Stephanie A. Cuello
SENIOR COUNSEL

April 25, 2023

VIA ELECTRONIC FILING

Adam J. Teitzman, Commission Clerk
Florida Public Service Commission
2540 Shumard Oak Boulevard
Tallahassee, Florida 32399-0850

Re: *Duke Energy Florida, LLC's Amended Demand Side Management Annual Report for Calendar Year 2022*; Undocketed

Dear Mr. Teitzman:

Please find enclosed for electronic filing Duke Energy Florida, LLC's Response to Staff's First Data Request (Nos. 1-11).

Thank you for your assistance in this matter and if you have any questions, please feel free to contact me at (850) 521-1425.

Sincerely,

/s/ Stephanie A. Cuello

Stephanie A. Cuello

SAC/clg
Enclosure

Cc: Michael Barrett, Division of Economics

Duke Energy Florida, LLC's Response to
Staff's First Data Request (1-11)
Regarding the Amended 2022 DSM Annual
Report

1. Please provide an Excel file (spreadsheet), in electronic format with cell formulas, of the company's Amended 2022 Report.

   <u>Response</u>:
   Please see Attachment A, DEF's Response to Staff's DR-1_DEF DSM Annual Report2022_rev031312 final.xlsx attached hereto and made a part hereof.

2. The cover page of the Amended Report states, in part, that the filing "correct[s] the calculation in all programs tabs except Custom, CLM, and CS." For the programs that were amended, please explain how the calculations were performed to arrive at the values for Annual Demand and Energy Savings per Installation.

   <u>Response</u>:
   Please see the Custom, CLM, and CS tabs within Attachment A, DEF's Response to Staff's DR-1_DEF DSM Annual Report2022_rev031312 final.xlsx attached hereto and made a part hereof.

3. Please answer the following regarding federal energy efficiency standards and Florida Building Code requirements.

   A. Please describe how Duke Energy Florida (DEF or company) has changed the way it monitors current federal energy efficiency standards and Florida Building Code requirements, compared to the method it used in 2021, if applicable.

      <u>Response</u>:
      DEF has not changed the method or the way it monitors current federal energy efficiency standards and Florida Building Code requirements.

   B. What impact, if any, did changes in federal or state standards have on the cost effectiveness of conservation programs in 2022?

      <u>Response</u>:
      There was no impact due to the changes in federal or state standards on cost effectiveness in 2022.

C. If applicable, what existing programs are under review for modification in 2023 to reflect changes to federal or state standards?

Response:
Residential Incentive Program, Low-Income Weatherization Assistance Program and Smart $aver Business Program are under review for changes to federal standards.

4. Please answer the following regarding DEF's conservation research and development (CRD) initiatives that evaluate emerging DSM opportunities:

   A. Identify and describe any new CRD initiatives that were launched in 2022.

   Response:
   Launched a project to evaluate the demand response capability of the Ford Lightning Electric Pickup Truck in a Vehicle-to-Grid (V2G) configuration. The pilot will consist of lab testing of the vehicle, electric vehicle charger and home integration system. We will also test the system in four employee volunteer homes. This project will focus on the capabilities of the Ford Lightning EV to provide V2G demand response, Vehicle-to-Home backup power and EV charging control. These systems could be used as a part of Duke Energy's Demand Response Program.

   B. Provide updates on the status of all on-going CRD initiatives that began before 2022, and if applicable, attach interim and/or final reports on work completed in 2022.

   Response:
   - Continued a project with the University of Central Florida (UCF) to document the value of long-duration customer-side energy storage systems. This project is using the technology at UCF's Microgrid Control lab to directly test a long-duration energy storage system. Use cases to be investigated include study of battery performance during charging and discharging, documenting the effects of cycling on battery performance (battery degradation, efficiency, etc.), optimal operation of a battery energy storage system in a distribution system with high penetration of solar energy, control of behind-the-meter distributed energy resources to provide services including, peak capacity management, Demand Response (consuming or generating), frequency regulation, ramping capability and voltage management.
   - Continued a pilot to develop software, firmware, and applications for a Smart Home Gateway to evaluate the potential for a future home energy management program and its ability to enhance the Company's future energy efficiency and DR programs. The Smart Home Gateway currently includes processing and communications capabilities to perform on-site operations including receiving energy data from the customer's AMI meter, communications using four radios and on-site processing. Capabilities are under development and testing that include enabling appliance demand response using CTA-2045 (EcoPort) local control and enabling local

control of Energy Management Circuit Breakers (EMCBs) for monitoring and demand response. These technologies will allow automatic control of devices according to the customer's preference, and enabling open-source, utility-demand response. The Smart Home Gateway can also potentially be used engage customer awareness of how energy is being used in the home.

- Continued a project with the University of South Florida (USF) to leverage customer-sited solar PV and energy storage at the USF 5th Avenue Garage Microgrid. The system provides load smoothing, islanding and demand response. A publicly available dashboard that shows live data, project specific facts and the capability of downloading data for further study is available for the site at https://dashboards.epri.com/duke-usfsp-parking. Results of this research may be used for design of a potential cost-effective, DR program. USF continued its research on the microgrid operation.
- Continued the Electric Power Research Institute (EPRI) Solar DPV project for data collection to document customer solar resources with a focus on larger PV arrays with and without energy storage. This project also provides the data stream for the dashboard mentioned above.
- Continued participation in an EPRI project to study the potential of using customer demand response to compensate for variable loads and intermittent renewable generation resources.
- Completed the EPRI Energy Management Circuit Breaker (EMCB) Project. This project explored the potential for developing a program for customer circuit breakers that include communication, metering, and remote operation for potential applications including EE, DR, and integration of distributed energy resources. The EMCB hardware and software in the field pilot program collected operational data from appliances in 9 customer homes. The hardware from this project is being utilized in other ongoing Technology Development pilots including the V2G Project and the Smart Home Gateway Project. The commercial version of the EMCB-EV (a self-contained electric vehicle charger) is still being studied for potential opportunities for controlled charging for EVs and Demand Response capabilities. This data will be used to document the operation of these breakers and assess the cost-effectiveness for potential EE and DR programs. Please see Attachment B, EMBC Phase 2 Final Report March 31, 2023_Draft.
- Continued a project that will provide knowledge in methods to utilize customer Wi-Fi infrastructure to develop a dedicated, durable, and secure utility communication channel to connected devices. The project will also provide knowledge on the effectiveness of Wi-Fi-signal-strength-improvement technology. This technology could lead to lower costs and improved cost-effectiveness for existing and future DR and EE programs.
- Continued a project for a study to evaluate the demand response capability of internet-connected residential batteries. Residential batteries potentially offer the ability to provide power reduction for demand response while eliminating any discomfort to the customer (as compared to residential appliance demand response). Certain battery manufacturers have developed technologies that allow for the collection of capacity and charge data, communication protocols for external aggregator software providers, and the ability to dispatch stored energy to serve the

needs of the customer or the grid. This project will focus on the capabilities of a particular aggregator to collect data from two battery manufacturers, the feasibility of utilizing aggregation technology for dispatching demand response event commands, and the net impact of these events on shaping demand. Such an aggregation system enables existing units that are already installed by residential customers in DEF territory to be used in this study. The results of this study could be used to develop a demand response program.

- Partnered with EPRI and other research organizations to evaluate EE, energy storage, and alternative energy / innovative technologies.

C. On what date was the Vehicle To Grid Ford Lightning EV technology study launched, and when is that study expected to conclude?

Response:
The Duke Ford Lightning Vehicle to Grid (V2G) Technology Demonstration launched on 8/22/2022. The project is expected to conclude in 2024.

5. Please answer the following regarding marketing and outreach efforts in 2022:

A. The number on online audits for residential customers conducted in the Home Energy Check program grew from 8,393 in 2021 to 25,919 in 2022. Specifically describe the marketing and outreach methods and techniques that were used to achieve these results. Address in your response why the company believes the marketing efforts were successful for attracting residential participants, but not successful for attracting non-residential customers via its Business Energy Check program. If applicable, describe what changes are planned to improve participation in the Business Energy Check program.

Response:
Home Energy Check:
In November of 2021 DEF successfully launched the new online platform of the Home Energy Check. The new online platform is more intuitive and customer friendly. This resulted in the increased participation from 2021 to 2022. Additionally, marketing efforts in 2022 included numerous campaigns such as customer emails, bill inserts, bill messages, and direct mail.

Business Energy Check:
The Smart $aver Business program (f/k/a Better Business) could meet the goals in prior years without advertising the Business Energy Check program. However, the changes in the measure mix for the Smart $aver Business program in the last filing required a marketing plan to include the Business Energy Check program. As a result, we are undertaking customer engagement and marketing supporting the Business Energy Check program in multiple areas, such as direct mail pieces, email blasts, and lead

generation from our internal business partners; there is a role to reach customers through business-appropriate internet areas, like LinkedIn.

B. Participation in the Neighborhood Energy Saver program grew from 537 in 2021 to 4,771 in 2022. Specifically describe the marketing and outreach methods and techniques that were used to promote this program, and why the company believes these efforts were successful.

Response:
The Neighborhood Energy Saver program utilizes the several marketing materials and outreach methods to promote the program to eligible customers including but not limited to the following:

- **Introductory letter** – letter to eligible customers announcing the program
- **Invitation to Community Information session** – We host a community information session/kick-off event for all eligible residents (specific to area the program is implemented in)
- **Partnership with local "who can help" organizations –** We identify and invite local community assistance organizations and our internal community affairs group to set up tables at our community event to provide information on how to secure essential services.
- **Appointment reminder postcard** – provide eligible customers with the date/time we will be in their neighborhood
- **Flyer** – informational flyer for distribution in the neighborhood that provides an overview of the program and measures that may be installed in the home after the audit
- **Post it note/leave behind** – note left on the customer's door if they are not home when our technician visits their home with a contact number to reschedule an appointment
- **Last chance postcard** – After 3rd attempt to install measures in the customers home, we send a "last chance" postcard to customers before leaving the neighborhood

In addition to the direct to customer marketing, the program also provides marketing to area stakeholders who can validate our program, generate word-of-mouth marketing, and assist us with creating a comfort level with residents and we believe these contribute to our successful efforts.

6. On Page 5 of the Report, DEF provides information about the Neighborhood Energy Saver program. Please answer the following:

   A. The titles for Columns d, f, and g display an asterisk at the end of the title. Please provide a definition for the asterisk.

Response:
Participants means “homes served.”

B. Please provide an Excel spreadsheet, in electronic format with cell formulas, that demonstrates the total number of installations for each measure subscribed in 2022, the savings per installation for each measure (generator), the total savings per measure (generator), and the summation of the savings per measure that equals the program total savings values at the generator (Annual Demand and Energy Savings per Installation shown for this program on Page 5).

Response:
Please see Attachment C, DEF’s Response to Staff’s DR1-6B.xls file attached hereto and made a part hereof.

C. Please provide an Excel spreadsheet, in electronic format with cell formulas, that provides the same types of data described in Item 5(B). above for 2022, but on a projected basis rather than actual basis, consistent with the savings goals for this program as established in Docket No. 20200054-EI.

Response:
Please see Attachment D, DEF’s Response to Staff’s DR1-6C.xls file attached hereto and made a part hereof.

D. What caused the increase in the number of participants in this program from 2021 (537 participants) to 2022 (4,771 participants) and the increase in program costs from 2021 ($524,000) and the tenfold increase to 2022 ($5,288,000)?

Response:
The increase in number of participants and the increase in program costs from 2021 to 2022 were both due to impacts from the COVID-19 pandemic. In 2021, the program was unable to deploy teams into homes to install measures and did not resume until May 2021. When resumed only a small number of field workers returned which in turn limited the amount of neighborhoods and homes that were reached. In the 2022 calendar year, participation grew as well as program costs due to the program being able to resume normal field operations and an increase in field workers which allowed the program to grow and reach more customers.

E. In 2022, the Utility Cost per Installation for this program was $1,108, whereas in 2021 the Utility Cost per Installation for this program was $552. Specifically describe the reasons for the change in costs from 2021 to 2022.

Response:

DEF total program costs in 2021 were less than 2022 due to lack of participation in the program from the continued impacts of the COVID-19 pandemic.

F. Has this program undergone a program modification in 2022? Please explain.

<u>Response</u>:
Yes. DEF requested approval to increase the program participation projection by an incremental 250 customers per year from 2022 to 2024 and for cost-recovery purposes for the estimated additional program expense for this program modification of $249,253 for 2022. Please see Order No. PSC-2021-0465-PAA-EG, issued December 20, 2021, in Docket No. 20210121-EG, *In re Petition for approval of modifications to demand-side management program plan and participation standards, by Duke Energy Florida, LLC.*

7. On Page 6 of the Report, DEF provides information about the Low Income Weatherization Assistance program. Please answer the following:

A. Describe all marketing and outreach efforts the company used in 2022 to provide enrollment-related information to its customers about the Low Income Weatherization program.

<u>Response</u>:
LIWAP meets directly with participating agencies and organizations to share information about program offerings and discuss what DEF can do to assist in getting incentives through the LIWAP program. We have also conducted Energy Education workshops for both agencies and customers.

B. The company reported that 134 participants enrolled in this program in 2022. Please provide a breakdown of this number reflecting the number of participants that were acquired via each of the county-level social service agencies that are shown on the company's "Low Income Weatherization" webpage. If applicable, state how the remainder of participants enrolled.

<u>Response</u>:
Below please see the breakdown of the number of participants from each county-level agency in 2022.

Agency	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Osceola Council On Aging	11												11
Pinellas County Urban League	4		4	6		9			4	6		9	42
Meals on Wheels		1				2		2		2			7
Centro Campesino			2							1	2		5
Mid Florida Community Services			3				9		7		4		23
Orange County Senior Pilot Program				5			3			4			12
Osceola Council on Aging				6	7				12				25
Marion County Community Services								6		3			9
													0
													Total
													134

C. Since 2015, participation in this program has never equaled or exceeded the company's projections for participation. Why has this program not reached participation projections? Please explain.

Response:
The LIWAP program is operated through local weatherization assistance agencies. Program participation is contingent on these partnering agencies weatherization priorities. It is also contingent on agency budgets, installed measures, workforce staffing and measure accessibility. Over the years, personnel at these agencies lacked interest in the program. In addition, many of our partners weatherization program include measures that are not included in our program offerings (i.e., windows, roofing). These are all contributing factors to the program not reaching participation projections.

D. Between 2015 and 2019, an average of 325 participants per year enrolled in this program. Since that time, the average has declined to 135. What efforts are underway to enhance participation in this program?

Response:
DEF continues to engage and work directly with the weatherization agencies and organizations to share program information. Currently, the program is finalizing the addition of Pinellas County Housing Authority to the LIWAP program. This will be a great agency to help increase participation in the program.

E. The net benefits for this program have declined from ($170,000) in 2021 to ($372,000) in 2022.

   1. Please explain the reason(s) for the difference between these year-to-year values, and how this is being addressed.

      Response:
      There was an error in the net benefits for this program. The error will be corrected and a Second Amended Annual Report will be forthcoming to correct the error.

2. Discuss how, or if, the net benefits amount identified in the Report impacts what resources the company commits to this program.

   Response:
   Please see response in Question #7.E.1.

3. Please explain how the net benefit for this program for 2022 exceeds the total program costs.

   Response:
   Please see response in Question #7.E.1.

F. Please describe how a qualified customer can enroll in this program. Address in your response the company's direct role in this process, and whether DEF customer service agents assist customers through the entire enrollment process, or whether the company's direct involvement ends if/when customers are referred to other social service entities (such as the Florida Department of Economic Opportunity, or county-level agency staff).

Response:
Enrollment and participation in the LIWAP program is dependent and operated through the weatherization agencies. DEF reimburses the weatherization agencies for measures they install. DEF does not have direct involvement with program enrollment.

G. Please explain how the offering, distribution, and accounting of DEF incentives in this program are coordinated through county level agencies and vendors.

Response:
Each participating Agency Department of Economic Opportunity (DEO) and local weatherization providers (collectively referred to as "Agencies") signs an Incentive Agreement with DEF. Incentives will be paid directly to the Agencies. Agencies are required to submit the following information along with all invoices by the tenth workday of each month (not to exceed forty-five (45) days from the date of installation):

- Customer information - including name, address, and DEF account number
- A list of installed measures and, where appropriate, pre-existing conditions
- Itemized invoice with a brief description of installed measures (incentive measures only) and program incentive for each weatherized home, or the DEF/LIWAP data information form

If the home is not selected for inspection, or after it has passed inspection, invoices will be processed for payment. DEF will input installed measures and paid incentives to a data base system. Submitted reports and invoices will be maintained on file.

H. Describe what resources or training, if any, the company provides to social service entities (such as the Florida Department of Economic Opportunity or county-level social service agencies in its service territories) to assist them with addressing enrollment-related questions from qualified customers about this program. Also, has the company tested the effectiveness of such entities to follow through with enrollment procedures, and if so, what were the results? Please explain.

Response:
N/A

I. What is the most direct and simplest method for low-income customers to quickly and easily get the specific details about this program (eligibility, incentives, how to enroll, etc.), and how is that method shared with customers?

Response:
The most direct and simplest method for low-income customers to quickly and easily obtain details about the program is through our website. The site provides a quick overview of qualifications as well as some of the weatherization offerings. Customers can also check eligibility, by clicking on the additional site provided: https://www.benefits.gov/benefit/1847. This link is a hub for Florida Weatherization Assistance Program.

8. Identify DEF's partnerships with government and non-profit agencies in 2022 designed to help identify low-income neighborhoods and educate customers on conservation opportunities. Address in your response whether any of these partnerships were new, changed, or modified in 2022, compared to prior years.

Response:

- Pinellas County Urban League
- Mid-Florida Community Services – Modified-new customers from Tampa Hillsborough Action Plan
- Capitol Area Community Action Agency
- Central Florida Community Action Agency
- Orange County Community Development – Modified-pilot program ended 2022
- Osceola County Council on Aging
- Meals on Wheels
- Lake County Community Action Agency
- Centro Campesino
- Tampa Hillsborough Action Plan – Changed-No longer providing weatherization services, customers are now being serviced by Mid Florida Community Services

- Rebuilding Together Tampa Bay – New
- Housing Authority of Marion County – New
- Pinellas County Housing Authority – New coming May/June 2023

9. On Page 9 of the Report, DEF provides information about the Smart $aver Business program, indicating that on each installation, the annual energy reduction amount (at the generator) is 17,483 kWh. In 2021, the annual energy reduction amount (at the generator) for this program was 98,817 kWh. Please explain the reason(s) for the difference between these year-to-year values.

   Response:
   As the economy started rebounding from COVID 19, larger customers were more able to implement updates to facilities quicker than our smaller medium customers. These projects tend to be larger for these customers and the measure mix of applications generally provided for higher kWh measures. The participation for the year was down from previous years coupled with the higher kWh values on the measures implemented, resulting in a higher kWh per participant value.

10. On Page 14 of the Report, DEF provides information about the Standby Generation program, indicating that on each installation, the annual winter and summer demand reduction amount (at the generator) is 189 kW. In 2021, the annual winter and summer demand reduction amount (at the generator) was 533 kW. Please explain the reason(s) for the difference between these year-to-year values.

    Response:
    DEF submitted page 14 of the Report with a calculation error, the error was corrected, and an amended report was filed. The kW (at the generator) numbers provided in Question 10 are referencing the original page 14 and not the amended report.

    In the amended report, the demand reduction disparity in 2022 is due to a smaller kW yield per installation averaged over three customers and is in direct contrast to the prior year with larger kW rated systems yielding significantly higher installation averages.

11. In 2022, what was the company's System Average Line Loss percentage?

    Response:

RESIDENTIAL/COMMERCIAL INDUSTRIAL LOSS FACTOR			
Residential	7.53%		
Commercial Industrial	5.13%		

DUKE ENERGY FLORIDA
2022
COMPARISON OF CUMULATIVE ACHIEVED MW & GWH REDUCTIONS at the Generator
PUBLIC SERVICE COMMISSION ESTABLISHED GOALS ORDER PSC-2020-0274-PAA-EG

RESIDENTIAL

	WINTER PEAK MW REDUCTION			SUMMER PEAK MW REDUCTION			GWH ENERGY REDUCTION		
YEAR	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE
2020	31	32	-5%	18	16	13%	35	9	277%
2021	47	60	-22%	28	29	-5%	61	15	292%
2022	71	85	-16%	43	41	5%	109	19	470%
2023		107			53			21	
2024		128			63			23	

COMMERCIAL / INDUSTRIAL

	WINTER PEAK MW REDUCTION			SUMMER PEAK MW REDUCTION			GWH ENERGY REDUCTION		
YEAR	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE
2020	24	5	354%	46	8	460%	40	6	582%
2021	34	10	244%	70	15	363%	62	10	531%
2022	39	15	166%	75	21	255%	65	12	432%
2023		20			27			14	
2024		24			32			14	

TOTAL

	WINTER PEAK MW REDUCTION			SUMMER PEAK MW REDUCTION			GWH ENERGY REDUCTION		
YEAR	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE	TOTAL ACHIEVED**	COMMISSION APPROVED GOAL*	% VARIANCE
2020	54	37	45%	64	24	168%	75	15	395%
2021	81	70	16%	98	44	120%	122	25	385%
2022	110	99	11%	118	63	89%	174	31	455%
2023		126			79			35	
2024		152			95			37	

*2020-2024 Goals are based on ORDER NO. PSC-2020-0274-PAA-EG, issued August 3, 2020
**Figures are rounded to the nearest whole number and are at the Generator

DUKE ENERGY FLORIDA
2022
COMPARISON OF ANNUAL ACHIEVED MW & GWH REDUCTIONS at the Generator WITH PUBLIC SERVICE COMMISSION ESTABLISHED ANNUAL GOALS*

RESIDENTIAL

YEAR	WINTER PEAK MW REDUCTION TOTAL ACHIEVED**	WINTER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	WINTER PEAK MW REDUCTION % VARIANCE	SUMMER PEAK MW REDUCTION TOTAL ACHIEVED**	SUMMER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	SUMMER PEAK MW REDUCTION % VARIANCE	GWH ENERGY REDUCTION TOTAL ACHIEVED**	GWH ENERGY REDUCTION COMMISSION APPROVED GOAL*	GWH ENERGY REDUCTION % VARIANCE
2020	31	32	-5%	18	16	13%	35	9	277%
2021	16	28	-42%	10	14	-26%	26	6	316%
2022	25	25	0%	16	12	29%	49	4	1203%
2023		22			11			2	
2024		21			11			1	

COMMERCIAL / INDUSTRIAL

YEAR	WINTER PEAK MW REDUCTION TOTAL ACHIEVED**	WINTER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	WINTER PEAK MW REDUCTION % VARIANCE	SUMMER PEAK MW REDUCTION TOTAL ACHIEVED**	SUMMER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	SUMMER PEAK MW REDUCTION % VARIANCE	GWH ENERGY REDUCTION TOTAL ACHIEVED**	GWH ENERGY REDUCTION COMMISSION APPROVED GOAL*	GWH ENERGY REDUCTION % VARIANCE
2020	24	5	354%	46	8	460%	40	6	582%
2021	11	5	124%	24	7	248%	22	4	454%
2022	5	5	1%	5	6	-17%	3	2	25%
2023		5			6			1	
2024		5			5			1	

TOTAL

YEAR	WINTER PEAK MW REDUCTION TOTAL ACHIEVED**	WINTER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	WINTER PEAK MW REDUCTION % VARIANCE	SUMMER PEAK MW REDUCTION TOTAL ACHIEVED**	SUMMER PEAK MW REDUCTION COMMISSION APPROVED GOAL*	SUMMER PEAK MW REDUCTION % VARIANCE	GWH ENERGY REDUCTION TOTAL ACHIEVED**	GWH ENERGY REDUCTION COMMISSION APPROVED GOAL*	GWH ENERGY REDUCTION % VARIANCE
2020	54	37	45%	64	24	168%	75	15	395%
2021	27	33	-18%	34	21	65%	47	10	370%
2022	29	29	0%	21	18	14%	52	6	743%
2023		27			17			4	
2024		25			16			2	

