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Visualization of Photovoltaic Output During 2017 Solar Eclipse

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SUMMARY

This paper describes the data integration in Dominion Energy as well as visualizations built upon the enterprise-level data platform. The output variation of solar sites during the 2017 solar eclipse is recorded by solar dashboards and the impact of solar on the power grid in Dominion Energy service territory is exhibited and analyzed.

KEYWORDS

Data visualization, Big data, solar eclipse

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Introduction

With increasing penetration level of photovoltaic (PV), the impact of PV on power grids is increasing. Since the PV output depends on solar irradiance, the weather condition plays an important role. Recently, there was a rare event on August 21, 2017, solar eclipse that is visible with a wide band across the United States [1]. In the service territory of Dominion Energy only partial solar eclipse is observed. By observing how the PV outputs change and how the grid responds during the solar eclipse, a relatively severe event for PV, it helps us to understand the impact of PV on the power grid. Moreover, it will help engineers and researchers better understand the impact of PV and figure out what is the best way to operate the grid and PV in the future, especially when the PV penetration is high.

However, to observe the impact of PV, it is important to be able to retrieve data from various PV sites in the field. To be able to retrieve data, data collection and data integration are needed. In Dominion Energy, the real-time PV output data is retrieved and stored in an enterprise-level data platform which is built upon the OSIsoft PI system (PI system). Based on the platform, end users can retrieve real-time data with various resolutions and visualize them in out-of-box applications. Meanwhile, the platform with adequate adapters and interfaces can provide reliable services to users for developing the customized applications. In following parts, two visualizations based on the out-of-box application and customized application would be introduced, respectively. These applications provide comprehensive and detailed information for the system operation and management.

In the rest part of the paper, the methodology of data integration in Dominion Energy is introduced in the next section. Moreover, the detailed information on two types of display built in Dominion Energy is described in the third part: one is based on the PI system, the other is the web-based application using real-time from the PI system. In the end, the impact of the solar eclipse on the Dominion energy is discussed.

Data Integration

Data integration is fundamental and critical to implement the vision of big data in terms of modeling, application and analytics [2]-[4]. The value of data can be exhibited by data mining only when it is possible for disparate data to link and seamlessly interweave with other data to derive a unified and global representation. In Figure 1, the IT infrastructure of big data integration is presented. There are four steps in data integration. First, the data are integrated through unified interface services. Unified interface services support connecting the platform to disparate data sources. Some interfaces enable history recovery, some simply access the historical data stored in third-party historians. These data sources are seamlessly interwoven into the platform independent of source, protocol or vendor. Interface services enable buffering to multiple servers, intelligent data reduction, single tag definition (tags configured on a PI server are synchronized to interface) as well as point by point security. Redundancy and auto point creation are also available on interface services.

Secondly, the data are archived into the data collective and the data-driven model is built: Taking advantage of exception and compression algorithms, data is instantly stored in the archive servers of the platform and made available to users in real-time. Meanwhile, the hierarchical data modeling can create a consistent representation of assets or processes and associate data in proper context, providing information related to the data itself. The model may provide the easiest way for users to find the information they need.

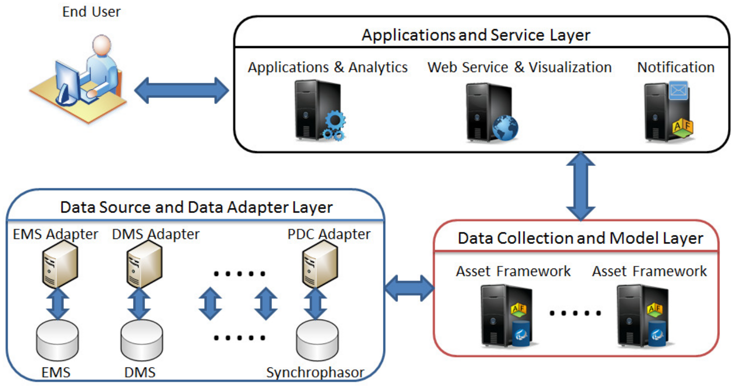

Figure 1. High level architecture of big data integration

Thirdly, the applications and services are provided to end users. To eliminate barriers to use data and models, the platform provides the popular tools such as Internet browsers, Microsoft Office and mobile devices for users. It is easy for them to work the data or implement analytics rather than waste time on data collection.

