE 6. WHAT THE GRID OPERATOR SEES



The data in Figure 6 depicts the possible hourly load values the grid operator would see under the alternative mix of DER technologies and weather conditions. In Figure 6, the thick Black line represents measured load without solar PV and battery storage. The solid Gold line represents measured load with solar PV generation on a clear sky day. The dashed Gold line represents measured load with solar PV generation on a high cloud day. The solid Green line represents measured load with solar PV generation and a battery storage strategy of using all the solar generation to charge the battery and then discharge the battery in the evening hours. The dashed Green line is the measured load on a high cloud day where there is less solar generation to charge the battery. This figure illustrates why the operational load forecasting problem must evolve from a forecast of the demand for electricity services to include a forecast of solar PV generation and battery utilization strategies.