*2020-2024 Goals are based on ORDER NO. PSC-2020-0274-PAA-EG, issued August 3, 2020
Figures are rounded to the nearest whole number and are **at the Generator

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Home Energy Check
Program Start Date: 1991, modifications approved in 2021
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	1,647,440	25,000	1.52%	31,560	31,560	1.92%	6,560
2021	1,673,995	1,648,995	50,000	3.03%	21,732	53,292	3.23%	3,292
2022	1,700,215	1,675,215	75,000	4.48%	37,725	91,017	5.43%	16,017
2023	1,726,425	1,701,425	100,000	5.88%				
2024	1,752,362	1,727,362	125,000	7.24%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	0.24	0.26	9,142	9,886
Summer kW Reduction	0.15	0.16	5,523	5,973
Annual kWh Reduction	631.57	682.97	23,825,814	25,764,871

Utility Cost per Installation:	$114
Total Program Cost of the Utility ($000):	$4,310
Net Benefits of Measures Installed During Reporting Period ($000):	N/A

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Residential Incentive Program (f/k/a Home Energy Improvement)
Program Start Date: 1996 with modifications approved in 2006, 2015, and 2020
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program/Measure Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program/Measure Participants	Actual Cumulative Number of Program/Measure Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	1,647,440	17,350	1.05%	19,200	19,200	1.17%	1,850
2021	1,673,995	1,673,995	33,283	1.99%	15,140	34,340	2.05%	1,058
2022	1,700,215	1,700,215	48,418	2.85%	10,318	44,658	2.63%	-3,760
2023	1,726,425	1,726,425	62,797	3.64%				
2024	1,752,362	1,752,362	76,458	4.36%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	0.34	0.37	3,549	3,838
Summer kW Reduction	0.22	0.24	2,291	2,477
Annual kWh Reduction	540.14	584.10	5,573,140	6,026,708

Utility Cost per Installation: $322
Total Program Cost of the Utility ($000): $3,322
Net Benefits of Measures Installed During Reporting Period ($000): -$1,064

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Neighborhood Energy Saver
Program Start Date: 2007 with modifications approved in 2015, 2018, 2020 and 2021
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants*	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants*	Actual Cumulative Number of Program Participants*	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	443,161	5,000	1.13%	950	950	0.21%	-4,050
2021	1,673,995	450,305	10,000	2.22%	537	1,487	0.33%	-8,513
2022	1,700,215	457,358	15,250	3.33%	4,771	6,258	1.37%	-8,992
2023	1,726,425	464,408	20,500	4.41%				
2024	1,752,362	471,385	25,750	5.46%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	1.78	1.93	8,507	9,199
Summer kW Reduction	1.20	1.29	5,705	6,170
Annual kWh Reduction	3,269.42	3,535.50	15,598,419	16,867,892

Utility Cost per Installation: $1,108
Total Program Cost of the Utility ($000): $5,288
Net Benefits of Measures Installed During Reporting Period ($000): -$4,070

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Low Income Weatherization Assistance
Program Start Date: May 2000 with modifications approved in 2005, 2015, 2017 & 2018
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program/Measure Participants*	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program/Measure Participants*	Actual Cumulative Number of Program/Measure Participants*	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	443,161	244	0.06%	139	139	0.03%	-105
2021	1,673,995	450,305	488	0.11%	133	272	0.06%	-216
2022	1,700,215	457,358	745	0.16%	134	406	0.09%	-339
2023	1,726,425	464,408	1,001	0.22%				
2024	1,752,362	471,385	1,257	0.27%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	0.60	0.65	81	87
Summer kW Reduction	0.36	0.39	49	53
Annual kWh Reduction	1,280.72	1,384.95	171,617	185,584

Utility Cost per Installation:	$1,881
Total Program Cost of the Utility ($000):	$252
Net Benefits of Measures Installed During Reporting Period ($000):	-$372

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Residential Load Management (a/k/a Residential Energy Management, Energy-Wise)
Program Start Date: January 1981, revision approved May 2000, 2nd revision approved 2006, 3rd revision approved 2015
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	1,208,538	2,500	0.21%	2,735	2,735	0.23%	235
2021	1,673,995	1,232,593	5,000	0.41%	1,604	4,339	0.35%	-661
2022	1,700,215	1,256,313	7,500	0.60%	767	5,106	0.41%	-2,394
2023	1,726,425	1,280,023	10,000	0.78%				
2024	1,752,362	1,303,460	12,500	0.96%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG
col f., Annual Number of Program Participants represents new accounts added to the program each year.

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	1.92	2.08	1,473	1,592
Summer kW Reduction	1.35	1.46	1,035	1,120
Annual kWh Reduction	0	0	0	0

Utility Cost per Installation: *	$82
Total Program Cost of the Utility ($000):**	$35,376
Net Benefits of Measures Installed During Reporting Period ($000):	$4,029

Utility cost per Installation is based on the total, cumulative number of year-end participants.
****Utility program costs for this program include incentives paid to eligible participants.***

Total Program Participants at End of Year 433,000

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Business Energy Check
Program Start Date: 1991
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	178,557	400	0.22%	429	429	0.24%	29
2021	181,015	180,615	800	0.44%	287	716	0.40%	-84
2022	183,346	183,346	1,200	0.65%	146	862	0.47%	-338
2023	185,608	185,608	1,600	0.86%				
2024	187,771	187,771	2,000	1.07%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator
Winter kW Reduction	0.03	0.04	5	5
Summer kW Reduction	0.08	0.08	11	12
Annual kWh Reduction	448.30	472.55	65,452	68,992

Utility Cost per Installation: $3,310
Total Program Cost of the Utility ($000): $483
Net Benefits of Measures Installed During Reporting Period ($000): N/A

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Smart $aver Business (f/k/a Better Business)
Program Start Date: April 1996 with modifications approved in 2006, 2015, 2016 and 2018
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	178,557	2,589	1.45%	951	951	0.53%	-1,638
2021	181,015	181,015	5,048	2.79%	167	1,118	0.62%	-3,930
2022	183,346	183,346	7,384	4.03%	172	1,290	0.70%	-6,094
2023	185,608	185,608	9,603	5.17%				
2024	187,771	187,771	11,712	6.24%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	3.27	3.45	563	593
Summer kW Reduction	4.45	4.69	766	807
Annual kWh Reduction	16,104.29	16,975.26	2,769,939	2,919,744

Utility Cost per Installation: $8,934
Total Program Cost of the Utility ($000): $1,537
Net Benefits of Measures Installed During Reporting Period ($000): -$2,317

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Smart $aver Custom (f/k/a Florida Custom Incentive Program)
Program Start Date: 1991
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	178,557	200	0.11%	134	134	0.08%	-66
2021	181,015	181,015	390	0.22%	21	155	0.09%	-235
2022	183,346	183,346	571	0.31%	0	155	0.08%	-416
2023	185,608	185,608	743	0.40%				
2024	187,771	187,771	906	0.48%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator
Winter kW Reduction	0	0	0	0
Summer kW Reduction	0	0	0	0
Annual kWh Reduction	0	0	0	0

Utility Cost per Installation: 0 — Total Program Cost (F34) divided by Completions (F17) gives you the utility cost per installation
Total Program Cost of the Utility ($000): $286 — Provided in CT-2 P 2 of DEF's ECCR True Up Filing to be filed on May 2, 2023
Net Benefits of Measures Installed During Reporting Period ($000): -$421

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Commercial Energy Management
Program Start Date: April 1996 - (Closed to new participants effective May 2000)
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	0	0	0.00%	0	0	0.00%	0
2021	181,015	0	0	0.00%	0	0	0.00%	0
2022	183,346	0	0	0.00%	0	0	0.00%	0
2023	185,608							
2024	187,771							

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator
Winter kW Reduction	---	---	0.0	0.0
Summer kW Reduction	---	---	0.0	0.0
Annual kWh Reduction	---	---	0.0	0.0

Utility Cost per Installation: $5,707 — Total Program Cost (F34) divided by Net Participants (F40) equals the utility cost per installation
Total Program Cost of the Utility ($000): * $337 — Provided in CT-2 P 2 of DEF's ECCR True Up Filing to be filed on May 2, 2023
Net Benefits of Measures Installed During Reporting Period ($000): N/A

**** Utility cost per Installation is based on the total, cumulative number of year-end participants.***
***** Utility program costs for this program include incentives paid to eligible participants.***

****Total NET Participants at the End of the Year*** 59

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Interruptible Service
Program Start Date: November 1992 - (Rate Schedule IS-1 is closed to new customers, and IS-2 became effective June 1996.)
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	697	16	2.30%	7	7	1.00%	-9
2021	181,015	681	26	3.82%	4	11	1.62%	-15
2022	183,346	671	30	4.47%	2	13	1.94%	-17
2023	185,608	667	36	5.40%				
2024	187,771	661	44	6.66%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings	Per Installation		Program Total	
(during the reporting period)	@ Meter	@ Generator	@ Meter	@ Generator
Winter kW Reduction	1,513	1,595	3,026	3,190
Summer kW Reduction	1,513	1,595	3,026	3,190
Annual kWh Reduction	0	0	0	0

Utility Cost per Installation: * $273,423
Total Program Cost of the Utility ($000): ** $47,029
Net Benefits of Measures Installed During Reporting Period ($000): $7,615

***** Utility cost per Installation is based on the total, cumulative number of year-end participants.**
***** ** Utility program costs for this program include incentives paid to eligible participants.**

Total NET Participants at End of Year 172

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Curtailable Service
Program Start Date: November 1992 - (Rate Schedule CS-1 is closed to new customers, and CS-2 became effective June 1996.)
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants*	Actual Cumulative Number of Program Participants**	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	697	1	0.14%	0	0	0.00%	-1
2021	181,015	696	1	0.14%	0	0	0.00%	-1
2022	183,346	696	2	0.29%	0	0	0.00%	-2
2023	185,608	695	2	0.29%				
2024	187,771	695	3	0.43%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator
Winter kW Reduction	---	---	0.0	0.0
Summer kW Reduction	---	---	0.0	0.0
Annual kWh Reduction	---	---	0.0	0.0

Utility Cost per Installation: *	$650,654	Total Program Cost (F34) divided by Net Participants (F40) equals the utility cost per installation
Total Program Cost of the Utility ($000): **	$2,603	Provided in CT-2 P 2 of DEF's ECCR True Up Filing to be filed on May 2, 2023
Net Benefits of Measures Installed During Reporting Period ($000):	N/A	

**** Utility cost per Installation is based on the program costs divided by the number of accounts participating in this program.***
***** Utility program costs for this program include incentives paid to eligible participants.***

Total NET Participants at End of Year 4

Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Standby Generation
Program Start Date: April 1993 with revisions approved 2006, 2015 and 2016
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants	Actual Cumulative Number of Program Participants	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	178,557	178,557	10	0.01%	5	5	0.00%	-5
2021	181,015	181,005	20	0.01%	5	10	0.01%	-10
2022	183,346	183,326	35	0.02%	3	13	0.01%	-22
2023	185,608	185,573	50	0.03%				
2024	187,771	187,721	65	0.03%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator
Winter kW Reduction	299	316	898	947
Summer kW Reduction	299	316	898	947
Annual kWh Reduction	0	0	0	0

Utility Cost per Installation: * $33,572
Total Program Cost of the Utility ($000):** $6,211
Net Benefits of Measures Installed During Reporting Period ($000): $2,520

***** Utility cost per Installation is based on the total, cumulative number of year-end participants.**
***** Total program costs for this program include incentives paid to eligible participants.**

Total NET Participants at End of Year 185

Energy Management Circuit Breaker Phase 2

Final Report

3020xxxxxx

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The authors would like to dedicate this report in memory of Tom Geist, a superlative human being, engineer, and friend. He will be sorely missed.

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ABSTRACT

EPRI worked with a group of eleven funding utilities and with Eaton Corporation to demonstrate tool development for a Wi-Fi enabled smart breaker, referred to in our project as the Energy Management Circuit Breaker (EMCB) that transfers data using internet connectivity. The project ran for a period of just under four years, including through the recent COVID pandemic. While project schedules proved challenging, the project was able to work with third party software developers and EPRI software developers to build tools designed to integrate the EMCB function set into a format that can support utility operations.

The key focus of the project was developing and demonstrating tools that could take advantage of the functions provided by the EMCB that include metering, on/off demand response control, electric vehicle charging, and power quality data capture.

Keywords

Smart Breaker

Demand Response

Load Metering and Control

Electric Vehicle Charging

EXECUTIVE SUMMARY

Deliverable Number: 3020xxxxxx

Product Type: Technical Report

Product Title: Energy Management Circuit Breaker Phase 2: Final Report

Primary Audience: Utilities interested in developing programs that rely on monitoring and/or control of end use loads including electric vehicle charging.

Secondary Audience: Parties interested in building load management and demand response programs for devices that lack onboard intelligence.

KEY RESEARCH QUESTION

Can tools be developed that would allow a wi-fi based smart breaker to be integrated into utility systems and processes?

RESEARCH OVERVIEW

Smart circuit breakers developed by Eaton Corporation were deployed to validate their operation using a variety of data collection and processing tools.

KEY FINDINGS

- Integration of the EMCB device was completed on a commercial demand response system, demonstrating the feasibility of using these devices at scale in utility program.
- While wi-fi provides an easy means of developing connectivity that can be embedded in products, it remains a challenge to address the cybersecurity concerns that prevent those devices from being applied on utility and business owned and managed IT systems.
- The use of cellular data modems allowed for easy application of these wi-fi based devices but doing so at scale would likely be cost prohibitive. Scale deployment at low cost remains a challenge with the cybersecurity concerns noted in the previous bullet.
- Devices that rely on live connectivity for operation have many discrete failure points where multiple vendors are responsible for the communications links. Troubleshooting communications failures can be complex requiring input from multiple players to find the root cause of failure.
- It remains a challenge to bridge data from devices that offer embedded metering to utility back-office systems. Communications links, data protocols and data formatting all remain challenges for transporting data from devices to utility.

WHY THIS MATTERS

The use of wireless connectivity continues to proliferate across a broad selection of consumer products. Many of these are beginning to offer features sets that may be of interest to utilities. Understanding how these devices can be integrated in a utility system remains a challenge to enable use of such devices.

HOW TO APPLY RESULTS

This report provides an overview of the testing and behavior of EMCB devices in the field. Through this project several commercial vendors were engaged to develop tool integrations with the EMCB. The EMCB devices themselves are now available as commercial products as are the platforms integrations which were performed and demonstrated in this project.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- EPRI’s Consumer Technologies program (P170) continues to investigate technologies that enable end use load control of a broad set of consumer devices. The Electric Transportation program (P18) continues to explore means of smart charging control of electric vehicle charging.
- Eaton now offers the EMCB device as a commercial product, both as a simple smart breaker and as an electric vehicle charger, under the commercial name “Eaton Smart Breaker”. These are now available for application by interested parties.

EPRI CONTACTS: John Halliwell, Senior Technical Executive, jhalliwell@epri.com

PROGRAM: Electric Transportation (P18)

ADDITIONAL FRONT MATTER SECTION(S)

Abbreviations:

A/C – Air Conditioning

AC – Alternating Current

AMI – Advanced Metering Infrastructure

ANSI – American National Standards Institute

API – Application Programming Interface – a term used to refer to internet/cloud-based service access

CT – Current Transformer – used to measure AC current

EMCB – Energy Management Circuit Breaker – the project name for Eaton's Smart Breaker product

EM - Energy Manager

EPRI – Electric Power Research Institute

EV-EMCB – Electric Vehicle Charger version of the EMCB

GPA – Grid Protection Alliance – company hired to provide software and data services the EPRI project

ID - Identifier

IP – Internet Protocol

kWh – kilowatt-hour – a unit of energy (1kWh = 1000 watt-hours; 1kWh = 3.6 x 10^9 mJ)

mJ – milli-Joule – a unit of energy (1 mJ = 2.778 x 10^{-10} kWh)

NIST – National Institute of Standards and Technology

NTP – Network Time Protocol

PQ – Power Quality

RMS – Root Mean Squared

SQL – Structured Query Language – a standardized programming language used to manage relational databases

TOU – Time of Use – a form of utility rate where pricing of electricity varies with time

UDP – User Datagram Protocol

URL – Uniform Resource Locator – an internet address

UUID – Unique Universal Identifier – a 128-bit value used to uniquely identify and object or entity on the internet

VP – Virtual Peaker – a demand response/management platform service company

Wh – watt-hour – a unit of energy

Wi-Fi – Wireless Fidelity – an acronym for a specific form of wireless communication under IEEE 802.11 standards

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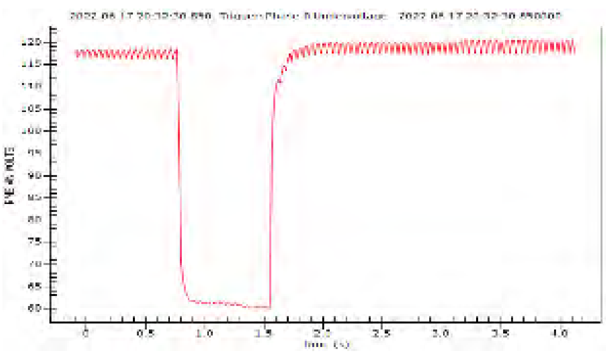
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1 OVERVIEW

The Energy Management Circuit Breaker Project

EPRI worked with a group of eleven funding utilities and with Eaton Corporation to demonstrate tool development for a Wi-Fi enabled smart breaker, referred to in our project as the Energy Management Circuit Breaker (EMCB) that transfers data using internet connectivity. The project ran for a period of just under four years, including through the recent COVID pandemic. While project schedules proved challenging, the project was able to work with third party software developers and EPRI software developers to build tools designed to integrate the EMCB function set into a format that can support utility operations.

The key focus of the project was developing and demonstrating tools that could take advantage of the functions provided by the EMCB that include metering, on/off demand response control, electric vehicle charging, and power quality data capture.

The Energy Management Circuit Breaker – Device Overview

The Energy Management Circuit Breaker (EMCB) combines the functionality of a standard thermal-magnetic circuit breaker with a remotely controllable on/off switch and embeds metrology allowing monitoring of the circuit being protected. The device can support single phase loads at 120/208/240Vac and can be deployed in split-phase and some 3-phase loads centers supporting a single-phase load.

Eaton planned to provide a total of five variations of the EMCB device:

- A single pole plug-on version
- A single pole bolt-on version
- A double pole plug-on version
- A double pole bolt-on version
- An electric vehicle charger version

The EMCB devices are designed as part of Eaton's BR (plug-on) and BAB (bolt-on) family of 1 inch pitch circuit breakers. The devices are listed to be deployed in Eaton branded load centers compatible with their BR and BAB family of breakers. The standard EMCB devices occupy one extra pole space to accommodate the additional electronics embedded in the breaker. The electric vehicle version requires two extra pole spaces to accommodate the added electronics. The devices are illustrated in Figure 1.

Figure 1 Left to Right – Single pole plug-on, double-pole plug-on, double pole bolt-on, electric vehicle version

While code does not mandate one or the other, plug-on breakers are usually the norm for residential load center installations, while bolt-on are used in commercial installations. These variations are shown in Figure 2.

Single pole devices can support 120Vac operation in a split-phase or 208Vac 3-phase load center. Double pole devices can support 240Vac operation in a split-phase load center or 208Vac operation in a 208Vac 3-phase load center.

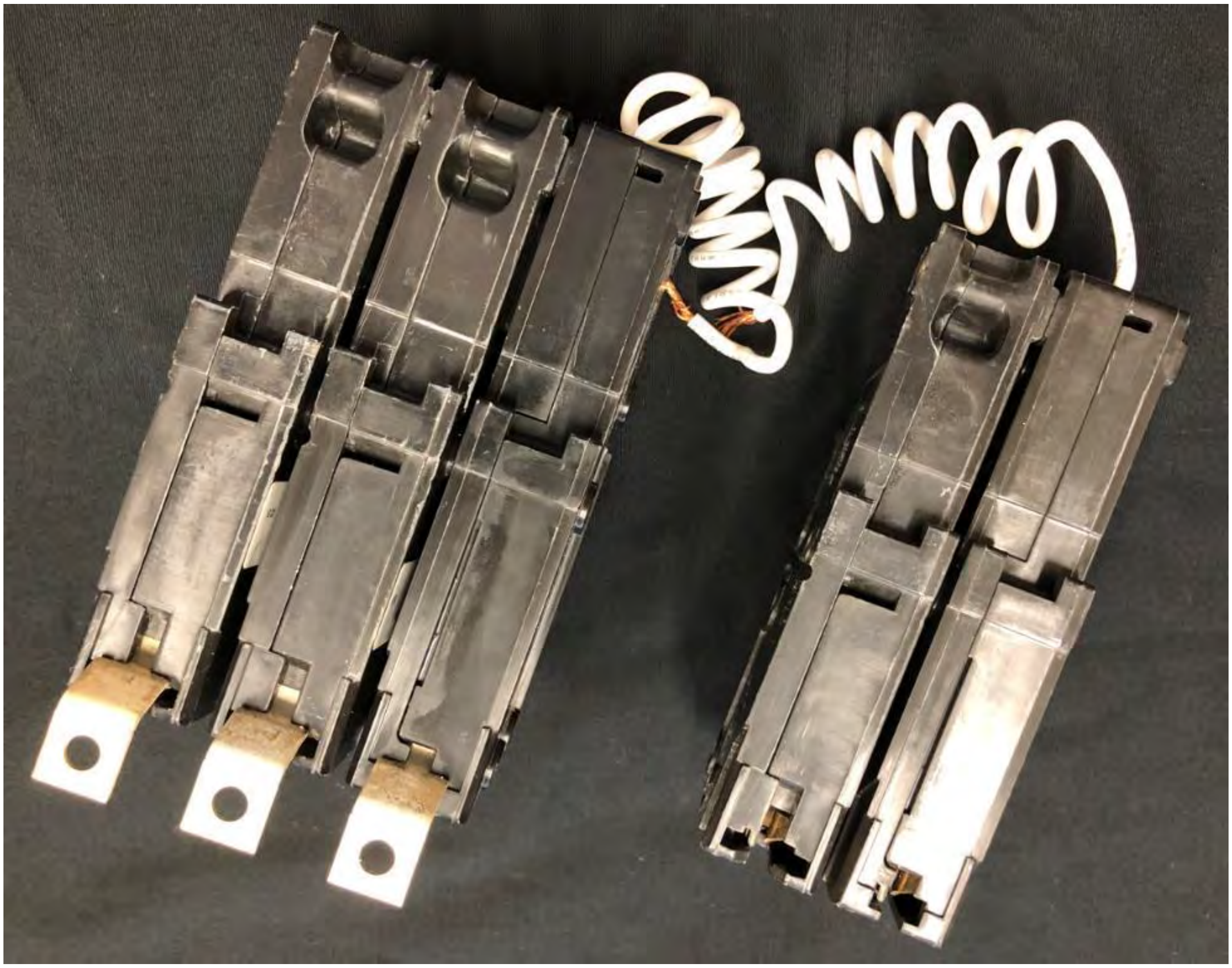


Figure 2 Left – Bolt-on EMCB; Right – Plug-on EMCB

The EV-EMCB has an additional module, taking a total of 4 slots in a load center as illustrated in Figure 3.

Figure 3 Electric Vehicle version of the EMCB. Note that it takes a total of four slots for this two-pole device.

The breakers operate as simple circuit protection devices without communications, providing their expected safety functionality. For remote communications, the breakers rely on a Wi-Fi radio embedded in the device that must be given access to a Wi-Fi network to communicate with Eaton's back office.

For our project Eaton provided a minimal set of tools to configure and commission EMCB devices but did not provide a back office that included tools to operate the devices. EPRI initially was planning to develop support software for the EMCBs in-house but decided that more benefit would be provided to funders by engaging with a commercial software as a service platform. This tool development is addressed in Section 5 of this report.