Finally, the backup strategy is required. The platform has redundant design and two groups of systems with same structure serve backup to the other. It can guarantee the reliability during the operation.

In terms of data sources, most real-time data still depend on the Supervisory Control and Data Acquisition (SCADA) since the deployment of RTUs is widely practiced and has provided the operators the ability of monitoring the operation status of the entire system. Meanwhile, the historical data from SCADA contain abundant raw information for Situational Awareness (SA) and system planning. On the other hand, with the increasing number of Phasor Measurement Units (PMUs), high resolution PMU data can provide more adequate dynamic responses and instantaneous values with accurate timestamps. In the distribution network, with the introduction of intelligent distribution automation equipment and distributed generation into the grid, the need to monitor, analyze, optimize and control the distribution system in real time is greater than ever, and the data from Distribution Management System (DMS) plays an important role to fulfill the above requirements. Since the real-time data regarding solar sites is mainly from EMS and DMS, the following applications may use the data of two systems to exhibit the impact of sun eclipse on PV.

Solar dashboard in the PI system

The core concept of visualizations within the PI system is to implement visualizations with minimum human effort. Thus, the PI system provides a web-based application which can visualize real-time data from data repository. The web-based application can offer multiple gadgets, such as values, trends and tabular tools and so on. As long as the displays are created, they can be shared by the public and visualize rich-data information with different timeframes.

As long as data is prepared and ready to use, end users in the PI system can organize the decent dashboard to monitor operating conditions and status of devices. During the sun eclipse on Aug. 21st, 2017, the pre-defined solar dashboard in the PI system records top five solar sites with the real power outputs, bus voltages and transmission lines associated with them in Figure. 2.

