**Abstract**

Due to the cost reduction of residential solar energy, residential rooftop photovoltaic (PV) has been proliferating in distribution systems. In many cases, utilities only install a bi-directional meter to record the net energy of customers with PVs. This mechanism is referred to as net energy metering (NEM). In the case of NEM, utilities only have access to the net demand, and the behind-the-meter (BTM) native demand and PV generation are unknown to utilities. The invisibility of BTM native demand and PV generation can cause problems for distribution system applications, such as load/generation forecasting, load modeling, service restoration, demand response, etc. Therefore, it is of significance to separate BTM PV generation and native demand from the net demand. We have come up with three approaches for estimating BTM PV generation and native demand using smart meter data and/or solar power exemplars.

The first approach is developed to disaggregate the BTM PV generation/native demand from net demand for individual customers with PVs, using a limited number of historical PV generation exemplars. This customer-level approach utilizes our finding that in a geographically bounded distribution system, the generations for different PVs are highly correlated. It also utilizes our second finding, i.e., the monthly nocturnal and diurnal native demands are significantly linearly correlated.

The second approach is developed to separate the aggregate BTM PV generation/native demand from the aggregate net demand for a group of customers with PVs, using a limited number of historical PV generation exemplars. This approach utilizes the spatial correlation of PV generations, and the spatial correlation of the native demands of two sizeable groups. Most importantly, the proposed approach employs the weak correlation between the aggregate native demand and the PV generation.

The third approach is developed to estimate the BTM PV generation and native demand both at aggregate and individual-customer levels. This approach does not require historical PV generation exemplars. In contrast, it takes advantage of a publicly available tool – PVWatts Calculator. This approach contains two stages: First, it utilizes the native demand spatial correlation between two sizeable residential customer groups for estimating the total native demand/PV generation time series for customers installed with PVs. Then, it allocates the aggregate BTM native demand/PV generation time series to each individual customer with PVs.

The three developed approaches have advantages and disadvantages and can apply to different cases. The first approach can apply to customer-level solar power disaggregation; however, it requires a dataset with a relatively long time period (typically longer than one year). The second approach can apply to a relatively shorter time window (e.g., a couple of days); however, it is less accurate for customer-level solar power disaggregation. The third approach can apply to the case that utilities only have recorded net demand data because it does not require historical PV generation exemplars.

In summary, our proposed approaches can recover PV generation and native demand for enhancing distribution system observability and thus provide useful information for distribution system monitoring, operation, planning, etc.