Project Timeline

The EMCB project was carried out in two distinct phases. This report focuses on phase 2 of the EMCB project.

Phase 1 focused on proof-of-concept of the EMCB device itself and issues related to deployment. The origin of the phase 1 EMCB project goes back to internal work at Eaton in 2013 and discussions with EPRI about building a project in 2014.

The EMCB phase 1 project was proposed in mid-2014 with a planned field test period from April of 2015 to March of 2016. Project was launched in August of 2014 and a contract with Eaton to provide 1000 EMCB devices was signed in June of 2015. The first demo EMCB devices become available in December of 2016 and the first device deployments occurred in January of 2017. The first electric vehicle EMCB was demoed in December of 2017 in the EPRI lab in Knoxville, TN. By August of 2018 nearly 250 EMCB devices had been deployed across 12 participating utilities.

The phase 2 EMCB Project, subject of this report, was targeted to address tool building and integration of the EMCB devices into utility systems. The project kickoff was held in Fall of 2018 with the project planned to run for nominally two years ending in late 2020. Two major impacts occurred just as the phase 2 project was launching:

- Eaton decided that their back-office approach needed revision in order to move to a commercial product.
- The EV-EMCB devices deployed in phase 1 were found to have a flaw that Eaton deemed serious enough that EPRI was asked to stand down use of all of these devices.

The impact of the updated back office was that the 1000 devices EPRI had purchased in the phase 1 project could not be used on Eaton's new back office. In early 2019 EPRI worked with funders to identify what products they would like to deploy in phase 2 and placed orders with Eaton for new EMCB devices for the phase 2 project. The first of the second generation EMCB devices were received in August of 2019 with 143 EMCB devices shipped to EPRI by the end of the month.

The standdown of the electric vehicle devices was initially expected to be limited in duration but ended up stretching until the end of 2022. A number of factors played into this delay including internal Eaton decisions on product development timelines, the COVID pandemic, and parts shortages related to the pandemic. As a stop gap, Eaton was able to remanufacture a small number of EV-EMCBs to support a single test site.

In January of 2020 a total of 12 EV-EMCBs were installed at the EPRI campus in Palo Alto, CA. This was done through field listing of the site since the individual EV-EMCBs had not completed re-certification via UL. Throughout 2020 and 2021 Eaton notified the project team about delays EV-EMCB production.

The COVID pandemic moved EPRI to limited on site work access starting in March of 2020. This greatly limited our lab access and delayed most of the utility work on the project for a period of several months. The EPRI team was able to get an internal waiver allowing for EMCB work to continue in the Knoxville, TN lab facilities in September of 2020.

EPRI worked with the Grid Protection Alliance (GPA) starting in June of 2020 to integrate the new Eaton API data flows to an EPRI housed SQL database. Data service up and running by June 17, 2020 with refinements being carried our over the next several months.

EPRI engaged with Virtual Peaker in mid-2020 with utility access being available to EMCB data on the Virtual Peaker platform in August of 2020.

Orbcomm began work on using local control to perform EV-EMCB charger management in August of 2020. Orbcomm progressed to the level of having ability to control the EV-EMCB devices in Palo Alto remotely but never was able to deliver a functional demo due to staffing issues and the COVID pandemic.

We received notice in October 2020 that Eaton was delaying production of 40A and 50A EMCB devices for minor redesign.

Eaton joined the EMCB phase 2 project as a funder in January 2021 allowing us to extend the term by 2 years to the end of 2022.

In October 2022 Eaton EMCB devices, under the product name “smart breaker” went on sale via Lowes home improvement stores website.

In December 2022 Eaton delivered the first new generation EV-EMCBs. A total of 21 EV-EMCBs were upgraded to the new generation at EPRI’s Palo Alto campus in March of 2023.

Some Key Lessons Learned

A multifunction device like the EMCB is difficult to categorize. It is like a demand response control device in that it can turn a load on and off. It is like a meter as it can accurately meter energy. It is like a low-cost power quality analyzer as it can capture power quality waveforms for voltage and current. For a utility, each of the listed functions is generally provided by a separate device that is supported by a separate software/system tool set. It also became clear that data from these different types of devices would normally be dealt with and used by different departments within a utility and the data used for very different purposes. The consequence of this is that it made finding a single commercial software platform that could fully support the EMCB functionality difficult. In the end, the project performed integrations with more than one vendor to take advantage of the different capabilities of the EMCB device.

This points to a key factor in deployment of a multifunction device. That device is only as flexible as the platform that interacts with it and processes data from the device. This means that a device feature is only available if the platform it is operating on can support that function.

During the project we were able to Integrate of the EMCB device with a commercial demand response software platform and demonstrate the feasibility of using these devices at scale in a utility program. The platform took advantage of the EMCB load control capabilities but required the software vendor to develop a more elaborate interface to allow for ingestion and display of metering data. Power quality functionality of the breaker was not supported.

Wi-Fi networks are widely deployed and the technology to implement a Wi-Fi interface at the product level is very cost competitive, having been miniaturized and mass produced due to widescale deployment in smart phones. While Wi-Fi provides an easy means of developing connectivity that can be embedded in products, gaining access to specific Wi-Fi networks is another story. The bulk of Wi-Fi networks are deployed with security enabled, and for most companies, there is a strong concern for cybersecurity in relationship to what devices are allowed on a network. For utilities, access to company networks is tightly controlled and it remains a challenge to address the cybersecurity concerns with IT system operators for a device like the EMCB. Proving that an internet connected device like the EMCB is not a security risk is nearly an impossible task. We were not able, in this project, to develop a narrative that would allow for deployment of the EMCB on any of our participating utility's network. The work around for the project was to use cellular data modems bypassing the need to use utility networks but doing so at scale would likely be cost prohibitive due to modem cost and monthly data fees. Scale deployment at low cost remains a challenge where tightly controlled Wi-Fi networks are concerned.

Devices that rely on live connectivity for operation have many discrete failure points where multiple vendors are responsible for the communications links. Troubleshooting communications failures can be complex requiring input from multiple players to find the root cause of failure. For our project, a connectivity issue could be within the EMCB device itself, a problem with the cellular data modem or Wi-Fi network the EMCB was operating on, a problem with the network supporting Eaton's back-office API, expired trust certificates on one of the interconnected platforms, a problem with Eaton's back office itself, or a problem with the third-party software platform being used to process EMCB data. A set of comprehensive tools to track communications issues was lacking in our project but would be a necessity for a scale deployment of EMCB like devices.

While the EMCB device collects metering data, getting that data into a format and communications channel to be of use to a utility metering system remains a challenge. Communications links, data protocols and data formatting will need to be addressed if EMCB like devices are to be used as utility meters.

2 TASK 1 – USE CASE DEVELOPMENT

During the EMCB project, a set of base use cases were developed for deployment of the EMCB devices. These use cases were published in EPRI Report 3002019639[1].

[1] Use-Case Specifications for the Energy Management Circuit Breaker (epri.com)

3 TASK 2 – METER TESTING PROTOCOL AND TESTING

Eaton's smart breaker, referred to as Energy Management Circuit Breaker (EMCB) in this test protocol, measures voltage, current, frequency, and inputs from a variety of built-in sensors (see Figure 4). Using measurements of voltage and current, it calculates 4-quadrant energy (that is, bidirectional energy including leading or lagging power factor). It does so within an accuracy of 0.2%, according to Eaton, meeting ANSI C12.20 specifications for revenue metering. Therefore, a potential use case that can be explored for the EMCB is sub-metering for electric vehicle charging, a lighting load, or even an entire 40 or 50 A subpanel.

In order for an EMCB to serve in a revenue metering capacity, it should integrate well with utility systems. An AMI head-end system, for example, may expect data to arrive every 15 minutes and it may expect time stamps to be synchronized to the minute.

Another requirement for revenue metering is no loss of data, even after a power interruption or a temporary loss of communications. These are the types of issues that are addressed in this protocol by characterizing the response of the EMCB under these conditions and by comparing its measurements to that of a reference instrument.

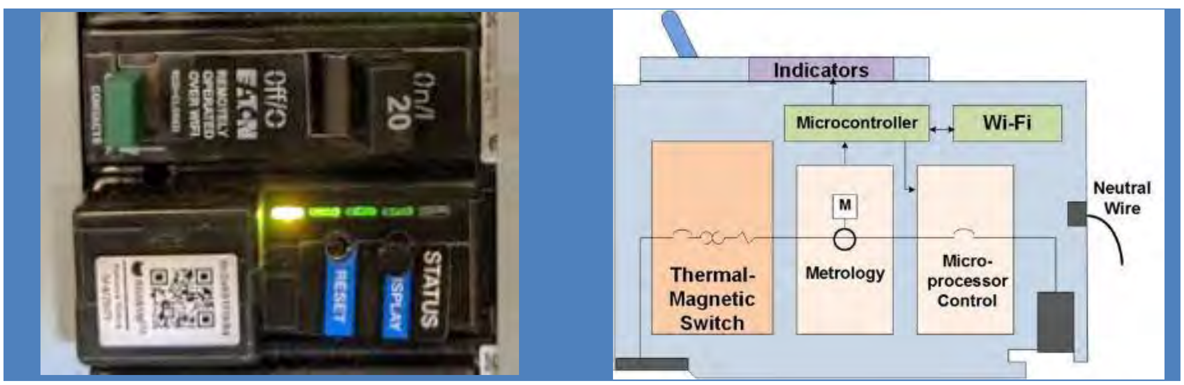


Figure 4. A single pole EMCB device (left) and simplified internal EMCB diagram (right)

Purpose

This test protocol is designed to evaluate the suitability of Eaton's EMCB to function as a revenue meter.

Important factors that are addressed in this protocol include:

- Accuracy of on-board instrumentation compared to a reference instrument
- Time synchronization using NTP server for compatibility with AMI head-end systems
- Data availability after temporary loss of communications
- Data availability in response to temporary loss of AC power

Examples of important considerations that are not addressed in this protocol include:

- NIST traceable certificates of calibration from the manufacturer
- Population sampling
- Temperature range over which the measurement accuracy is guaranteed
- Testing over the full range of load
- Testing over different breaker sizes and pole configurations
- Testing over different EMCB hardware/firmware revisions

Equipment Needed for EMCB Testing

1. A calibrated power meter, to be used as a reference instrument, having an accuracy specification of 0.02% or better (10x that of the ANSI revenue meter specification). Be sure to include the CT accuracy in the total accuracy assessment for the reference meter.
2. 2.Familiarity with Eaton's API and access to an API communicator tool such as Postman.
3. 3.A Wi-Fi router under test control (one which can be switched on or off)
4. 4.Resistive loads for 120V and 240V AC supply (values determined by test)
5. 5.Capacitive loads for 120V and 240V AC supply (values determined by test)

Test Preparation

All tests in this protocol use the same physical test setup as shown in Figure 5(shown for a 2-pole breaker under test).

1. First, connect the EMCB, instrumentation and loads. Be careful to connect the benchtop instrumentation downstream of the EMCB, as shown in Figure 5, so that the benchtop meter will include only load current and not the power drawn by the EMCB electronics.
2. By default, the EMCB clock is not synchronized to the minute. It will be necessary to synch the EMCB clock using the API as follows:
    - Method: PUT
    - URL: /devices/UUID/telemetry/settings/alignment
    - Body: {"alignment": "clock"}
3. Become familiar with the telemetry data from the EMCB. In the Eaton API, you can poll for a short report or a full report. The differences are described in Appendix A. Use the following for a short report:
    a. Method: GET
    b. URL: /devices/UUID/data/telemetry/meter/latest
    c. Body: leave blank

    Or the following for a full report:

d. Method: GET
e. URL: /deviceData?$filter=deviceId eq '{UUID}'
f. Body: leave blank

Either report is sufficient for the tests in this protocol. Both reports contain the parameter of interest, which is “energy delivered.” A sample excerpt is provided here. Note that “deliveredWH” is available, but in a lower resolution than needed for the purposes of this protocol. Instead, use “delivered” under “energy” in units of mJ. To convert mJ to Wh, divide by 3.6 x 106.

```
"energy": {
  "generatedWH": 0.89,
  "deliveredWH": 69556.1,
  "generated": 3214560,
  "delivered": 250401947025
},
```

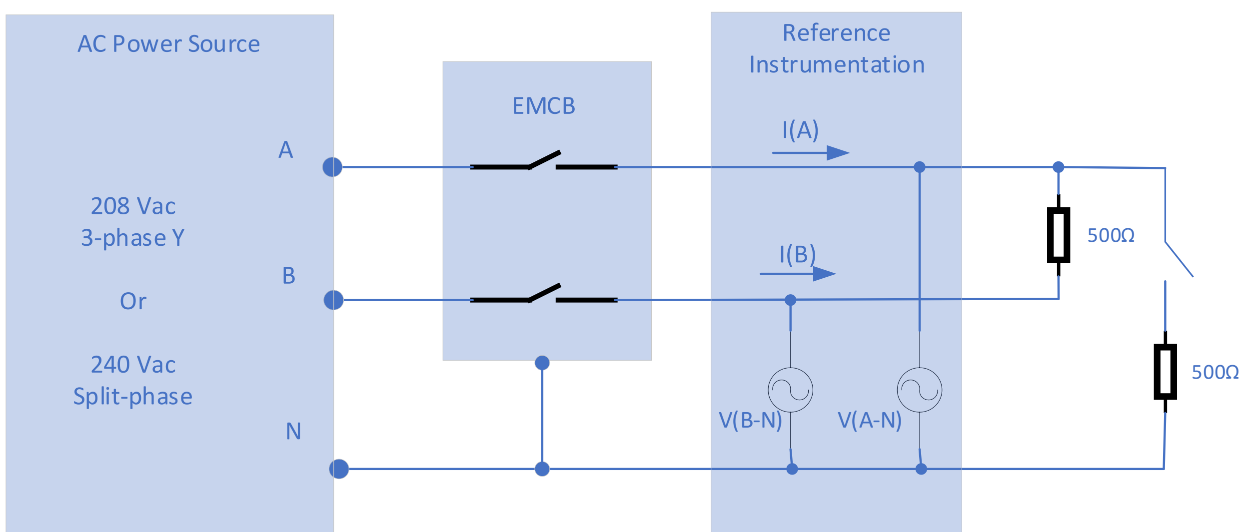


Figure 5. General Test Setup Showing 2-pole EMCB Example

General Procedure for All Tests

The objective is to accurately measure all energy being delivered to the loads over a specific test period, usually defined as one hour. Instruments are readied while the loads are initially OFF. At a specific time, the instruments begin their energy measurements and then the load is switched ON. After the test period, the loads are shut off and the instruments are polled for their readings. This timing is depicted in Figure 6. Because the EMCB updates every 5 minutes, it is important to know exactly when that update occurs so that instrument readings and load energization can be synchronized to this boundary.

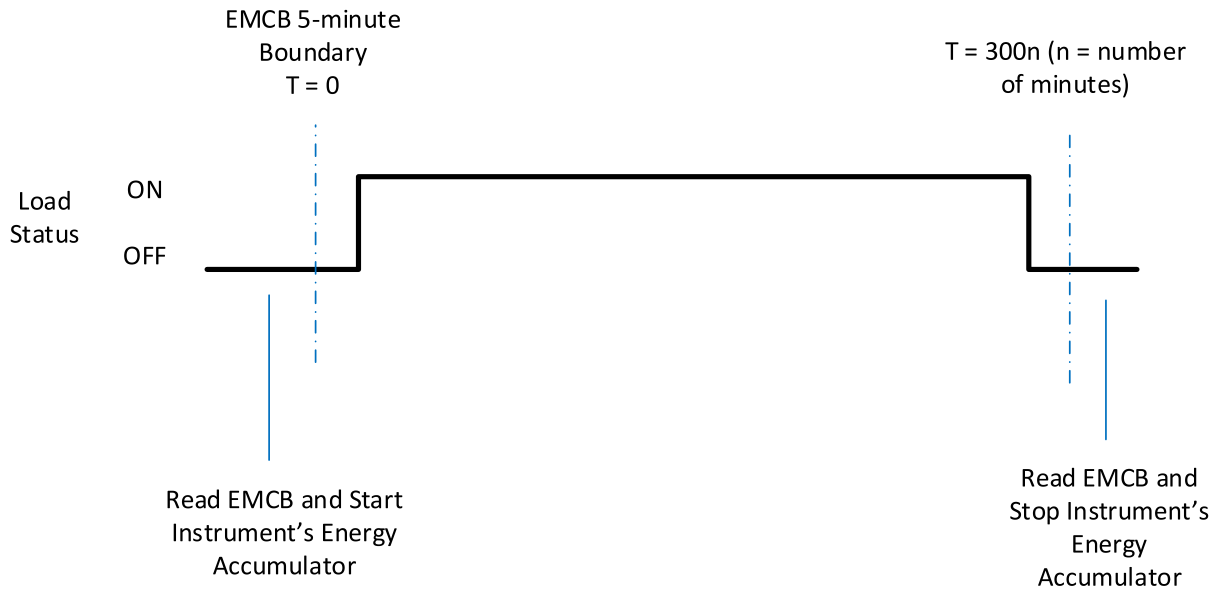


Figure 6. Timing Diagram for Timed Tests

The procedure is as follows:

1. Verify the 5-minute boundary for telemetry data of the EMCB by reading a timestamp. For example, the timestamp may be 4:05:01.
2. At approximately 30 seconds before the 5-minute interval boundary,
    a. Shut off all loads. The EMCB breaker handle is suitable if no external load switch is available.
    b. Reset the reference instrument's energy accumulator to zero.
    c. Read the EMCB using the API call "Get Device Data" or "Get Latest Telemetry Data." Keep the response for evaluation later.
3. At approximately 10 seconds after the 5-minute interval boundary,
    a. Start the reference instrument's integrator.
    b. Switch on the load(s).
4. Wait for the dwell duration (typically 1 hour or 24 hours)
5. At approximately 30 seconds before the last 5-minute boundary of the dwell period (e.g. 1 hour) defined in the test, switch off the loads.
6. At approximately 10 seconds after the last 5-minute boundary of the dwell period in the test,
    a. Read the EMCB using the API call "Get Device Data" or "Get Latest Telemetry Data." Keep the response for evaluation later.
    b. Stop or hold the reference meter's integrator.
7. Browse the first and second energy readings from the EMCB
    a. Look for the the parameter "Energy Delivered" (not "EnergyDelta"). The value is reported in mJ and is at full resolution.
    b. Subtract the first reading from the second reading.
    c. Divide by 3,600,000 to convert mJ to Watt-hours.
8. Assess the energy reading from the reference instrument

9. Calculate percent error: ((RefMeter-EMCB) / RefMeter) * 100

Test 1 – Meter Accuracy Evaluation

This test involves a measure of energy consumed over a defined period. The EMCB is compared against a reference meter.

1. Connect the EMCB to a 120/240 V split-phase AC source.
2. Test over range of resistive load for one hour at each load
    a. Test 1a: 0.5A on phase A-N and phase B-N
    b. Test 1b: 25% full scale (e.g. 5 A on a 20A breaker)
    c. Test 1c: 50% full scale (e.g. 10 A on a 20A breaker)
    d. Test 1d: 100% full scale
3. Test for accurate energy metering with low power factor
    a. Test 1e: Connect 25% of full-scale load and add capacitive load sufficient to reduce the power factor to approximately 0.7.
4. Optional: Repeat Tests 1a – 1e with a source voltage of 208V having 120° angle between phases.

Test 2 – Data Availability After Loss of Communications

The purpose of the test is to document the EMCB behavior in response to temporary loss of communications. If the EMCB is to play a role in energy metering, it must continue to measure energy consumption during a loss of communication. Further, it should report meaningful and accurate data upon the return of communication without any loss of data.

1. Supply an AC source, either 208 V or 240 V AC.
2. Load the EMCB approximately 25%.
3. Connect the EMCB to a Wi-Fi network that can be controlled by the test operator.
4. Begin a one-hour timed test as in Test 1. Use the timing diagram in **Error! Reference source not found.**.
5. Approximately 15 minutes after the beginning of the 1-hour test, switch OFF the router. Verify that the EMCB has lost communications by observing its connection LED. It should flash RED when communication is lost).
6. At approximately 45 minutes into the 1-hour period, switch ON the router and observe the EMCB reconnecting to Wi-Fi.
7. At the end of the 1-hour period, following the timing diagram in **Error! Reference source not found.**, shut off the loads and compare the instrument readings.
8. Repeat this test for a 24-hour test period.

Test 3 – Data Availability After Loss of AC Power

The purpose of the test is to document the EMCB behavior in response to temporary loss of AC power. If the EMCB is to play a role in energy metering, it must continue to measure energy consumption during a loss of AC power. Further, it should report meaningful and accurate data upon the return of communication without data loss.

1. Connect the EMCB to an AC source (either 208 V or 240 V AC) that can be controlled by the test operator, but power the reference instrument separately so as not to interrupt its measurement.
2. Load the EMCB approximately 25%.
3. Begin a one-hour timed test as in Test 1. Use the timing diagram in **Error! Reference source not found.**.
4. Approximately 15 minutes after the beginning of the 1-hour test, switch OFF the AC power.
5. At approximately 45 minutes into the 1-hour period, switch ON the AC power and observe the EMCB rebooting and connecting to Wi-Fi.
6. At the end of the 1-hour period, following the timing diagram in **Error! Reference source not found.**, shut off the loads and compare the instrument readings.
7. Repeat this test for a 24-hour test period.

Details of EMCB Data Using Application Programming Interface Requests

This section details how data was received from the EMCB devices using Eaton's Application Programming Interface (API). It should be noted that Eaton has refined and modified their API over the course of the project. It is recommended that an interested reader consult with Eaton's online API documentation[2] for the latest format and data content of their supported API queries.

Comparison of Two Types of Data Requests: "Get Device Data" and "Get Latest Telemetry Data"

Energy data can be retrieved from an EMCB in two different ways: an abbreviated report and a full report. These two queries produce slightly different responses. The table below compares these two readings polled from the same device.

Note that *Energy Delta* refers to the energy delivered since the last update. This is normally 5-minutes, expressed as seconds in the parameter Delta Time. Energy Delta will not be useful for tests in this protocol lasting more than 5 minutes. In contrast, the *Energy* reading is an

[2] https://api.em.eaton.com/docs

accumulated value. Using this parameter requires calculating the difference between two readings, noting the time stamps.