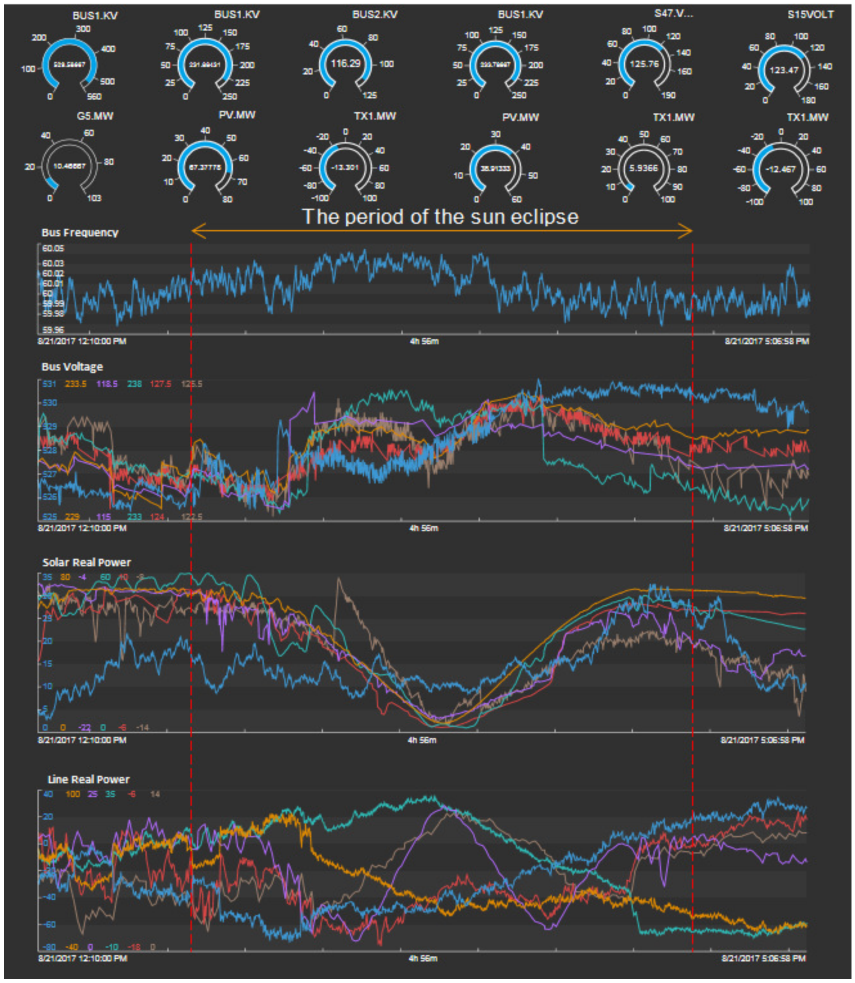

Figure 2. Solar dashboard in the PI system

Web-based Solar Dashboard

Data was polled indirectly from an OsiSoft PI server on an interval of every 15 seconds. Changes in the data triggered updates across various components across the dashboard keeping a uniform state where needed.

In the web-based solar dashboard, there are four primary components, the map, the table, the graph, and the gauges. The dashboard is written using HTML, CSS, and JavaScript and uses the Vue.js framework as the primary means of handling updating the webpage after loading a large number of data points.

The table, shown in Figure 3, was designed with the user's experience in mind. Hovering over a generation site on the map highlights and scrolls to the corresponding row in the table. When hovering over a row, a cursor scrolls over to the generation site on the map without panning. Hovering over the Virginia aggregate row or the North Carolina aggregate row highlights all sites in the table belonging to that respective state. Clicking on the checkbox next to these rows will toggle the visibility of all of the sites that belong to that state. Columns can be sorted at the user's leisure and rows will animate to relocate themselves to their appropriate positions even when the data is updated. There are 5 different columns:

- Rank: the ranking can determined based on the data in the rest of the columns

- Site: the name of the generation site and the substation transformer to which the solar site is connected. Moreover, some other useful information related to the status of a site or the corresponding transformer is represented symbolically. For example, whether the solar site is connected to transmission or distribution, whether the recloser of the solar site is open, tripped, or closed, whether there is a backfeeding from the distribution to the transmission via the transformer.
- The nameplate capacity of the generation site.
- The number of megawatts currently being generated at that location and an arrow that shows if the generation has increased or decreased since the last time it was updated.
- That same number of megawatts expressed as the percentage of its nameplate capacity. This column turns red when a site produces more than its nameplate capacity; this is common during peak hours on smaller generation sites.

RANK	Site (Substation)	Cap (MW)	Gen (MW)	Gen (%Cap)
	Total	737	260	35.3%
	Virginia	166	84.3	50.7%
	North Carolina	570	176	30.8%
1	Solar Site 1 (Substation 1 TX4)	103	69.6	67.6%
2	Solar Site 2 (Substation 2 TX4)	80	39.9	49.9%
3	Solar Site 3 (Substation 3 TX3)	60	27	45%
4	Solar Site 4 (Substation 4 TX3)	20	14	70%
5	Solar Site 5 (Substation 5 TX3)	14	9.6	68.6%
6	Solar Site 6 (Substation 6 TX3)	12	8.5	70.8%
7	Solar Site 8 (Substation 8 TX2)	23.1	7	30.3%
8	Solar Site 7 (Substation 7 TX1) NEW	20	6.9	34.5%
9	Solar Site 9 (Substation 1 TX3) NEW	17	6.8	40%
10	Solar Site 10 (Substation 2 TX4)	20	5	25%
11	Solar Site 11 (Substation 3 TX2)	5	4.6	92%
12	Solar Site 13 (Substation 5 TX3)	19.9	3.8	19.1%

Figure 3. Table of a set of solar sites in web-based solar dashboard

The map, shown in Figure 4, uses Leaflet for mapping with OpenStreetMap or ESRI Imargery for map tiles depending on the mode. Generation sites are displayed with colorized markers indicating the site’s current megawatt generation versus its nameplate capacity. The darker the color of the marker, the higher the percentage of generation. Sites that produce over their nameplate capacities are depicted as smoking to help them stand out more. Clicking on a site’s marker shows more information about a site and displays a small graph of the generation and connected transformer load.