Table 1. EMCB Data – Comparing Two Types of Data Request

General Description	Get Device Data (full report)	Get Latest Telemetry Data (short report)	Units	Notes
Energy Delivered	250401947025	250401947025	mJ	
Energy Delivered WH	69556.09	69556.1	W·h	Note the rounding.
Energy Generated	3214560	3214560	mJ	
Energy Generated WH	0.8929333	0.89	W·h	Note the rounding.
EnergyDelta Delivered	5584265	5584265	mJ	
EnergyDelta Delivered WH	1.5511848	1.55	W·h	Note the rounding.
EnergyDelta Generated	0	0	mJ	
EnergyDelta Generated WH	0	0	W·h	
Delta Time	301	301	seconds	
Time Stamp	1656094934	1656094932	Epoch time in seconds	

Full Text of an API Response to "Get Latest Telemetry Data"


```
{
 "data": {
  "energyDelta": {
   "generatedWH": 0,
   "deliveredWH": 1.55,
   "deltaTime": 301,
   "generated": 0,
   "delivered": 5584265
  },
  "currentA": {
   "min": 181,
   "max": 183,
   "avg": 183,
   "val": 182
  },
  "energy": {
   "generatedWH": 0.89,
   "deliveredWH": 69556.1,
   "generated": 3214560,
```

```
      "delivered": 250401947025
    },
    "frequency": {
      "min": 59973,
      "max": 60027,
      "avg": 59991,
      "val": 60003
    },
    "voltageAN": {
      "min": 115060,
      "max": 115484,
      "avg": 115281,
      "val": 115066
    },
    "hwSamples": 75,
    "ts": 1656094932
  }
}
```


Full Text of Response to "*Get Device Data*"


```
{
  "data": {
    "accelerometer": {
      "telemetry": {
        "x": {
          "val": 0.004
        },
        "ts": 1656094934,
        "y": {
          "val": 1.028
        },
        "z": {
          "val": 0.036
        }
      }
    },
    "breaker": {
      "metadata": {
        "ratedVoltage": {
          "val": 120,
          "ts": 1656003806
        },
        "ratedCurrent": {
          "val": 20,
          "ts": 1656003806
        },
        "numPoles": {
          "val": 1,
          "ts": 1656003806
        }
      },
      "settings": {
        "remoteHandlePosition": {
          "val": true,
```

"ts": 1654548177
}
}
},
"device": {
"telemetry": {
"lightLevel": {
"val": 32279
},
"ts": 1656094934,
"deviceFreeMemory": {
"val": 42788
},
"rssi": {
"val": -21
}
},
"metadata": {
"isConnected": {
"val": false,
"ts": 1656095219
},
"numBoots": {
"val": 800,
"ts": 1656094042
},
"numWakeReasonException": {
"val": 4,
"ts": 1656093850
},
"macAddress": {
"val": "0c2a690e1a94",
"ts": 1656094042
},
"ipAddress": {
"val": "192.168.0.124",
"ts": 1656094042
},
"bootROM": {
"val": "e87ddfb - release-38.17 - Thu Nov 15 09:49:52 2018 - eaton",
"ts": 1656094042
},
"osDevice": {
"val": "ba1d312 - release-42.6 - Wed Apr 28 09:07:31 2021 - eaton",
"ts": 1656094042
},
"osAgent": {
"val": "4b7c94b - v2.60.0 - Tue Apr 20 08:04:55 2021 - Electric Imp",
"ts": 1656094044
},
"idDeployment": {
"val": "058bc775-e065-3cca-82f6-7710d6463e53",
"ts": 1656094044
}
}
},

```
"meter": {
 "telemetry": {
  "currentA": {
   "val": 182
  },
  "ts": 1656094934,
  "voltageAN": {
   "val": 115066
  },
  "frequency": {
   "val": 60003
  },
  "rawEnergy": {
   "q1mJpA": 12273340,
   "q2mJpA": 2734196,
   "q3mJpA": 422806,
   "q4mJpA": 250387893254,
   "q1mJpB": 1766155,
   "q2mJpB": 57558,
   "q3mJpB": 0,
   "q4mJpB": 14276,
   "q1mVARspA": 76970032,
   "q2mVARspA": 25142398,
   "q3mVARspA": 2835901,
   "q4mVARspA": 74895891122,
   "q1mVARspB": 110868810,
   "q2mVARspB": 767016,
   "q3mVARspB": 225071,
   "q4mVARspB": 118319
  },
  "rawEnergyDelta": {
   "q1mJpA": 0,
   "q2mJpA": 0,
   "q3mJpA": 0,
   "q4mJpA": 5584265,
   "q1mJpB": 0,
   "q2mJpB": 0,
   "q3mJpB": 0,
   "q4mJpB": 0,
   "q1mVARspA": 0,
   "q2mVARspA": 0,
   "q3mVARspA": 0,
   "q4mVARspA": 1415849,
   "q1mVARspB": 0,
   "q2mVARspB": 0,
   "q3mVARspB": 0,
   "q4mVARspB": 0,
   "deltaTime": 301
  },
  "energy": {
   "delivered": 250401947025,
   "deliveredWH": 69556.09,
   "generated": 3214560,
   "generatedWH": 0.8929333
  },
  "energyDelta": {
```

```
        "generated": 0,
        "delivered": 5584265,
        "deliveredWH": 1.5511848,
        "generatedWH": 0,
        "deltaTime": 301
      }
    },
    "metadata": {
      "loadPresent": {
        "val": true,
        "ts": 1654548181
      },
      "loadState": {
        "val": 1,
        "ts": 1654548181
      }
    }
  },
  "thermometer": {
    "telemetry": {
      "temperature": {
        "val": 88.5875
      },
      "ts": 1656094934
    }
  },
  "deviceId": "{daa69b7c-5de7-4f38-83f5-7501beb3f130}",
  "serialNumber": "30000c2a690e1a94"
 }
}
```


Testing Using the Protocol

The Test Plan was used to make measurements of EMCB accuracy in May of 2022. Accuracy was found to be better than the specified 0.2% for resistive loads – worst case measured error was 0.017%. Slides presented in Figures 7 through 11 illustrate the work.

EMCB Energy Metering – Test Plan

- Test against a benchtop meter for accuracy.
  - AC supply 208V and 240V
  - Combination of L-N and L-L connected loads
- Test response to loss of AC power for 30 minutes. If ok, extend to 24 hours.
- Loads with non-unity power factor.
- Repeat some tests at higher/lower current demand.
- Test response to loss of Wi-Fi for 30 minutes. If ok, extend to 24 hours.
- Interval and clock synch issues:
  - EMCB reports average values every 5 minutes
  - EMCB doesn't synch to clock by default, but has the capability
  - Assess clock drift within 24-hour period

Figure 7 – Test Plan Summary

Test Setup

- Test 1: Switch SW1open
- Test 2: Switch SW1 closed

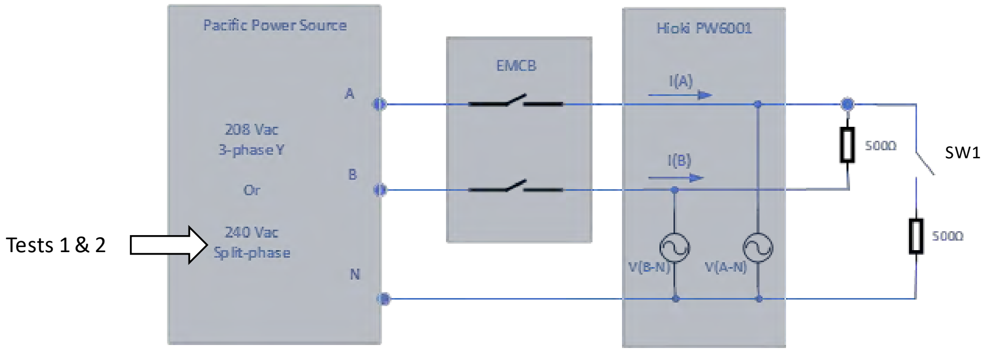


Figure 8 – Test Setup Illustrated

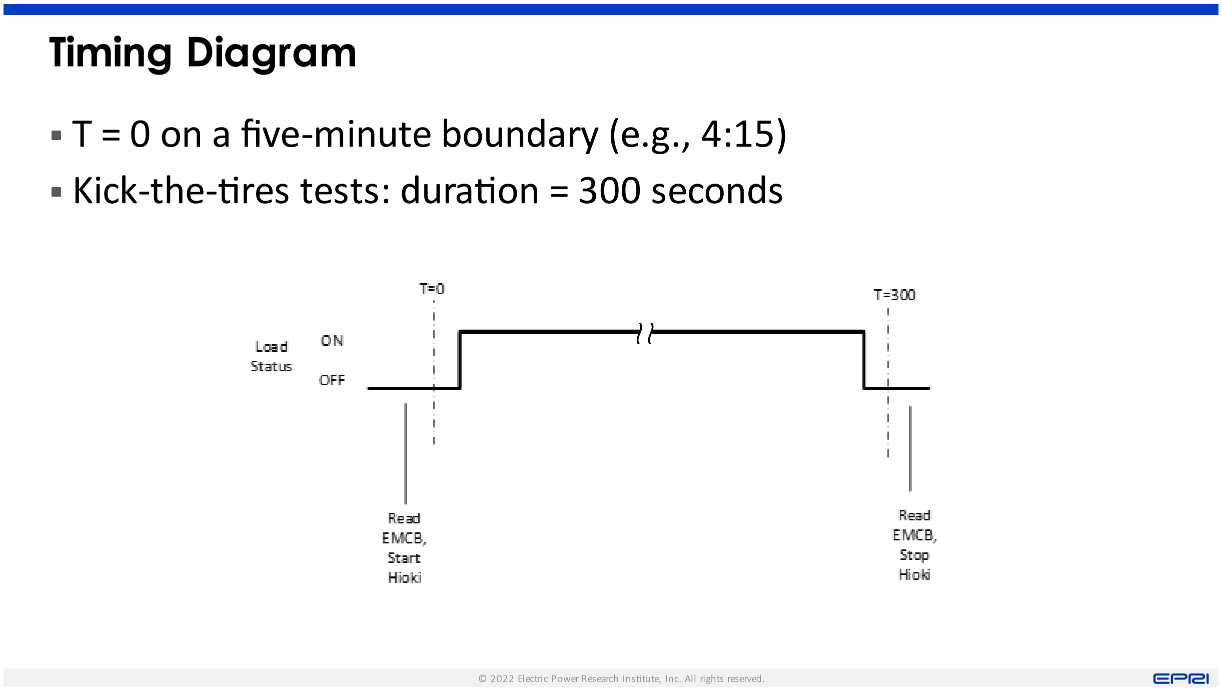


Figure 9 – Testing Timing Diagram Illustrated

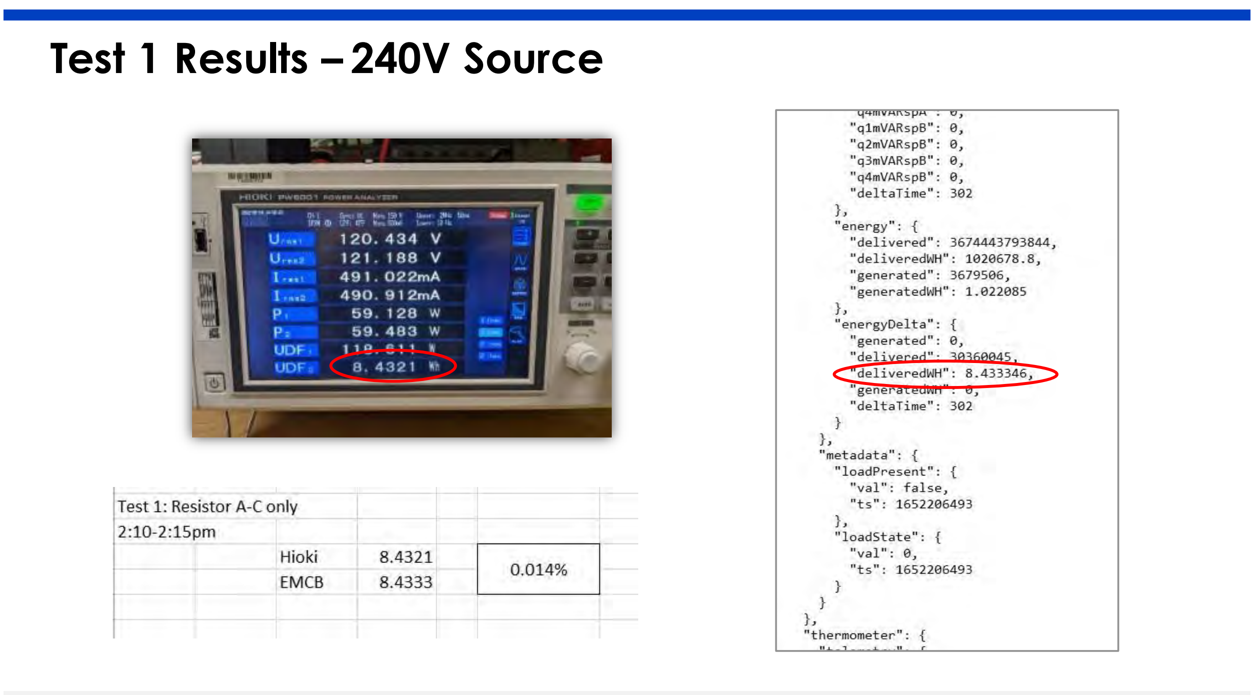


Figure 10 – Test 1 - 240V Test Results

Test 2 Results – 240V Source

Test 2: Resitor A-C and A-N			
4:10-4:15pm			
	Hioki	11.4322	0.001%
	EMCB	11.4323	

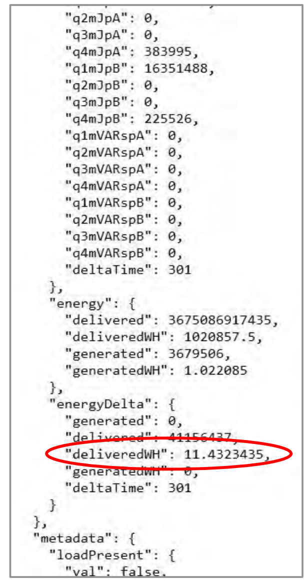

"q2mJpA": 0,
"q3mJpA": 0,
"q4mJpA": 383995,
"q1mJpB": 16351488,
"q2mJpB": 0,
"q3mJpB": 0,
"q4mJpB": 225526,
"q1mVARspA": 0,
"q2mVARspA": 0,
"q3mVARspA": 0,
"q4mVARspA": 0,
"q1mVARspB": 0,
"q2mVARspB": 0,
"q3mVARspB": 0,
"q4mVARspB": 0,
"deltaTime": 301
},
"energy": {
"delivered": 3675086917435,
"deliveredWH": 1020857.5,
"generated": 3679506,
"generatedWH": 1.022085
},
"energyDelta": {
"generated": 0,
"delivered": 41156437,
"deliveredWH": 11.4323435,
"generatedWH": 0,
"deltaTime": 301
}
},
"metadata": {
"loadPresent": {
"val": false,

Figure 11 – Test 2 240V Results

One-hour Test at 208V

- Source: 208V
- Switch SW1 closed

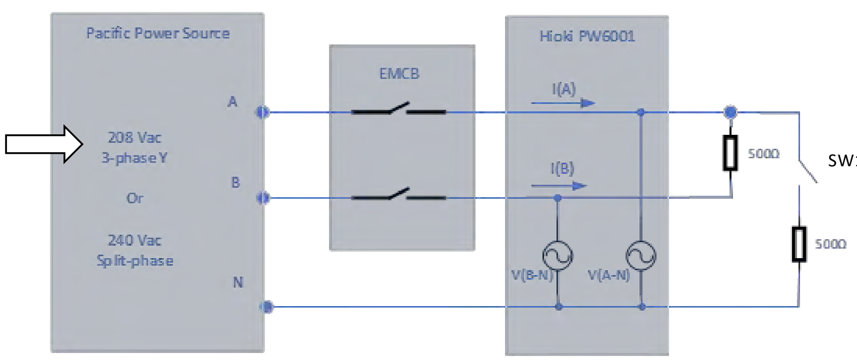


Figure 12 – One Hour Duration 208V Test Setup

Results: One-hour Test

- Source: 208V
- SW1 closed (load A-B and A-N)

EMCB Raw Data

10:55am

"energy": {
"delivered": 3675768298151,
"deliveredWH": 1021046.75,
"generated": 3683150,
"generatedWH": 1.0230973
},

9:55am

"energy": {
"delivered": 3675346887107,
"deliveredWH": 1020929.7,
"generated": 3683150,
"generatedWH": 1.0230973
},

EMCB	9:55	3.676E+12
	10:55	3.675E+12
	diff (mJ)	421411044
	diff (Wh)	117.05862
Hioki	Hioki	117.078
% Difference		0.0166%

EPRI

Figure 13 – Results of the 1-hour 208V Test

4 TASK 3 – DATA ANALYTICS TOOL SPECIFICATION

The Data Analytics Tool Specification was published in EPRI Report 3002023208[3].

[3] Integration of an Energy Management Circuit Breaker into Utility Systems: Tool Development (epri.com)

5 TASK 4 – DATA ANALYTICS TOOL DEVELOPMENT, DEPLOYMENT, AND DATA COLLECTION

One of the key goals of the project was to develop tools that would all an EMCB-like, Wi-Fi based device to function as a utility asset. Given the broad capabilities of the EMCB, this was realized via multiple tools and vendors.

EPRI Interaction with Software Vendors

Eaton's multi-function smart breaker includes capabilities like RMS trending, triggered waveform snapshot, fast RMS capture, on/off control, and additional hardware features. Currently, however, Eaton does not offer a software suite that takes advantage of these hardware features and that is geared toward the needs of utilities. Instead, exposes an API so that third party software vendors can provide the applications for their specific audience. Thus, the features that are ultimately exposed to the end user are limited in scope by the software vendor.

In an effort to maximize the value of the EMCB for project funders, EPRI involved multiple software vendors, each servicing a particular use case or aspect of the EMCB. For example, some funding members in EPRI's Phase II project are interested in using the EMCB as a power quality tool. Satisfying this case would utilize the EMCB's excursion triggering and waveform snapshot capabilities, whereas a completely different feature set would be used to satisfy another use case such as a utility-scaled demand response platform.

EPRI contracted with three software vendors, each selected to develop a tool (or tools) to address a particular use case or application as shown in **Error! Reference source not found.** and described individually in the following sections.

Table 2. EMCB Use Case and Associated Vendor Contracted by EPRI

Application	Vendor
Power quality	Grid Protection Alliance
Data archiving	Grid Protection Alliance
Demand Response and RMS data visualization (both aggregated and individual breaker)	Virtual Peaker
EV charge management application for EV-EMCB using local control	OrbComm

The Power Quality Tools noted here are described in more detail in Chapter 9 "Power Quality Activities".

Demand Response and RMS Data Visualization – Virtual Peaker

EPRI worked with Virtual Peaker, a software as a service company, to integrate and provide online tools for EMCB data display and device management. This system came online in March of 2019. Virtual Peaker already had an established platform for demand response that communicates with many OEM devices such as thermostats. For a fee, funded by members of EMCB Phase II, Virtual Peaker integrated the EMCB as a new device into their existing platform. Virtual Peaker's platform, built for scale, includes software features such as device management, user enrollment, logical groupings for devices, event scheduling, analytics, and historian. It also lets the user browse by device and graph 5-minute interval RMS voltage, current, and power data for one day, one week, or one month at a time.

Project funders were given access to the Virtual Peaker toolset beginning Q2 of 2019 through a shared account. Members were able to see and control their own devices and because the account was shared, they could browse other members' device data. Using the honor system, members agreed to control only their own devices. Members were given anonymized usernames such as UTIL1, UTIL2, UTIL3, etc., so that they could easily identify their own devices while being able to view anonymized data from other member's devices. The Virtual Peaker service was live until the end of 2022.

EV Charge Management via Local Control - Orbcomm

EPRI worked with OrbComm to develop a set of site management tools for a deployment of electric vehicle version EMCB devices at EPRI's campus in Palo Alto California. At the time, Eaton was soon to release a new version of their API and a 2nd generation EV-EMCB, but having no concrete release dates, EPRI contracted with OrbComm to begin the work using current versions with the option to modify code in the future as Eaton released updates. The scope of work is given in Figure 14. That work proved to be unsuccessful, with OrbComm's software team failing to complete the code development work. This was attributed to impacts of COVID-19 which struck India (where much of the code work was being completed) very hard. Lack of staff continuity was the primary issue. In response, OrbComm proposed to provide the code to EPRI in its unfinished state. EPRI considered the option, but ultimately decided to discontinue the work.

Details of the proposed control algorithm for EV charging control is detailed in Appendix F.

Introduction and Background

Phase 2 of the Energy Management Circuit Breaker (EMCB) project is underway. This phase of the EMCB project is focused on development of supporting software tools for the EMCB to enable utilities to make use of fielded EMCB devices and the data they produce. As a part this effort, there is interest in developing tools that can manage the electric vehicle version of the EMCB devices (EV-EMCB).

Objectives

Develop a tool that allows for remote peak power management and monitoring of the EV-EMCB devices installed at EPRI's Palo Alto office facilities.

Third Party Intellectual Property

Orbcomm will be using a platform that they have developed to perform the control functionality.

Tasks

Two tasks have been identified for this effort and are detailed following.

1. **EV-EMCB Integration**
   Orbcomm will work with EPRI to define a simple system that integrates monitoring and control of the Palo Alto EV-EMCBs into a cloud-based platform service. Orbcomm with work with EPRI to define tool capabilities and the user interface. The user interface shall provide a way for inputting a system "maximum-power-capacity" in kW. Orbcomm will integrate their system with Eaton's EMCB API service to manage up to 21 Eaton EV-EMCB devices.

2. **Peak Power Management Demonstration**
   Orbcomm will support EPRI in performing demonstration of peak power management with the set of EV-EMCB devices noted in Task 1 using the tool defined in Task 1. The field demonstration would run from roughly August 2020 through August of 2021. Orbcomm will implement this algorithm provided by EPRI:

Figure 14. Statement of Work to Orbcomm for EV-EMCB Demonstration in Palo Alto

Using the Eaton API to Control and Interact with EMCB Devices

On October 12-13, 2022, at a face-to-face member meeting in Pittsburgh, PA, Viswanath Ananth of EPRI demonstrated his successful implementation of local control using Eaton's latest hardware and the new commercial API. Select slides from that presentation are shown below as Figure 15 through Figure 22. The full presentation can be found in Appendix D.

15 shows the landing page of Eaton's developer portal where documentation exits for 3rd party integrators and software developers to develop applications with Eaton's API. Specific documentation on local control is shown in 16.

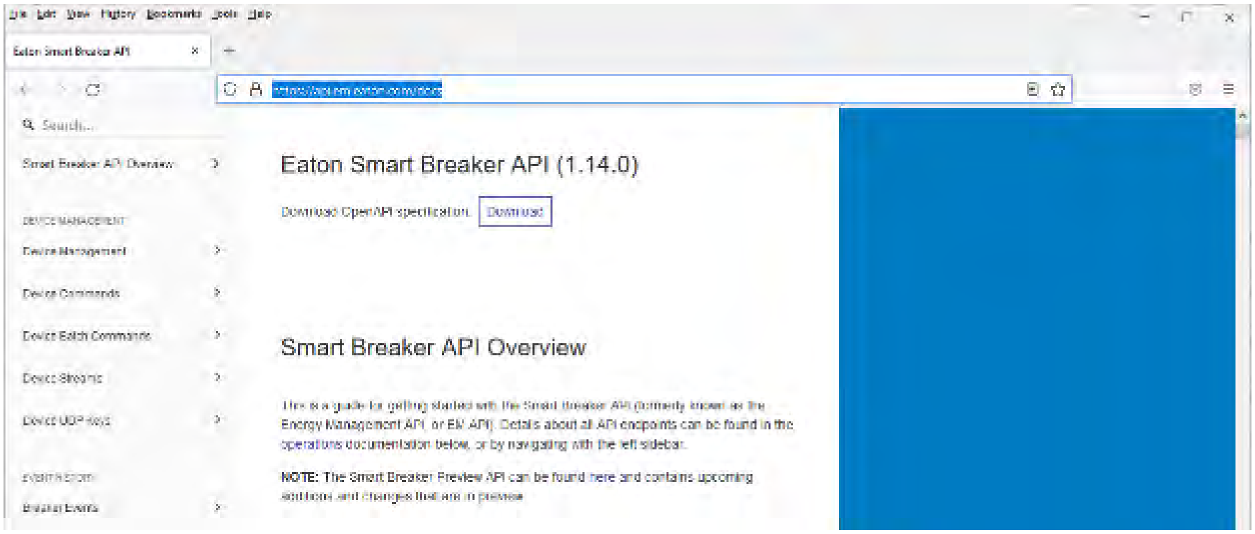


Figure 15. Cloud Based Control of EMCBs Through Eaton's Application Programming Interface[4]

Local Control of EMCB Devices

See appendix D for a more in-depth discussion of local EMCB control.

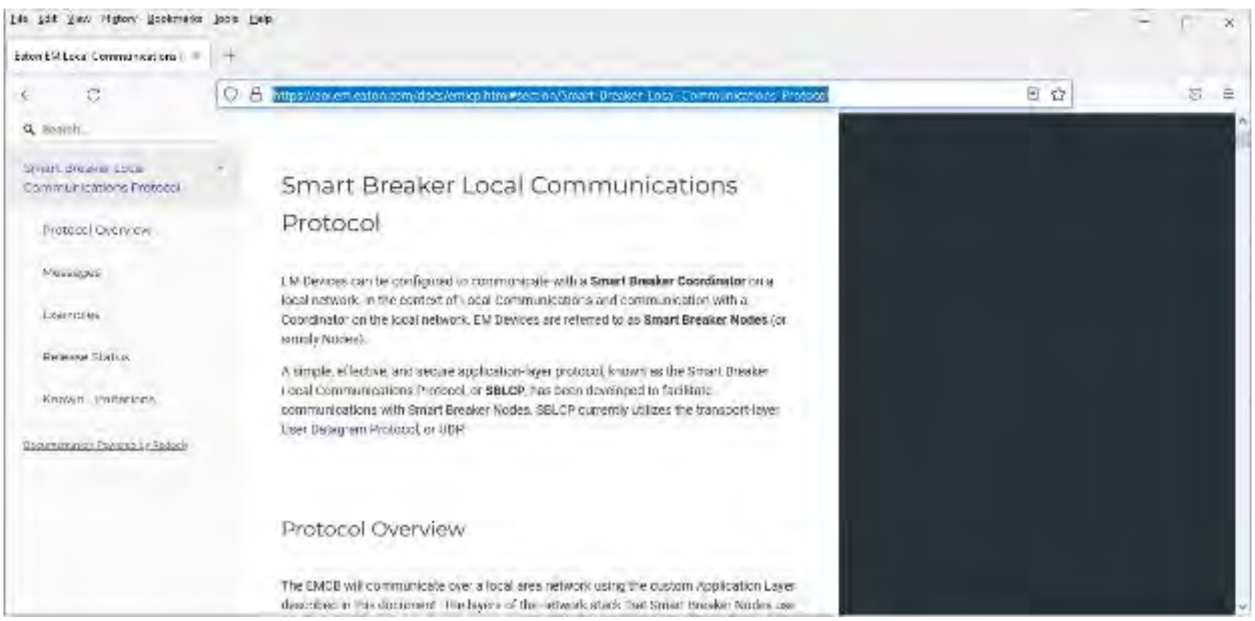


Figure 16. Local Control of EMCBs[5]

[4] https://api.em.eaton.com/docs

[5] https://api.em.eaton.com/docs/emlcp.html#section/Smart-Breaker-Local-Communications-Protocol

Key learnings on local control, taken from Eaton's website and through conversations with technical support, are summarized in Figure 17 and Figure 18.

Local Control of EMCBs

- Requires a local controller to execute in the same LAN as the nodes
  - Discover nodes in the local network
  - Control and status messages to be initiated by controller, and responses provided by nodes
- Communication by the nodes are based on:

  Transport Layer: User Datagram Protocol (UDP)

  Network Layer: Internet Protocol (IP)

  Physical Layer: Wi-Fi (2.4 GHz)

  Nodes will listen to the network's broadcast address as well as their individual IP addresses (for unicast messages) on **port 32866**. Nodes will reply to the source address and port for received and validated datagrams. Invalid datagrams will fail silently, with no response.

Figure 17. Local Control Lessons Learned (1 of 2)

Local Control of EMCBs

- Security of the local messaging is controlled by
  - sequence number (chosen randomly by a node at bootup time)
  - cryptographic signature that is attached to every message
  - Allocation of unicast and broadcast symmetric keys called "UDPKeys" in documentation in the devices (requires cloud API access for setup)
- Setup of UDPKeys in the device
  - Generate UDPKeys using cloud API (unicast and broadcast) expires in 7 days
  - Allocate generated keys to devices using cloud API
  - Regenerate and re-allocate UDPKeys before they expire to continue to use the local controller.

Figure 18. Local Control Lessons Learned (2 of 2)

Figure 19 is a system-level diagram showing how local control works. In this configuration, the EMCB can work without an Internet connection for about 7 days, at which time, the API security key needs to be renewed.

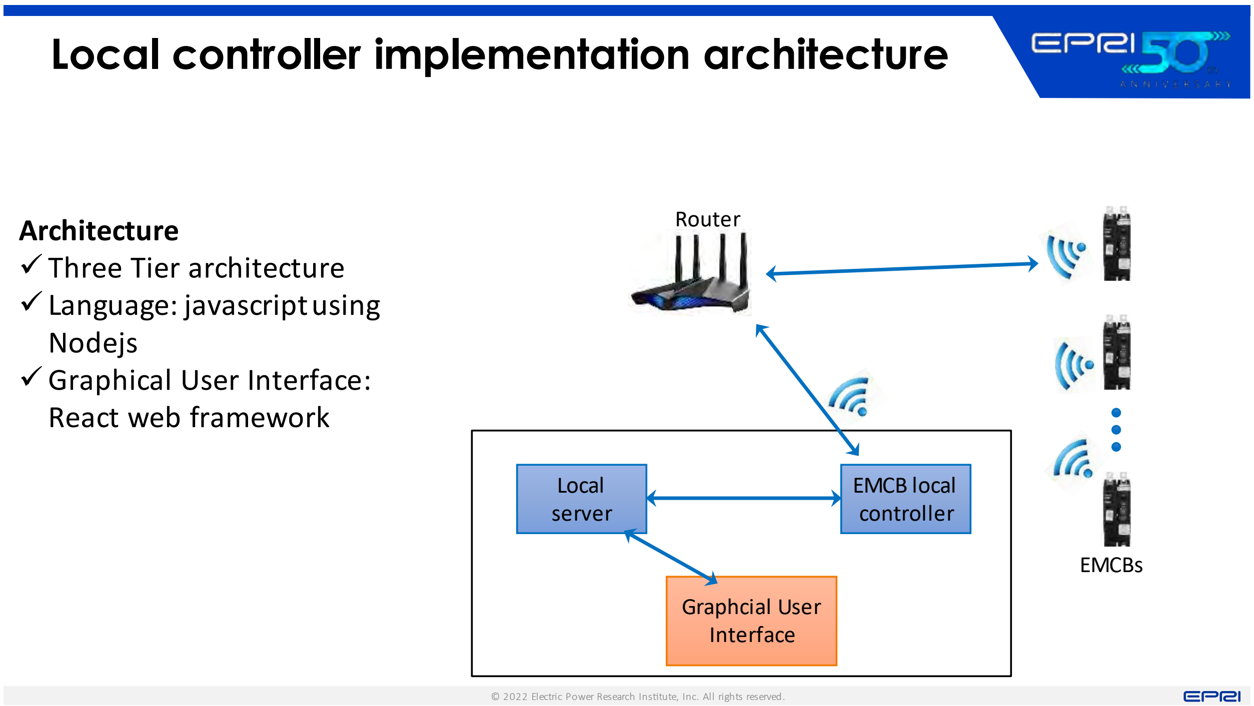


Figure 19. Local Controller Implementation Architecture

Having gone through the exercise in-house, EPRI benefits from the learnings and can pass those learnings to members who might also want to develop applications. Figure 20 lists some key suggestions from the experience of having developed a simple local control application.

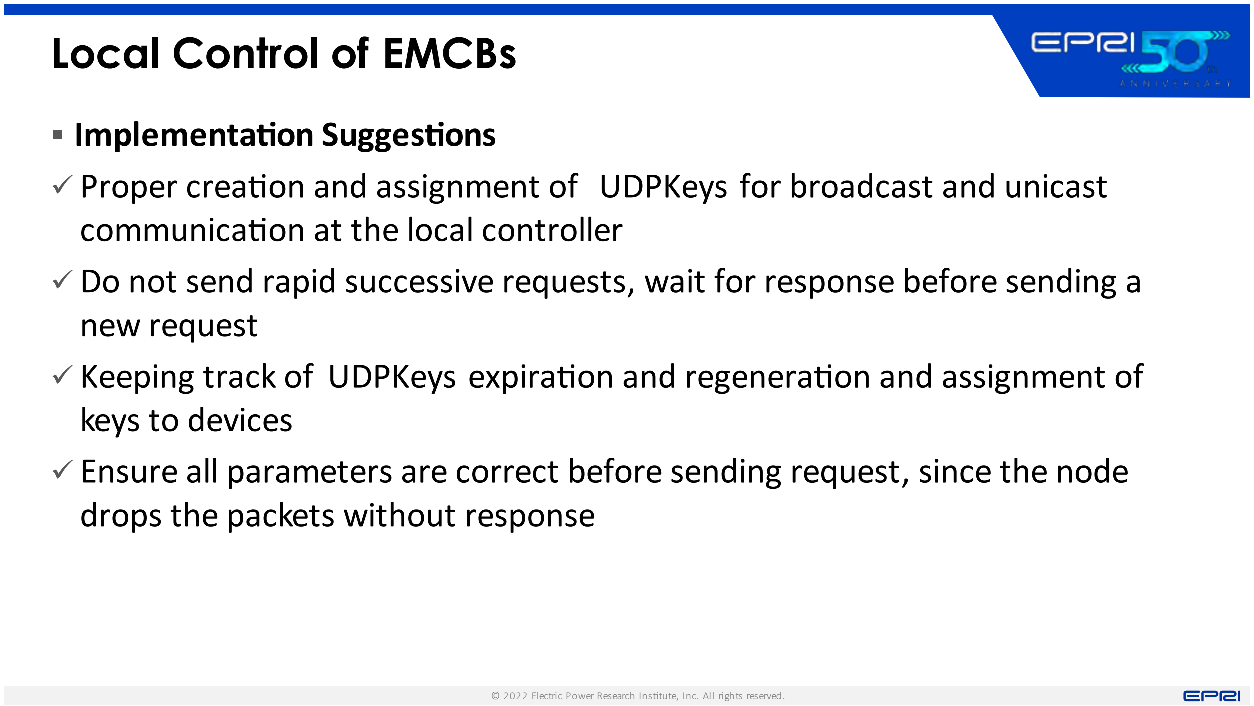


Figure 20. Key Suggestions for Developing Local Control of EMCB Devices

Figure 21 and Figure 22 show screenshots of the simple local control application that Viswanath Ananth of EPRI demonstrated October 12-13, 2022 at a face-to-face member meeting in Pittsburgh, PA. Figure 21 shows live readings of RMS current sampled every 10 seconds. Figure 22 shows the window where the user can control the on/off state of the breaker's remote switch.

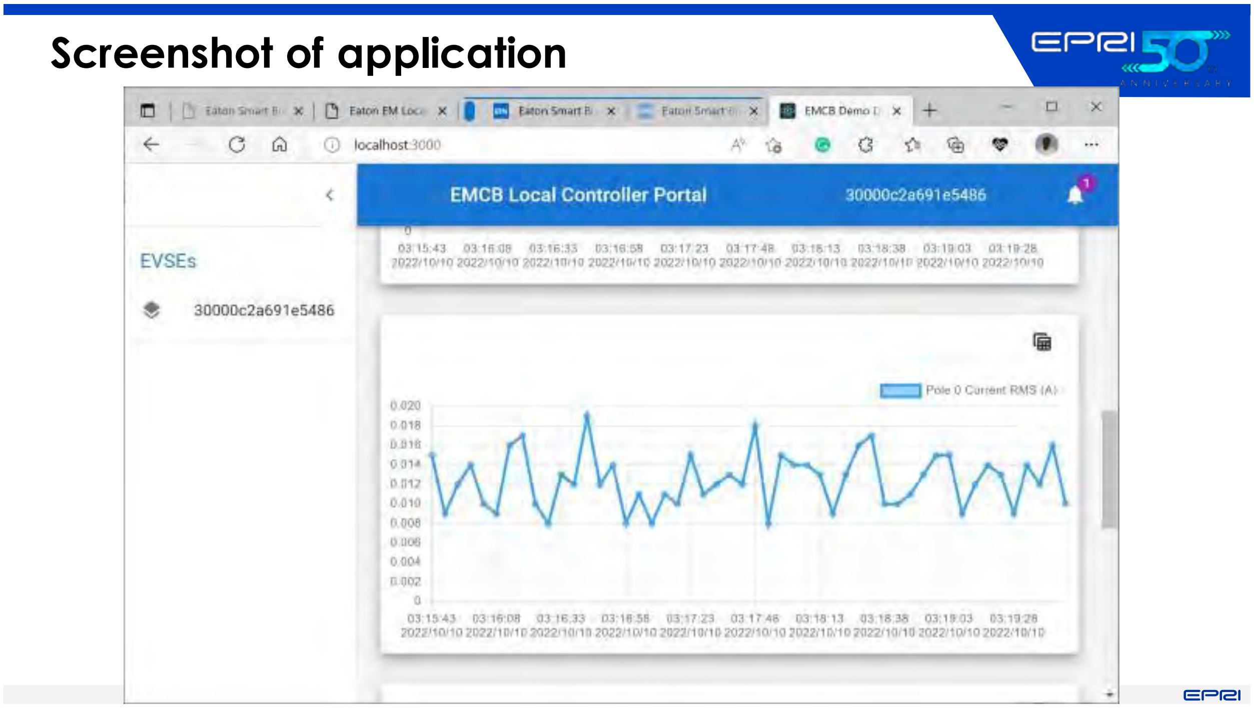


Figure 21. Local Controller Implementation Architecture

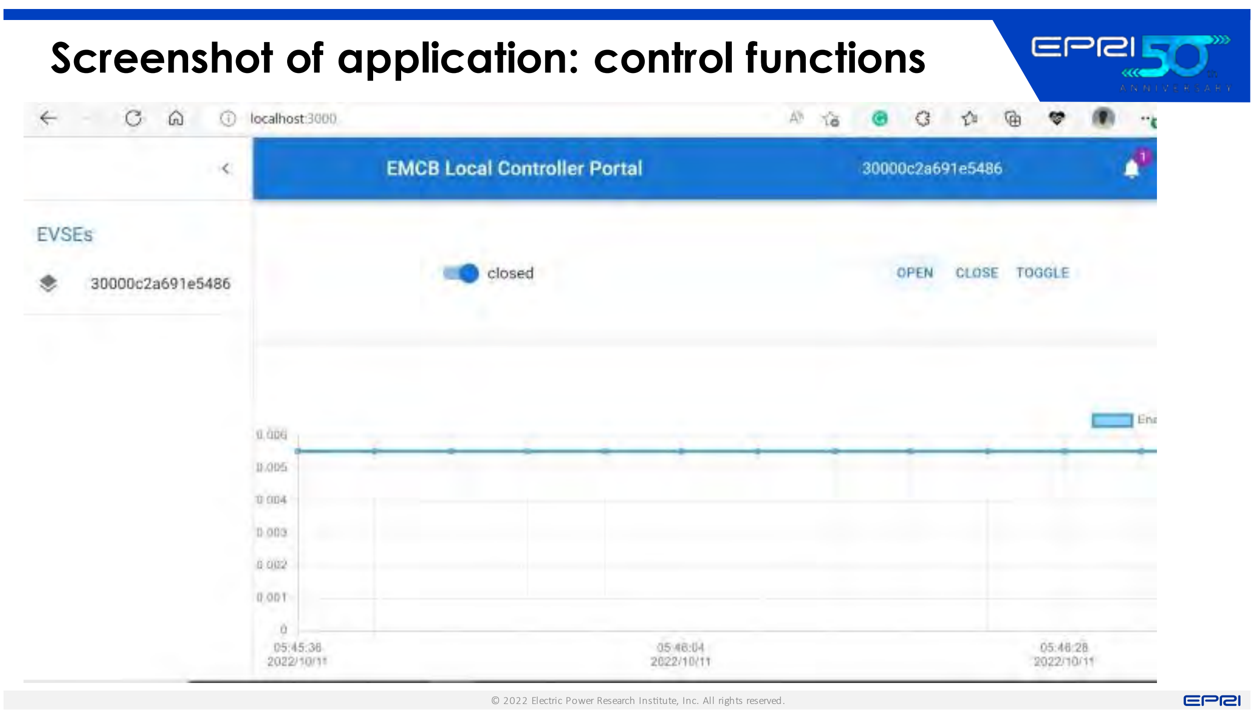


Figure 22. Local Controller Implementation Architecture

Eaton's Software

The following are software options provided by Eaton for their customers. These are mobile apps geared toward consumers rather than utilities but are listed here for completeness.

Eaton EV Charger Manager

Eaton has recently released a new "Eaton EV Charger Manager" app for use with their EV-EMCB. It is presently a mobile app only and is available to Apple and Android users. It is geared toward consumers, having features such as schedule charging for TOU rates, energy monitoring with statistics, real-time status updates, and others. Following is a link to the product page on Eaton's website:
https://www.eaton.com/us/en-us/products/electrical-circuit-protection/circuit-breakers/connect-ev-smart-breaker-chargers/green-motion-ev-charger-manager-app.html

Eaton Smart Energy Manager

Eaton's Smart Energy Manager is a mobile app for use with the standard EMCB. It is geared toward homeowners who want to schedule usage at the circuit level for TOU rates, for monitoring energy consumption, and control circuits remotely. Following is a link to the product page on Eaton's website:
https://www.eaton.com/us/en-us/products/electrical-circuit-protection/circuit-breakers/connect-smart-breakers/smart-energy-manager-app.html

Eaton EM Install Smartphone App

EPRI and Phase II members have been using a mobile app called EM Install extensively for commissioning breakers. This app is available for both Apple and Android devices. It is simply a utility app for connecting newly installed EMCBs to the customer's Wi-Fi network, registering the device in the cloud, and associating it with the user's account. Eaton has integrated the installation functions of EM Install their newer consumer apps and has a long-term plan to deprecate this app.
https://www.eaton.com/content/dam/eaton/products/electrical-circuit-protection/energy-management-circuit-breaker/em-install-app-quick-start-guide-PA003026EN.pdf

6 TASK 5 – FIELD DEPLOYMENT

Utilities in the project were provided with an order for to request EMCB devices for deployment as illustrated in Table 3. The initial form include following, detailed all the EMCB options intended by Eaton in 2019. EV-EMCB components were not made available until late 2022.

Table 3 EMCB Order Form Used in EMCB Project Circa 2019

Energy Management Circuit Breaker Order Form

EPRI EMCB Phase 2

Requestor Name	TypeNameHere
Date	Month, Day, Year
Ship to:	
Name	
Contact Phone Number	
Address Line 1	
Address Line 2	
Address Line 3	City, State, ZIPCODE
Special instructions	

Quantity Requested	Description	Eaton Part Number
	Standard Plug On, Single Pole, 15A	BREM1015
	Standard, Plug On, Single Pole, 20A	BREM1020
	Standard, Plug On, Double Pole, 15A	BREM2015
	Standard, Plug On, Double Pole, 20A	BREM2020
	Standard, Plug On, Double Pole, 30A	BREM2030
	Standard, Plug On, Double Pole, 40A	BREM2040
	Standard, Plug On, Double Pole, 50A	BREM2050
	Standard, Bolt On, Single Pole, 15A	BABEM1015
	Standard, Bolt On, Single Pole, 20A	BABEM1020
	Standard, Bolt On, Double Pole, 15A	BABEM2015
	Standard, Bolt On, Double Pole, 20A	BABEM2020
	Standard, Bolt On, Double Pole, 30A	BABEM2030
	Standard, Bolt On, Double Pole 40A	BABEM2040
	Electric Vehicle, Plug On, Double Pole, 40A Note: Please order 1-each EV cable and 1-each installation kit as needed per EV breaker	BREVEM2040
	EV Cable	HVCOSAEMR3PF506RL7620
	Option 1) EV breaker load center installation kit	EVDIRCONNECT
	Option 2) EV breaker junction box installation kit	EVJUNCTBOX
	Option 3) EV breaker pedestal installation kit	MPLEVPOST
	Cell Modem (Up to five per collaborator)	
	iPod (One per collaborator. Ask if you need more.)	

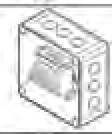
March 7, 2019

Note, quantities below are for the specific kit. Use the order form above to specify the number of kits.

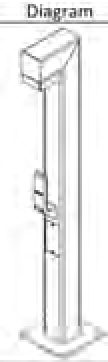
EVDIRCONNECT: Installation Kit for Direct Connection to Load Center

Material Name	Quantity	Diagram
Cord Management Bracket with Four #10 x 1-1/2" Phillips Pan Head Screws	1	
¾" NM/SE Strain Relief Connector with Locknut	1	

EVJUNCTBOX: Installation Kit for Junction Box Method

Material Name	Quantity	Diagram
Cord Management Bracket with Four #10 x 1-1/2" Phillips Pan Head Screws	1	
Altech 105-405 Junction Box with Pre-Installed Terminal Blocks	1	
¾" NM/SE Strain Relief Connector with Locknut	3	
Nylon Cord Connector: 1/2" Conduit Size, 0.17" to 0.45" Cord Diameter Range	2	

MPLEVPOST: Installation Kit for MPLEVPOST Post Method

Material Name	Quantity	Diagram
MPLEVPOST Post Assembly with Pre-Installed Strain Relief	1	

March 7, 2019

Device deployments were carried out by funder over the full life of the project. Roughly 200 EMCB devices were acquired in the project from Eaton with the bulk of these being distributed to funders. Over the life of the project about 100 devices were active in fielded locations.

To support the project, EPRI installed EMCB devices in both Knoxville, TN and Palo Alto, CA. Knoxville deployed only standards EMCB devices, primarily in the lab environment, thought a small number were installed on operating equipment including electric vehicle charging stations. Twelve EV-EMCBs were installed on the Palo Alto campus under a field listing completed by UL. Work on the installs was completed in January of 2020. Figures 23 and 24 illustrate the pedestal units used.

Figure 23 Dual Port EV-EMCB Charging Station Installed in Palo Alto, CA.

Figure 24 Americans with Disabilities Act (ADA) Parking Space Served by EV-EMCB.

These stations were operated continuously from January of 2020 until March of 2023, when they were replaced with second generation EV-EMCBs (now under the Eaton product name of EV Smart Breakers).

7 TASK 6 – EVALUATION OF DATA ANALYTICS TOOLS BASED ON FIELD USE

In an effort to maximize the value of the EMCB for project funders, EPRI contracted with multiple software vendors, each servicing a particular use case or aspect of the EMCB. This chapter provides a summary of how these tools were used including feedback that EPRI collected during the field demonstration, both from members and from EPRI's own use of the tools.

Virtual Peaker

Project funders began using the Virtual Peaker (VP) toolset during Q2 of 2019. Since then, EPRI engaged in an ongoing process of collecting user feedback and communication with the VP team.

Although Virtual Peaker is an established software, the EMCB integration was new, bringing with it the need for some additions at EPRI's request (with input from members). New graphs and new server-side calculations introduced the potential for minor issues and stimulated conversations about limitations and desirable features as users began to use the software. EPRI maintained a list of issues, some of which were submitted by members and some by EPRI. A list of tracked issues appears in Table 4. Virtual Peaker promptly addressed issues and kept EPRI informed of the status. For example, users preferred to see average values rather than instantaneous values in the time-series data.

Another example is shown in Figure 25, where missing data is represented by a curved line from the last known data point. This can result in confusion, especially for gaps of only a few minutes. The team requested that missing data points be shown as gaps in the plot.

Table 4. Virtual Peaker Early Issues List

Description of Issue
Palo Alto EV-EMCB data missing
Instantaneous rather than Avg values being graphed
"Last updated" timestamp not updating correctly
Missing data plotted as straight lines from last known
Would like to add min/max values to graphs
Online/Offline status not reflecting conditions
Display labeled kW, but displaying apparent power
Some breakers not responding to DR events
Manual opt-out of events causing synch issues

The team requested the addition of features that would be useful for gathering insight about connected loads. For example, the team requested the addition of Min/Max values to graphs. Virtual Peaker satisfied this request with a tooltip as shown in Figure 26.