The gauges, shown in Figure 5, display the same information as that in the aggregate table. One additional information is the aggregate transformer loads. The transformer loads are directional; which can show whether this particular transformer has backfeeding or not.

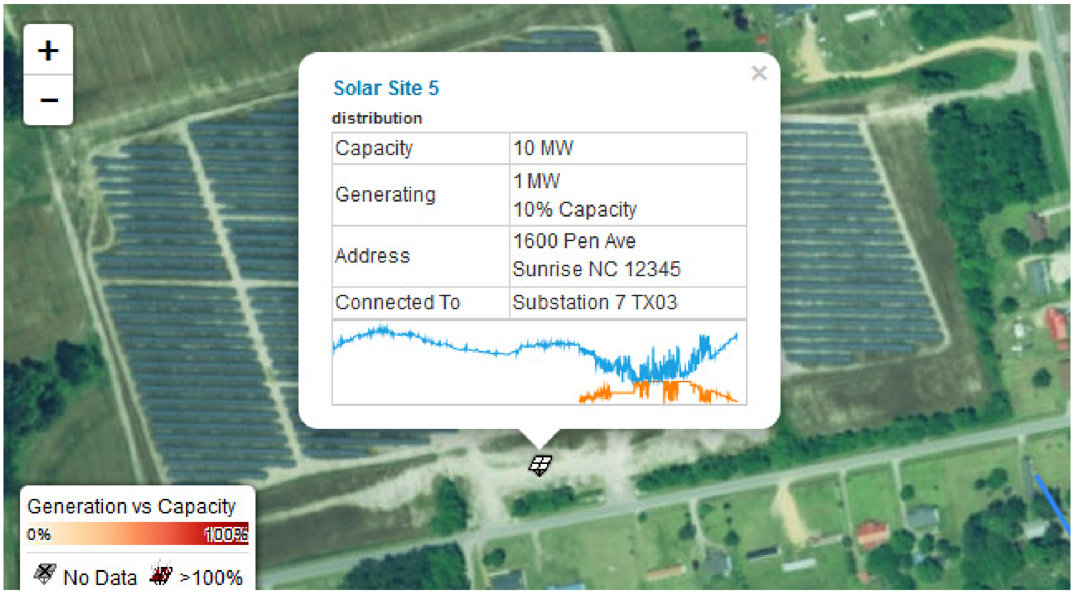

Figure 4. Map of a particular solar site in web-based solar dashboard

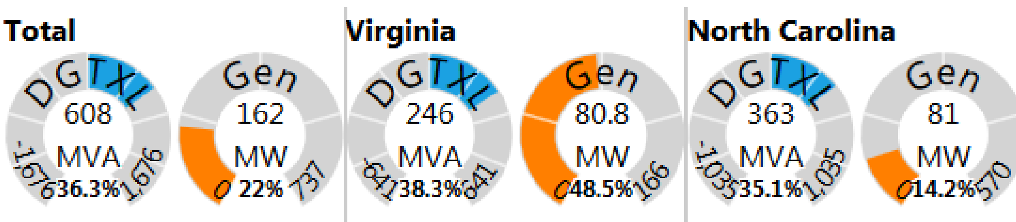

Figure 5. Gauges of a particular solar site in web-based solar dashboard

The graph, shown in Figure 6 and Figure 7, is primarily handled by the Dygraphs JavaScript library which excels at plotting thousands of data points with ease. The graph displays the total generation in orange, the total distributed generation transformer load in blue, and the total demand (generation + load) in green. Recloser events such as a tripping event are also displayed as labels on the graph. For the user's convenience there are four different modes of displaying data. Raw mode shows each and every data point meticulously on the graph. Smoothing mode makes it easier to see the trends in otherwise noisy data using exponential smoothing - the user may adjust the smoothing factor to suit their needs. Candlestick mode displays the data over adjustable intervals as a candlestick plot. Integrated mode calculates the integral of the data over an adjustable interval and displays it as a step chart.