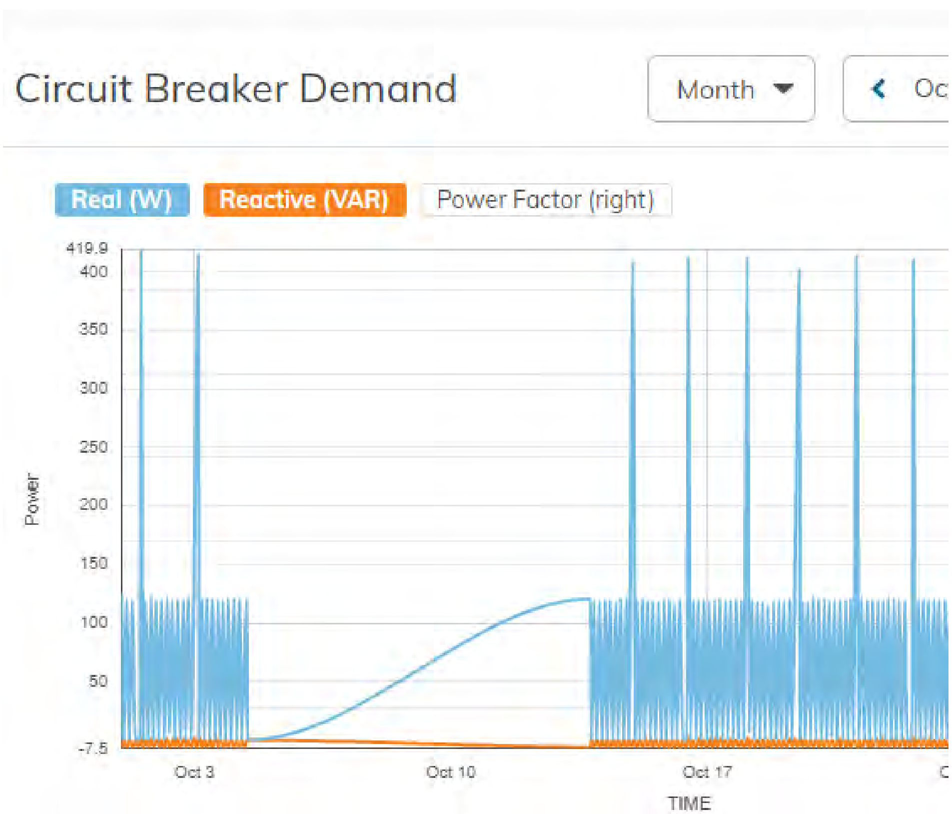


Figure 25. Tracked Issue – Handling of Missing Data in Graphs

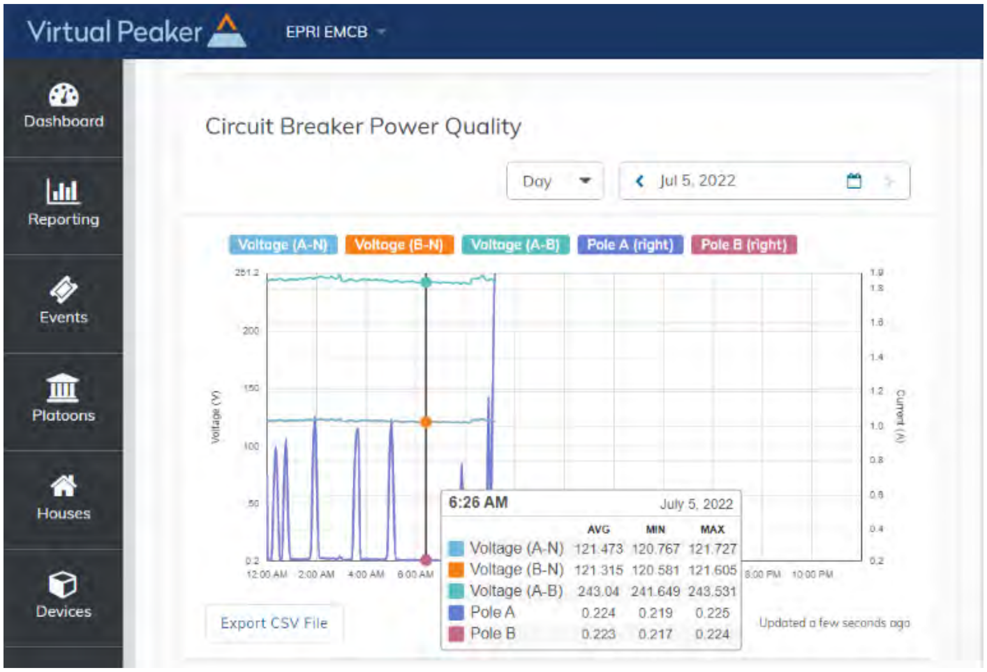


Figure 26 Tooltip showing min/max/average values

Another member observed that the power data from an EMCB feeding an air conditioning unit was showing inconsistent peaks. The expectation is that the peaks would be roughly uniform as the A/C unit cycled. The data is shown in Figure 27. The member connected a second instrument for comparison. The results can be compared directly in Figure 27 and Figure 28, where the graph shown in both figures is for the same A/C unit over the same period.

The point illustrated here is that the choice of a 5-minute sampling interval for the EMCB and the decision to plot average values results in a graph that does not resolve detail for rapidly cycling loads such as A/C units. EPRI and VP agreed, but because the cost is high for increasing the data volume at scale, the sampling interval was not changed. However, the addition of the Min/Max tooltip feature helps in this scenario.

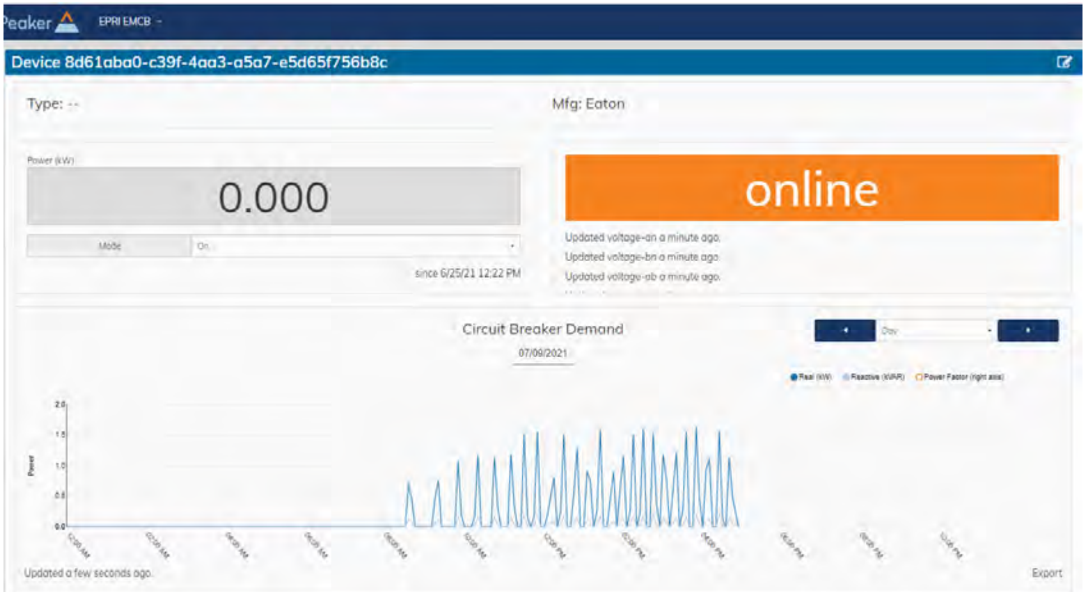


Figure 27 Power data reported by an EMCB at 5-minute intervals and viewed in Virtual Peaker

Figure 28 Power data recorded at 1-minute intervals by a TED instrument

Data Archiving Tool

Grid Protection Alliance was contracted to develop a data archiving tool for EPRI. The work involved the development of a server application, or data handler, to direct incoming EMCB data to the appropriate intake folder, where data is sorted by utility and by type (telemetry, which is synchronous, or waveform, which is asynchronous). That work was completed in early 2019 with all 5-minute RMS trend data and all waveform snapshots flowing to EPRI's SQL database on EPRI servers continuing through December 2022. Throughout most of the project, more than 100 EMCBs reported continuously. Figure 29 shows in 6-month intervals the number of EMCBs reporting. Data arrived compressed and totaled 43.6 GB for the Phase II project. In total, approximately 1.7 billion data values were imported.

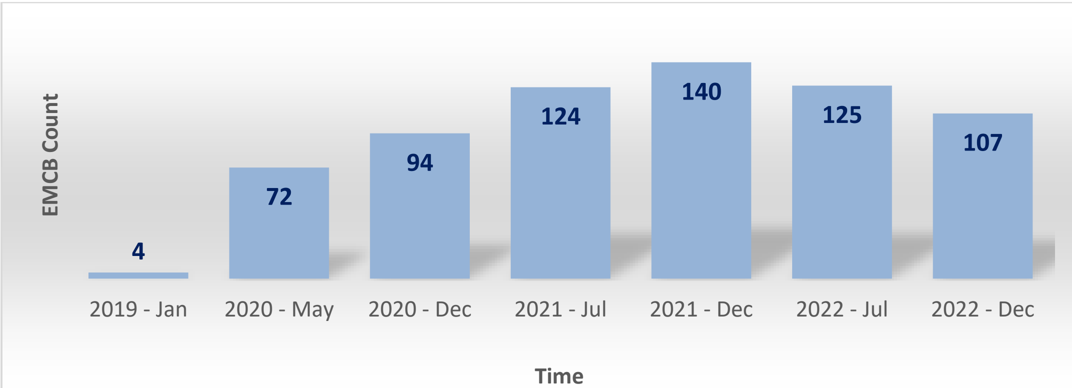


Figure 29 Number of EMCBs reporting data throughout the Phase II project

In May 2021, EPRI discovered that only one waveform was being received when multiple EMCBs were seeing the same voltage sag at the same time. Normally, each EMCB would detect the condition and send a waveform if configured to do so.

Figure 30 Voltage sag test setup

The issue was discovered when using a voltage sag generator and two EMCBs on the same circuit (see Figure 30). To troubleshoot the issue and test for repeatability, EPRI created four voltage sags, each on the minute so the sags could be correlated to the timestamp on the corresponding waveform data generated by the EMCBs. The events were generated at 5:18pm, 5:19pm, 5:20pm, and 5:21pm and are summarized in Table 5. Both EMCBs under test captured all four voltage sags, however, the highlighted entries represent those that were transferred by the data handler to EPRI's database. Note that in each case, only one waveform was sent, and not always the same device had sent it. The waveforms that were transferred to the database are shown in Figure 31. Note the four underlined items and their device IDs in the filenames. These match the highlighted items in Table 5. When the problem was resolved, all EMCBs that saw the same voltage sag would be represented in the database. During the troubleshooting, EPRI found that the issue resided with the data handler and worked with GPA to duplicate the issue and to resolve it.

Table 5 Record of volage sags captured by two EMCBs under test

Device ID: daa69b7c-5de7-4f38-83f5-7501beb3f130			Device ID: 4878fa03-f070-4b2b-b7d6-b403c5140f09	
Time Stamp	**Event Type**		**Time Stamp**	**Event Type**
2022-03-04T17:18:02Z	waveform		2022-03-04T17:18:02Z	waveform
2022-03-04T17:19:00Z	waveform		2022-03-04T17:19:02Z	waveform
2022-03-04T17:20:01Z	waveform		2022-03-04T17:20:02Z	waveform
2022-03-04T17:21:01Z	waveform		2022-03-04T17:21:02Z	waveform

Name	Date modified
4878fa03-f070-4b2b-b7d6-b403c5140f09-Meter.Waveform.20220304T171802.pqd	3/4/2022 1:10 PM
4878fa03-f070-4b2b-b7d6-b403c5140f09-Meter.Waveform.20220304T171902.pqd	3/4/2022 1:10 PM
4878fa03-f070-4b2b-b7d6-b403c5140f09-Meter.Waveform.20220304T172102.pqd	3/4/2022 1:10 PM
4878fa03-f070-4b2b-b7d6-b403c5140f09-Meter.Waveform.20220304T172707.pqd	3/4/2022 1:10 PM
daa69b7c-5de7-4f38-83f5-7501beb3f130-Meter.Waveform.20220304T172001.pqd	3/4/2022 1:10 PM
daa69b7c-5de7-4f38-83f5-7501beb3f130-Meter.Waveform.20220304T172707.pqd	3/4/2022 1:10 PM

Figure 31 Record of waveforms sent to EPRI's SQL server

Another incident worth noting was a partial loss of EMCB functionality in Virtual Peaker that occurred briefly during Q1 of 2022. Once discovered and reported to VP, the issue was promptly identified and corrected. The issue was caused by an expired API key. These types of issues are bound to happen when multiple vendors are involved. Consider the communication path illustrated in Figure 32 where each link in the chain is subject to downtime during firmware/software updates, maintenance, hardware failures, and so forth. Issues such as API key expiration can be ironed out over time as the vendors establish a routine.

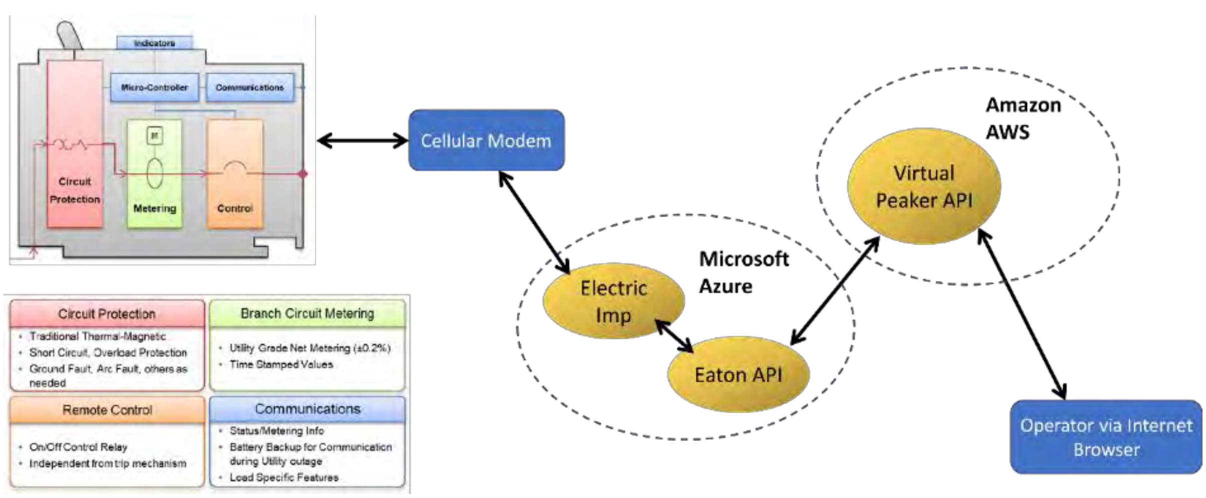


Figure 32 Functional diagram of system communication and data flow for the Virtual Peaker EMCB system

Power Quality Tools

One of the Phase II members was interested in using EMCBs as power quality monitors at key industrial customer sites where power quality issues had been reported. In the summer of 2022, one of these industrial customers reported multiple production interruptions that were attributed to power reliability issues. To help determine whether the reported incidents were indeed related to the AC power, EPRI was able to quickly access data from the EMCB installed at that site and report the conditions captured by the EMCB on the date of the incident. The 5-minute RMS trend data for that date is shown in Figure 33, showing two voltage sags in the afternoon. Looking at the EMCB's FastRMS data in Figure 34, more detail is given. The duration of the first event was approximately 0.6 second and the magnitude was about 62%. The duration of the 2nd event was approximately 0.7 second and the magnitude was also about 62%. A takeaway of this experience is that the EMCB can be effective as a low-cost and permanently installed power quality monitor. EPRI's power quality toolset made the data retrieval and analysis efficient.

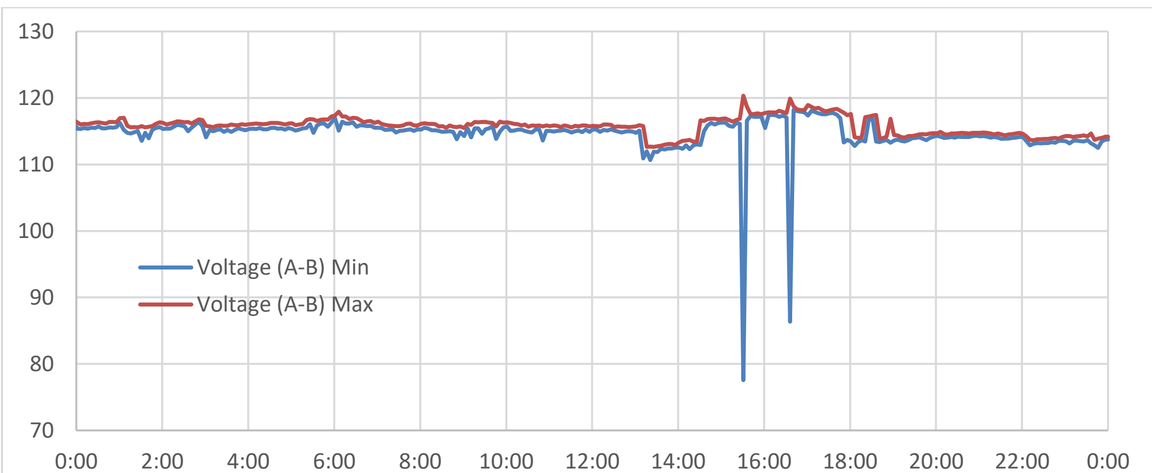


Figure 33 Voltage trend data showing voltage sags at an industrial site

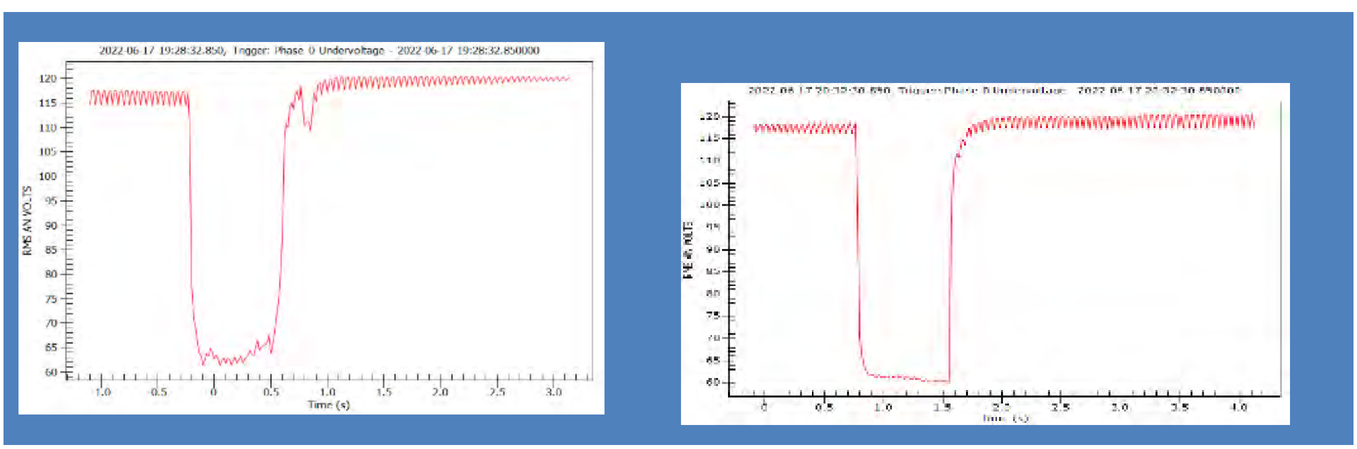


Figure 34 Fast RMS captures for two sag events

Data Archiving – Grid Protection Alliance

EPRI contracted Grid Protection Alliance to develop a custom data archiving tool for use throughout the EMCB project. The work involved the development of a server application, known as a data handler, to direct both synchronous and asynchronous time-stamped data to EPRI's SQL database. That work was completed in early 2019 with all 5-minute RMS trend data and all waveform snapshots flowing to a SQL database on EPRI servers. All devices that were part of the EMCB project were included in the archive. This includes fielded devices from member utilities across the country as well as EPRI-maintained devices in Palo Alto, Knoxville, and Aurora.

Tool Analytics Summary

This chapter provides examples of the more significant findings and issues. Many others are documented in the presentation materials shared during bi-weekly member meetings. Each of the software tools provided value to members. One thing that became clear is that the 11 member utilities have very different use cases because they have unique problems to solve. The EMCB was shown to be useful for demand response when paired with Virtual Peaker software. It was also found to be useful for basic power quality troubleshooting when paired with open-source PQ tools.

8 TASK 7 – COMPARATIVE PRODUCTS

Over the course of the EMCB project, EPRI monitored developments of other manufacturers of products that included similar functionalities to the EMCB device. This included products that embedded metering, power quality waveform capability, on/off type control and electric vehicle charging.

Products were observed to fall into seven broad categories:

- Circuit breaker format
- Custom service panel (load center) solution where metrology and/or control are embedded in the service panel
- Systems that use current transformers and voltage taps to monitor energy
- Standalone devices designed to monitor and/or control one load in a dedicated fashion
- Commercial switchgear style breakers/disconnects
- Limited or Non-contact devices
- Electric vehicle EMCB comparative products

Two companies with products that related well with the EMCB were invited to present at one of the EMCB meetings: SpanIO and Atom Power.

A List of Comparative Products with Web Links

Following is a list compiled of products that offered one or more attributes similar to the Eaton EMCB device.

- ABB (remote monitoring load centers)
- Aeotec – Home Energy Meter Gen5
- Aeotec – ZW095 Home Energy Meter Gen 5
- Atom Power (solid state breaker load center)
  - This remains the most similar product found from other manufacturers.
- Avi-on Labs
- Belkin WeMo

- Blixt - solid state breaker (non form factor)
- Blue Line EnergyCloud
- Curb
- Current Cost
- Eachen
- Eaton (they have intelligent load centers in addition to the EMCB)
- Efergy - Engage
- Electro Industries/Gauge Tech - Shark 50B BACnet MS/TP Communicating Power Meter
- ETC Sensor IQ Intelligent Breaker System
- Eyedro
- Grid 4 C
- ICT Distribution Series 3 Intelligent 200A Dual Bus Breaker Panel with TCP/IP for remote monitoring, remote control, HTML and SNMP
- Kasa Smart (smart plugs)
- Koben Systems Inc (My Homegrid – automated intelligent load center)(Ontario, Canada)
- Koolbridge Solar (intelligent load center)
- Leviton (remote control load centers)
    - This was the second most similar product to the EMCB, but it lacked dynamic load control.
- LynTec (intelligent load center)
- Pluton Power – DIN rail based on/off control with metrology
- Powerwise Systems – Sitesage
- Racepoint Energy
- Savant (they have a breaker form factor dimming control that is Bluetooth based)
- Schneider Electric Masterpact MTZ (air circuit breakers)

- Schneider Electric Residential Energy Management
- Schneider Powerlink Intelligent Panelboards (Commercial, healthcare, retail)
- Smappee
- SpanIO (intelligent load centers)
- Ted Pro

9 TASK 8 – POWER QUALITY ACTIVITIES

Power Quality Tools – Grid Protection Alliance

The Open PQ Dashboard is a web-based system, initially developed by EPRI and maintained with continued development by Grid Protection Alliance, Inc. (GPA) and supporting utilities, that provides a wide-area visualization and system-wide status of power quality. The dashboard's objective is to provide a quick and efficient method to identify and report meaningful PQ information from a large amount of power quality measurement resources.

The EMCB is a natural candidate to be a source of data for this dashboard because, like other power quality instruments, it can provide voltage trend data and it can trigger waveform capture on voltage and/or current excursions. EPRI, through EMCB Phase II funding, developed a scope of work with GPA to develop a data-handler and device management environment for getting trending and event data from the EMCB into the OpenXDA suite of tools and to host a demo for Phase II members to include field measurements. A system diagram is depicted in Figure 35. The EMCB Manager will be available as a service provided by GPA after a demo period of 2-3 months.

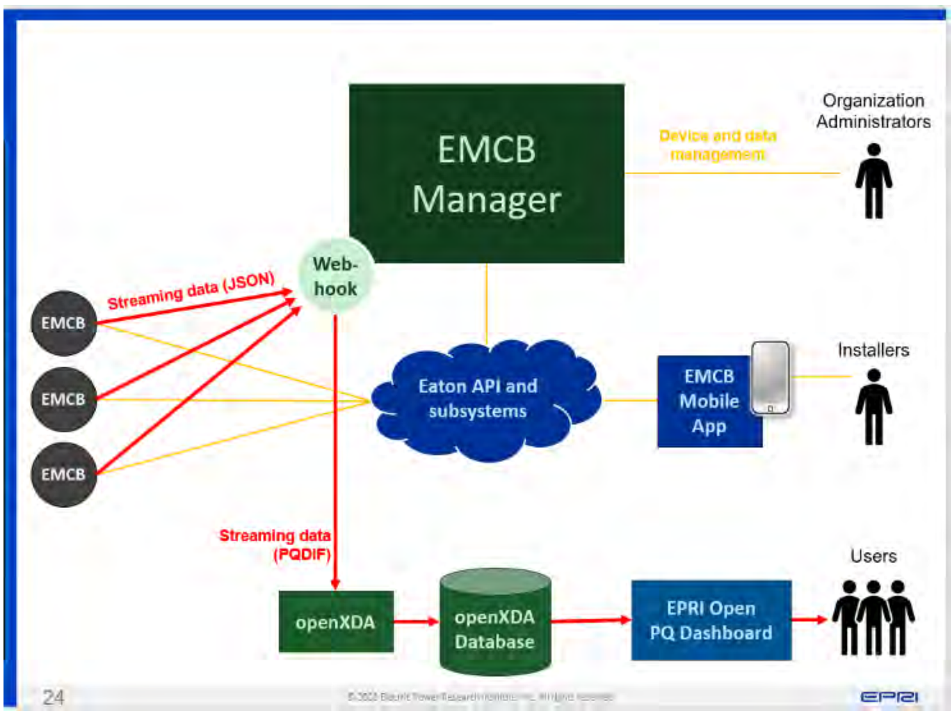


Figure 35. Architecture for EMCB Power Quality Data Processing

Figure 36 and Figure 37 show examples of EMCB data once made available in Open PQ Dashboard. Figure 2 is a fleet-level summary view showing the total number of power quality events reported by all devices for a date or range of dates. Figure 3 is a device-level view of waveform data in openSee, showing details of a particular event.

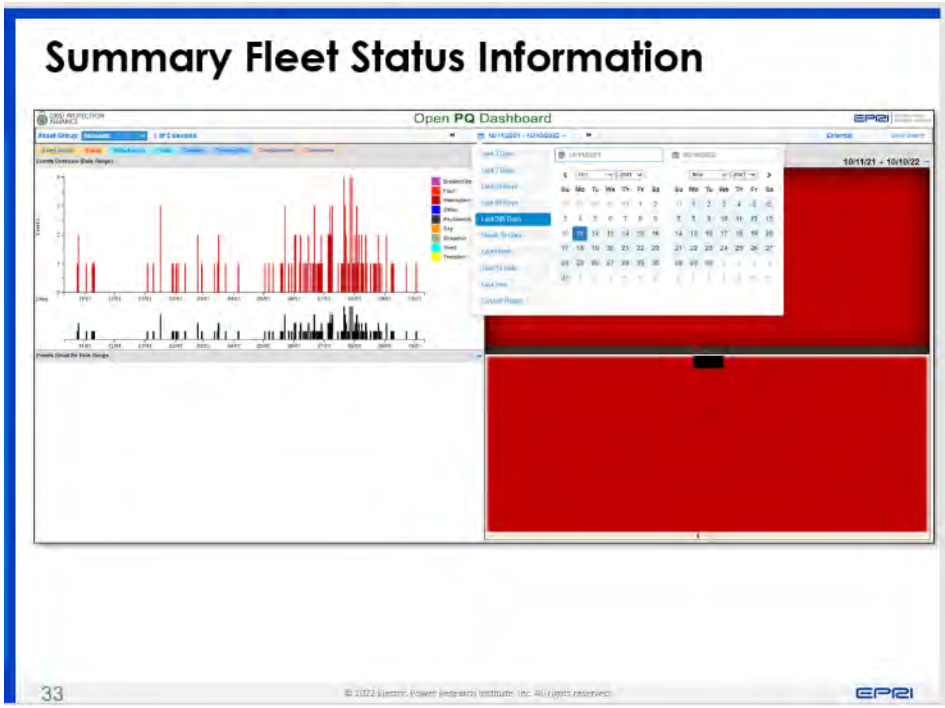


Figure 36. Summary View of EMCB Data Reporting in Open PQ Dashboard

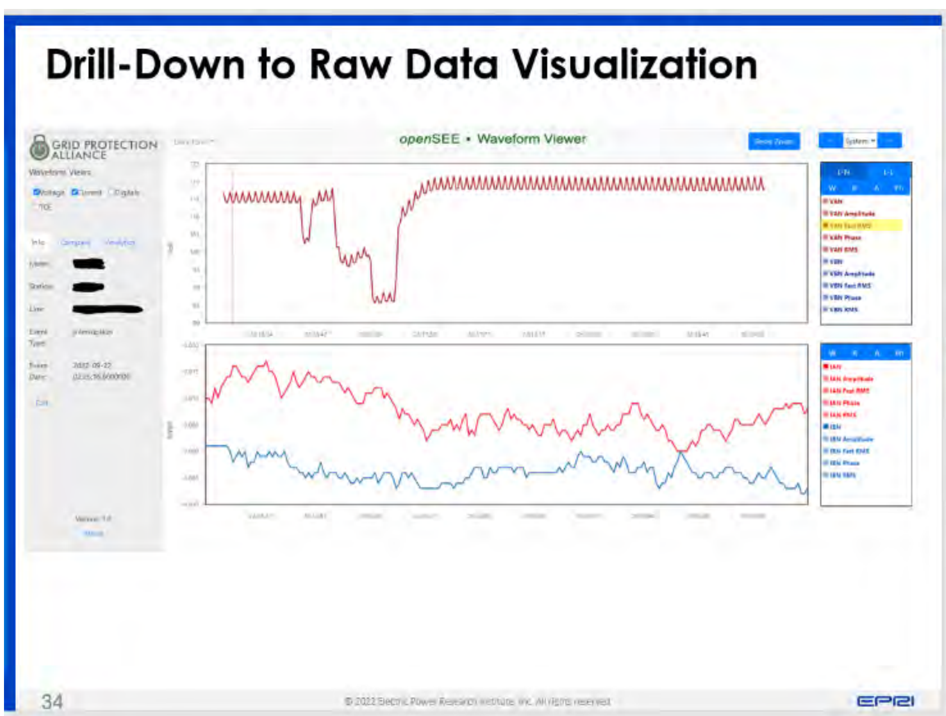


Figure 37. Drill-Down to Device Level Data in Open PQ Dashboard

Once EMCB data is ingested into the PQ Dashboard environment, it can be further analyzed with other software components such asTrenDAP. Figure 38 and Figure 39 show examples of the statistical analyses available in TrenDAP.

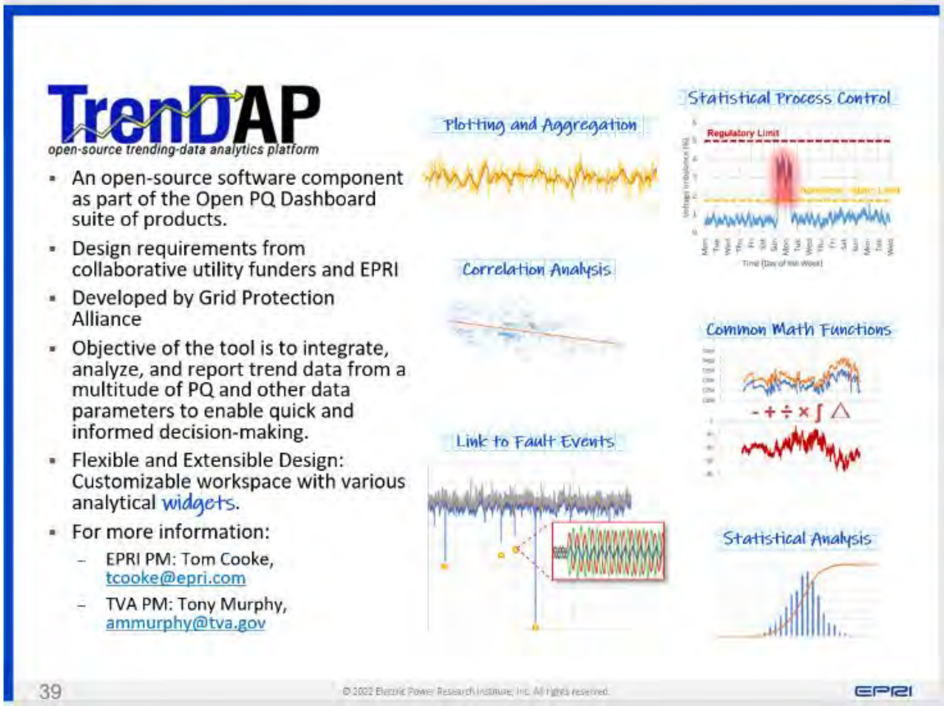


Figure 38. TrenDAP Overview (1 of 2)

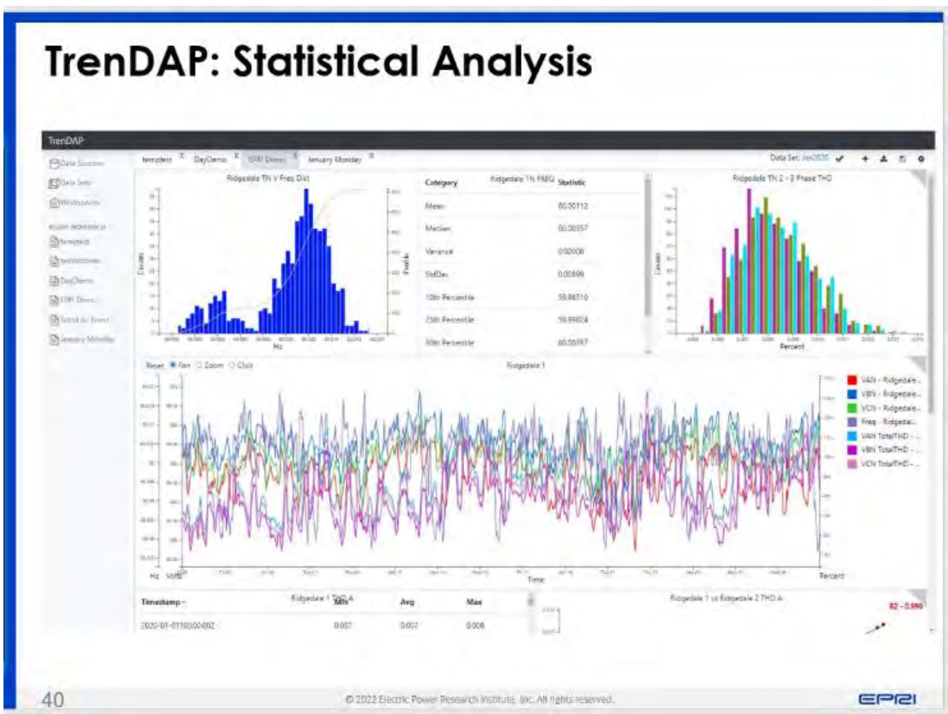


Figure 39. TrenDAP Overview (2 of 2)

Additional information on Power Quality work with EMCB devices can be found in Appendix B *Using EMCB Devices for Power Quality Studies*.

10 TASK 9 – DATA ANALYSIS

The data analysis task of the project is covered by this summary project report. Highlights of some of the project activities are found in Appendix G.

A EMCB METERING AND RELATIONSHIP TO UTILITY METERING DATA SYSTEMS

Integrating EMCB data into Metering Systems

An AMI Perspective

Ed Beroset
Principal Technical Leader
Advanced Metering Systems (161F)

12 October 2022

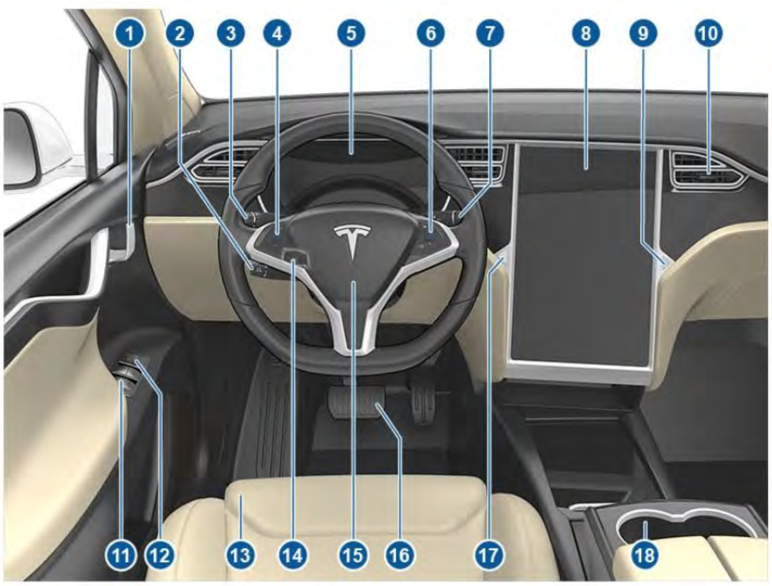
www.epri.com

Why EPRI is involved: purpose of EPRI's AMI research (161F)

- Collaborative research to
  - Maximize value
  - Minimize risks
  - Improve the feature of AMI
- Research drivers
  - Changes in available systems, technology, standards
  - Diverse and evolving regulatory expectations
  - New AMI system uses and value streams
  - Solid state meter performance and reliability

How to Drive a Car

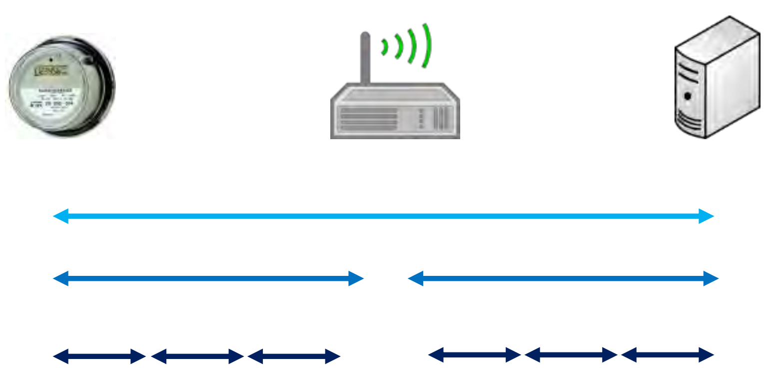
What about electric?



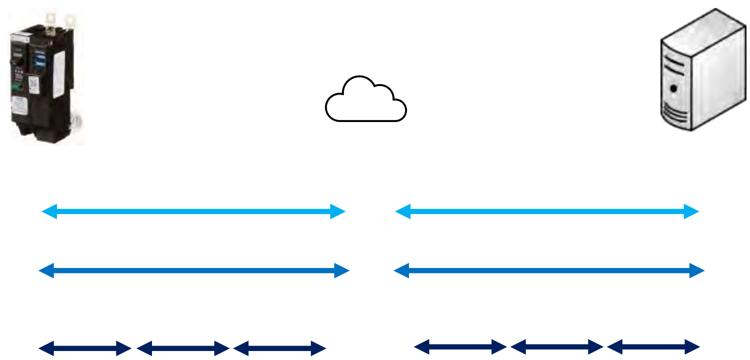
Why this matters

- Standards play important role in success of meter deployments
- Using metering standards, utilities and vendors
  - Better equipped to plan for devices and systems over time
  - Consider the costs and benefits for their individual organization
  - Plan for addressing future needs in a manner that is
    - Safe
    - Secure
    - Accurate
    - Affordable

Theoretical fully standard AMI network



Metering Circuit Breaker Data



In-Cloud Processing Responsibilities

- Convert existing data structures into standard protocol structures
  - ANSI C12.19 Tables
  - COSEM Objects
- Participate in standard communications
  - ANSI C12.22 Communications
  - DLMS Communications
- Support ad hoc reads
- Possibly synthesize “virtual meter” from individual breakers
- Honor protocol-level provisioning

API to C12.19 Table Conversion

Get Most Recent Meter Telemetry Data

- {
- "data": {
- "currentA": { " val": 0, "min": 0, "max": 0, "avg": 0 },
- "voltageAN": { "val": 0, "min": 0, "max": 0, "avg": 0 },
- "frequency": { " val": 0, "min": 0, "max": 0, "avg": 0 },
- "energy": { "delivered": 0, "generated": 0, " deliveredWH": 0, "generatedWH": 0 },
- "energyDelta": { "delivered": 0, "generated": 0, " deliveredWH": 0, "generatedWH": 0, "deltaTime": 0 },
- "currentB": { "val": 0, "min": 0, "max": 0, "avg": 0 },
- "voltageBN": { "val": 0, "min": 0, "max": 0, "avg": 0 },
- "voltageAB": { "val": 0, "min": 0, "max": 0, "avg": 0 },
- "hwSamples": 0,
- "ts": 0
- }
- }

Table 23 Current Register Data Table

```
TYPE COINCIDENTS_RCD = PACKED RECORD
        COINCIDENT_VALUES        : ARRAY[ACT_REGS_TBL.NBR_OCCUR] OF NI_FMAT2;
END;
TYPE DEMANDS_RCD = PACKED RECORD
        IF ACT_REGS_TBL.DATE_TIME_FIELD_FLAG THEN
                EVENT_TIME : ARRAY[ACT_REGS_TBL.NBR_OCCUR] OF STIME_DATE;
        END;
        IF ACT_REGS_TBL.CUM_DEMAND_FLAG THEN
                CUM_DEMAND : NI_FMAT1;
        END;
        IF ACT_REGS_TBL.CONT_CUM_DEMAND_FLAG THEN
                CONT_CUM_DEMAND : NI_FMAT1;
        END;
        DEMAND : ARRAY[ACT_REGS_TBL.NBR_OCCUR] OF NI_FMAT2;
END;
TYPE DATA_BLK_RCD = PACKED RECORD
        SUMMATIONS : ARRAY[ACT_REGS_TBL.NBR_SUMMATIONS] OF NI_FMAT1;
        DEMANDS : ARRAY[ACT_REGS_TBL.NBR_DEMANDS] OF DEMANDS_RCD;
        COINCIDENTS : ARRAY[ACT_REGS_TBL.NBR_COIN_VALUES] OF COINCIDENTS_RCD;
END;
TYPE REGISTER_DATA_RCD = PACKED RECORD
        IF ACT_REGS_TBL.DEMAND_RESET_CTR_FLAG THEN
                NBR_DEMAND_RESETS        : UINT8;
        END;
        TOT_DATA_BLOCK          : DATA_BLK_RCD;
        TIER_DATA_BLOCK         : ARRAY[ACT_REGS_TBL.NBR_TIERS] OF DATA_BLK_RCD;
END;
TABLE 23 CURRENT_REG_DATA_TBL = REGISTER_DATA_RCD;
```


Potential issues for research

- What is required for data translation to metering protocol?
- Will utilities accept non-utility owned cloud-based solution?
- How will circuit breakers be validated for accuracy?
- Do existing regulatory frameworks allow non-meter metering?
- How might utilities provide submetering services with breakers?
- Can DER management be supplemented with breakers?

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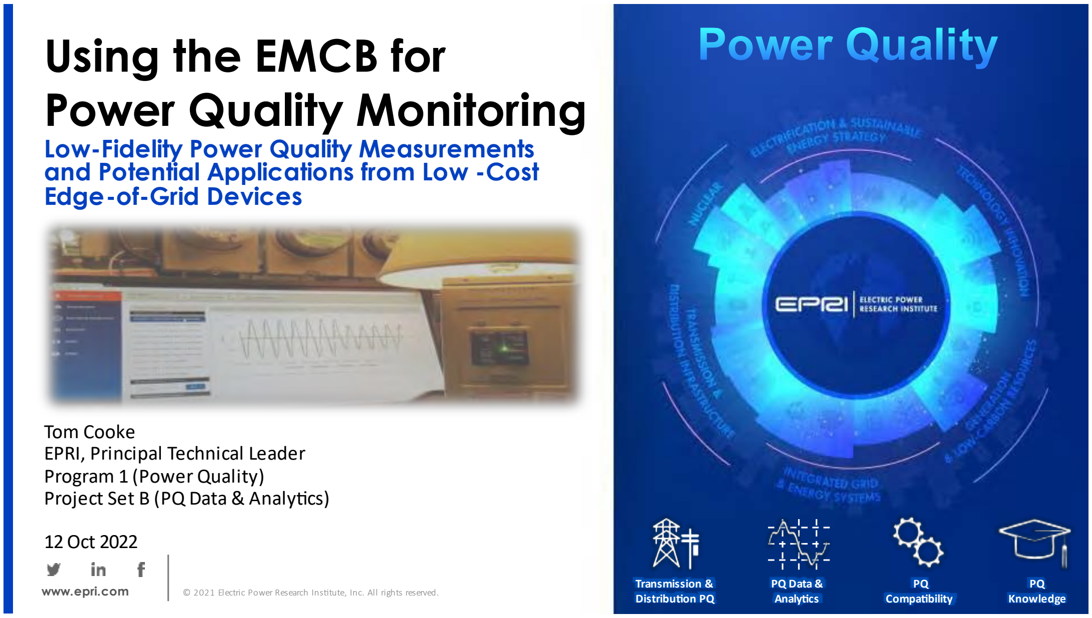
EPRI Technical Report

- **Toward a World Standard Advanced Meter Application Layer Protocol:** An Analysis of the Current and Possible Future State of the Industry
- Product ID: 3002013398
- https://www.epri.com/#/pages/product/3002013398/

Using the EMCB Devices for Power Quality Studies

B USING THE EMCB FOR POWER QUALITY STUDIES



PS1B Areas of Research

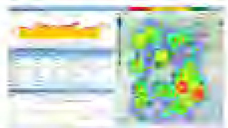
- Understanding new and evolving PQ data sources (such as relays, switches, and smart meters) is essential for the modern electric utility
- Application and analysis of PQ and other data resources is perhaps the fastest and lowest-cost way to enhance value for proven grid operations and analysis.
- Utilities are faced with a "data tsunami" that this project set is working to anticipate and manage through data integration, validation, and visualization tools.

Gather

- PQ Capabilities from Multiple Resources
- System Assessment
- Sensors
- New Data Measurement Methods
- Meter placement strategies

Process

- Data Management
- Data Validation Methods
- Aggregating and Consolidating Data
- Application of Data Analytics
  - Fault Location
  - Waveform Characterization

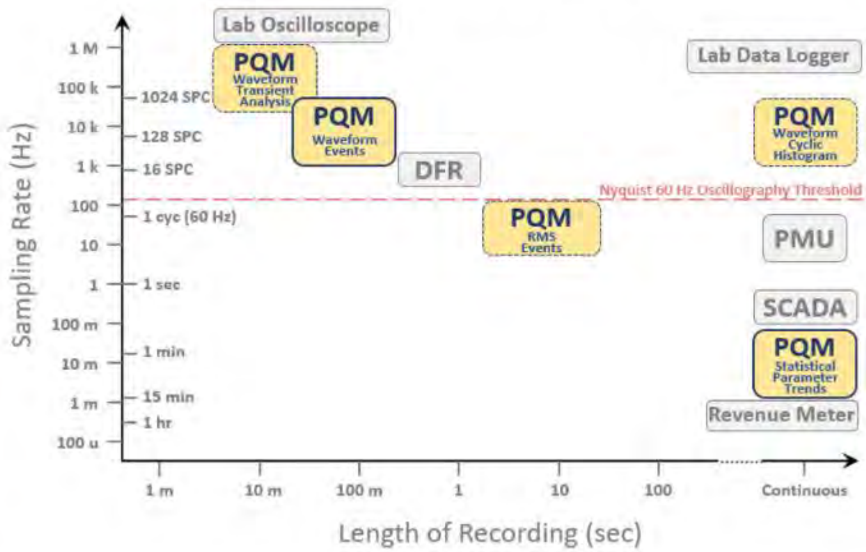


Report

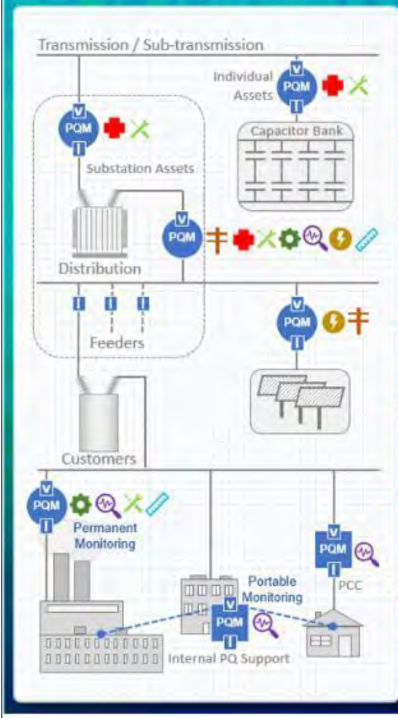
- Platform Development
- Data Visualization
- Data Dissemination
- Federated Data Integration
- Benchmarking

Where does PQ monitoring fit in to the grid?