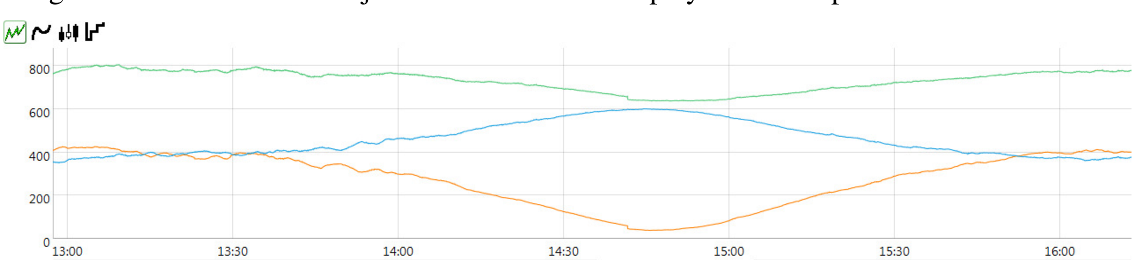

Figure 6. Graph of total solar output, netload and load in web-based solar dashboard

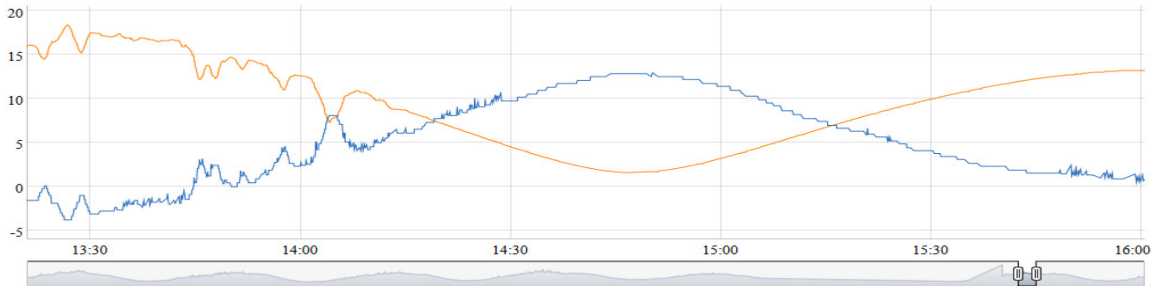

Figure 7. Graph of a particular solar output, netload and load in web-based solar dashboard

Observation

From Figure 2 and Figure 6, at approximately 12:45pm Eastern Time (ET), solar generation peaked in Dominion territory around 430 MW. The eclipse began at 1:05pm ET, and the eclipse peak which means 88% of the sun was blocked at 2:45pm ET. At the peak of the eclipse, solar generation had dropped to 40 MW. So over the course of 1 hour 40 minutes, around 400 MW of solar generation was lost (i.e. ramped down) due to the eclipse. The eclipse ended around 4:05pm ET, at which point the solar generation had risen back up to around 410 MW. So over the course of 1 hour 20 minutes, around 370 MW of solar generation came back online.

Moreover, from Figure 2, no major voltage excursions occurred. It is found that during the peak time of eclipse, the voltage did decreased compared to pre-eclipse and post-eclipse. At the peak of the eclipse, solar generation was at its minimum, lowering the system voltage slightly. However, due to the generator voltage control in transmission system, the voltage was still in the acceptable range. As the solar generation came back as the eclipse passed, system voltage rose with it. From other information in PI, we also observed that there is neither major transmission line flow excursion nor frequency excursions.

Conclusion

This paper describes the data integration in Dominion Energy as well as the PI-based and web-based solar dashboard. The solar output during the 2017 solar eclipse is recorded and the impact of solar on the power grid in Dominion Energy service territory is analyzed. Even though there was 400 MW loss of solar generation during the eclipse, the grid in Dominion Energy service territory did not experience serious voltage and frequency excursion. With the solar dashboard ready, further analysis and application can be done to better operate the grid with high penetration of solar energy.

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