Grid Data Acquisition Sampling Spectrum



Value of Power Quality Monitoring



Distribution and Transmission Management

A power quality monitor (PQM) is the digital fault recorder (DFR) of the distribution system and much more. If used effectively, locating PQMs at a distribution substation secondary provides the most information and value for grid operations.

Susceptible Customers

Some customer processes economically require 24/7 highly reliable and quality power.

Customer Service

Customers will always have electric power issues that need attention. The PQM is one of the first tools used to gather meaningful information in a PQ investigation.

Asset Health

Assets whose catastrophic failure cost more than monitoring.

Predictive Maintenance

Replacing reactive and preventative monitoring with predictive monitoring.

Performance Benchmarking

In order to attract and keep valuable customers, benchmarking of power quality can be required to set realistic expectations of quality service.

DER Regulation

Quality power starts at generation. More important is making sure that DERs are operating in concert with the rest of the grid.

5 EPRI

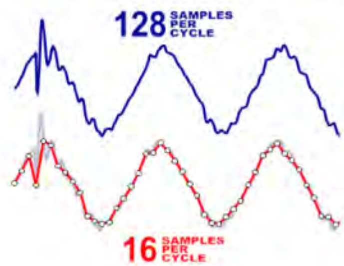
Why is the EPRI PQ Program interested in this research

- Problem
  - Growth of non-linear loads and distributed generation is creating grid stability/ power quality (PQ) issues.
  - Presently we lack sensors/monitoring for actionable information at the grid-edge.
  - Cost of deploying standard PQ monitors are a barrier.
- Research Objective
  - Identify the principal benefits and applications that can be derived from low-cost / low-fidelity PQ monitoring devices at edge of grid.
- Potential Applications
  - Voltage Regulation / Balance
  - Distribution Harmonics
  - Fault Location (including incipient)
  - Sequence of Events Support
  - Asset Health
  - Modeling Support

6 EPRI

Example of PQ Measurement Limits

	Low			Standard		High		
	$<300	$<800		$1.2-2k		$5k		
Samples per Cycle	4	16	32	64	128	256	512	1024
Time Specs								
Sample Rate (Hz)	240	960	1920	3840	7680	15360	30720	61440
Highest Freq. (Nyquist)	120	480	960	1920	3840	7680	15360	30720
Highest Freq. (Nyquist / 2)	60	240	480	960	1920	3840	7680	15360
dT (microSeconds)	4167	1042	521	260	130	65	33	16
PQ Capabilities								
Voltage Int/Sags/Swells	✓-	✓	✓+	✓+	✓+	✓+	✓+	✓+
Oscillitory Transients				✓-	✓-	✓	✓	✓+
Impulsive Transients						✓-	✓	✓
Bytes for 10 Cycle Recording	80	320	640	1280	2560	5120	10240	20480
Number of Recordings @ 1MB	12500	3125	1563	781	391	195	98	49
Highest Odd Harmonic	1	7	15	31	63	127	255	511

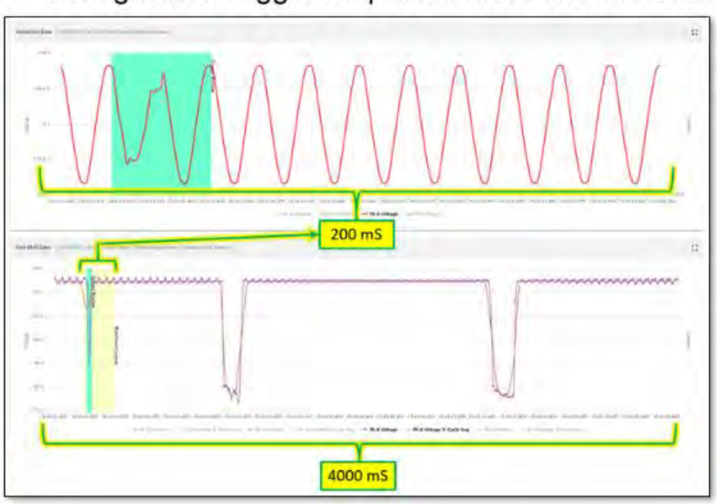


7

EPRI

Waveform and Fast RMS Capture

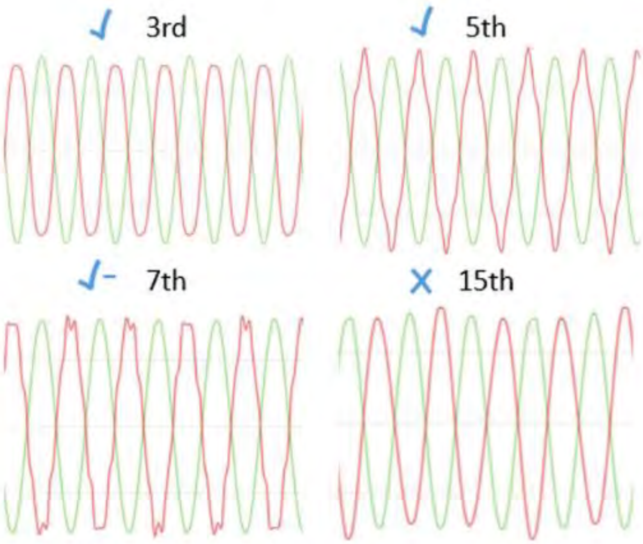
- Waveform: 1 kHz Sampling
- Fast-RMS: 3 & 1 Cycle Period
- Configurable Trigger Amplitude and Pre/Post Event Timing



8

EPRI

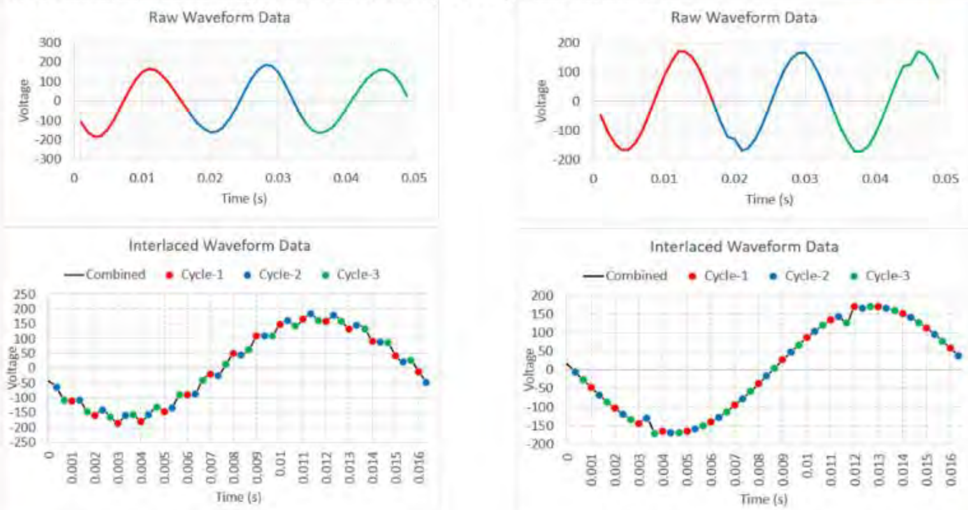
EMCB Harmonic Waveforms



EPRI

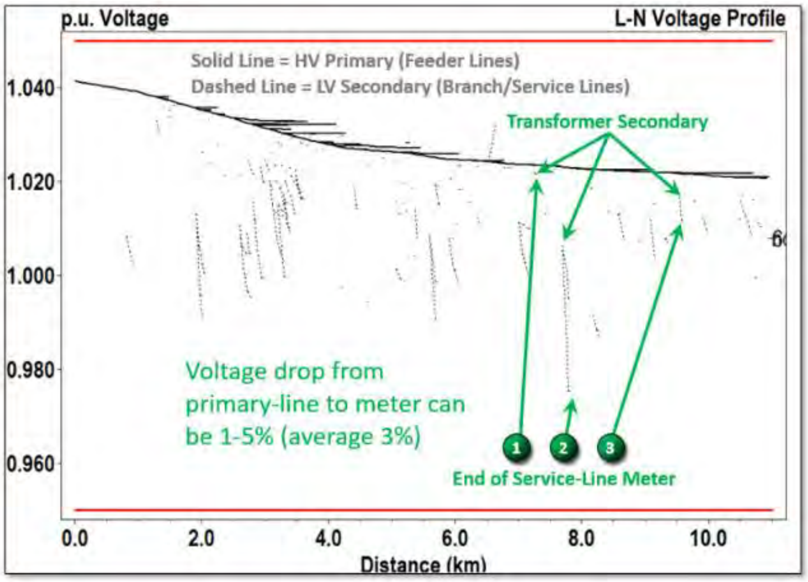
Possible Solution for Harmonics Sampling

- Waveform Interlacing
- Requires steady-state waveform signature for 3 cycles
- Chance of aliasing from low frequency modulations



EPRI

Application: Voltage Regulation
Meter Placement



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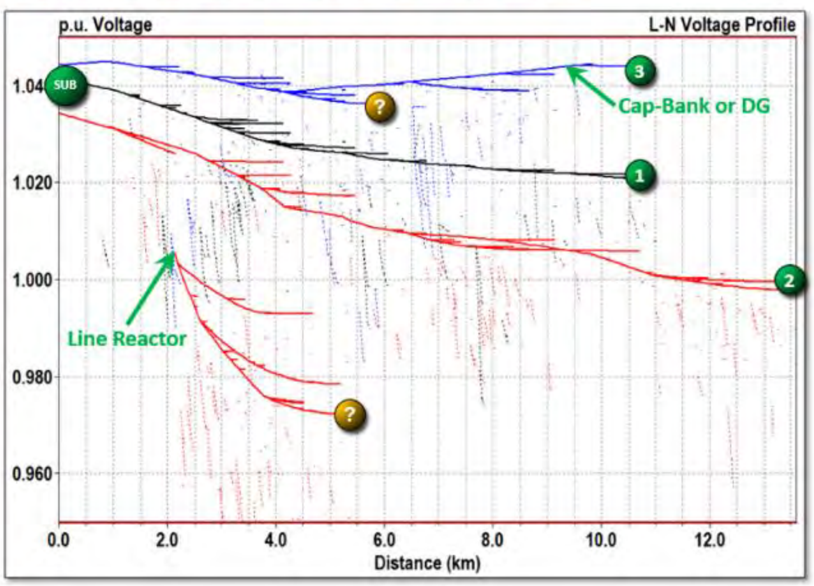
Application: Voltage Regulation
Beginning and End of Feeder



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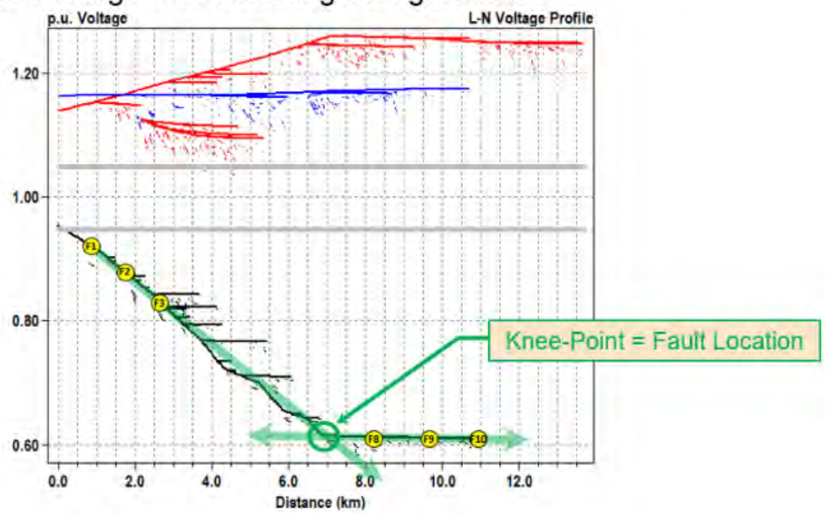
Fault Location

- More efficient method for fault location
- Traditional methods rely on a substation monitor and primary line modeling that must be maintained and accurate.
- Models change with switching configurations



  EPRI

EPRI
Power Quality
PS1B: PQ Data & Analytics

AGENDA

- PS1B Overview
- EMCB Interest and Potential
- PQ-EMCB Field Deployment
- GPA: EMCB Manager
- EMCB Data Reporting: Open PQ Dashboard
- TrendDAP
- Q&A

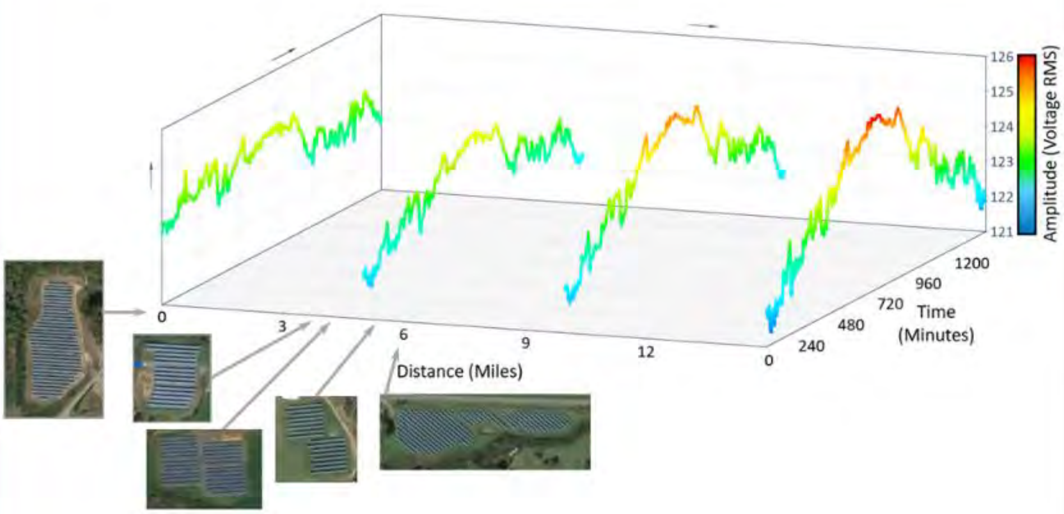
tcooke@epri.com

EPRI PQ-EMCB Field Deployment

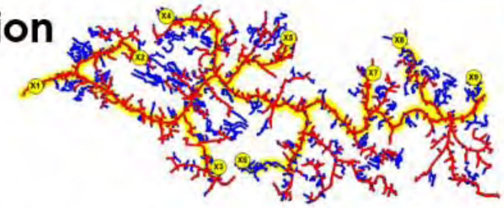
  EPRI

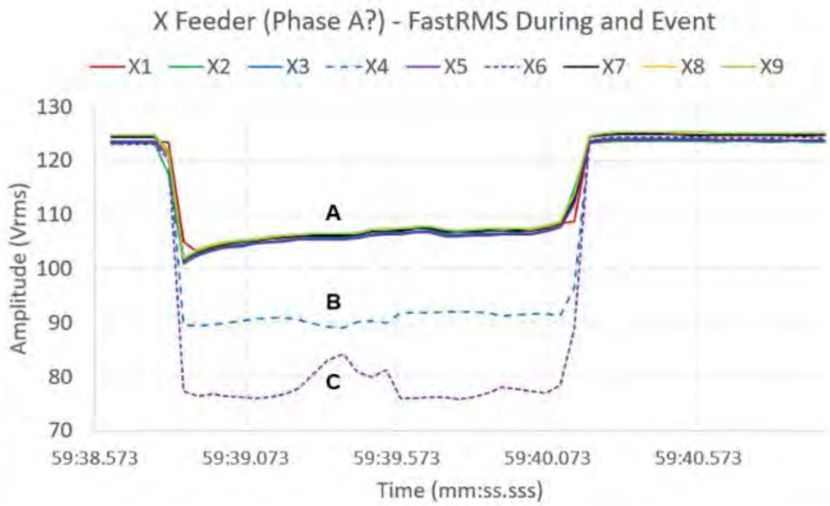
EMCB-PQ Deployment

Voltage Regulation



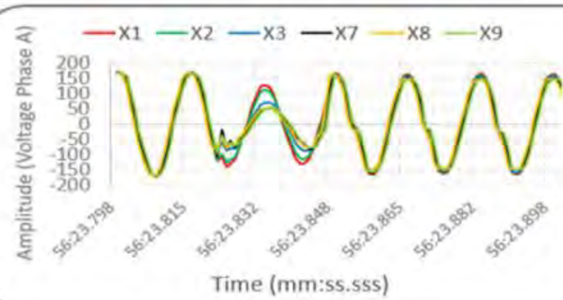
Phasing Verification





EPRI

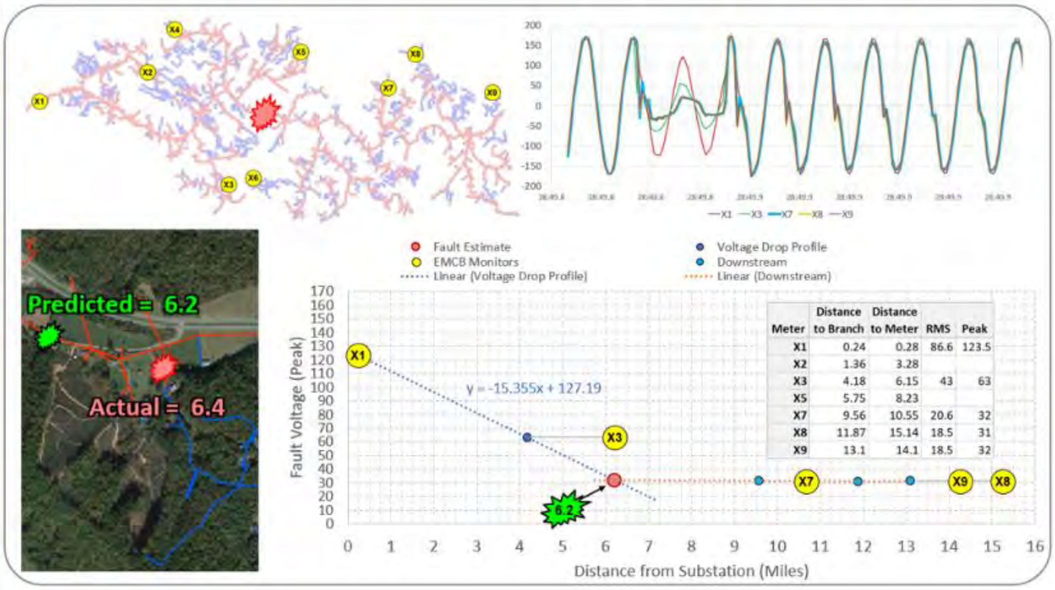
Incipient Fault, 8/9/2018, 4:56:23 PM



Meter	Distance to Branch	Distance to Meter	RMS	Peak
X1	0.24	0.28	88	127
X2	1.36	3.28	79	112
X3	4.18	6.15	53	72
X7	9.56	10.55	40	54
X8	11.87	15.14	40	56
X9	13.1	14.1	40	56

EPRI

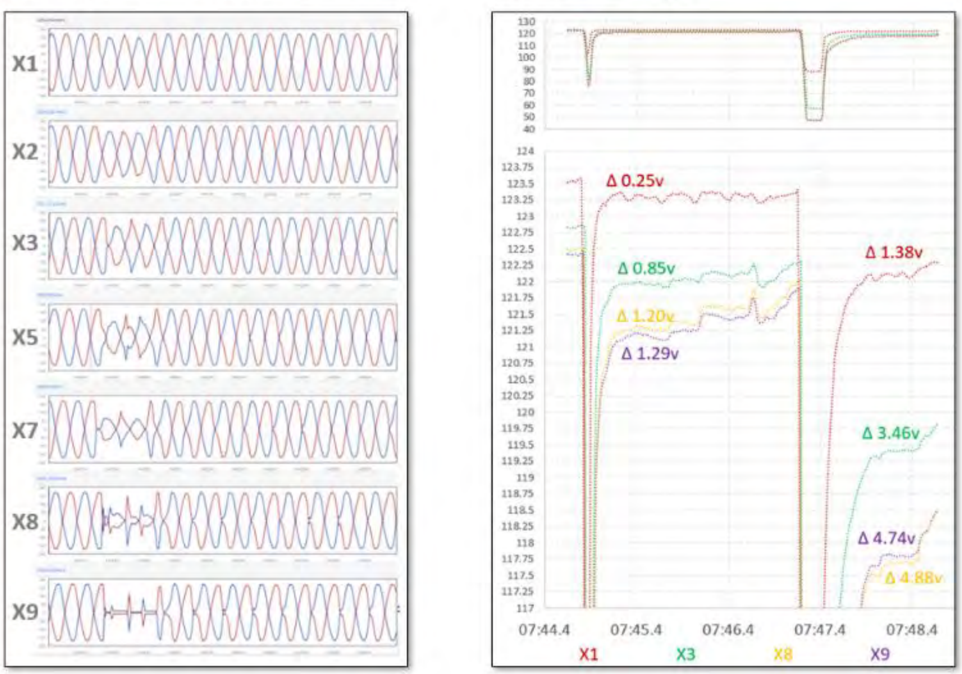
Accuracy of Fault Location



Meter	Distance to Branch	Distance to Meter	RMS	Peak
X1	0.24	0.28	86.6	123.5
X2	1.36	3.28		
X3	4.18	6.15	43	63
X5	5.75	8.23		
X7	9.56	10.55	20.6	32
X8	11.87	15.14	18.5	31
X9	13.1	14.1	18.5	32

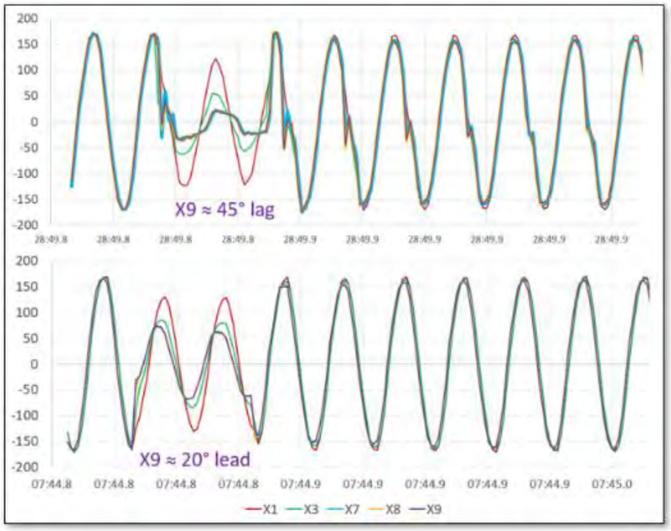
19 EPRI

Incipient Faults and State Change

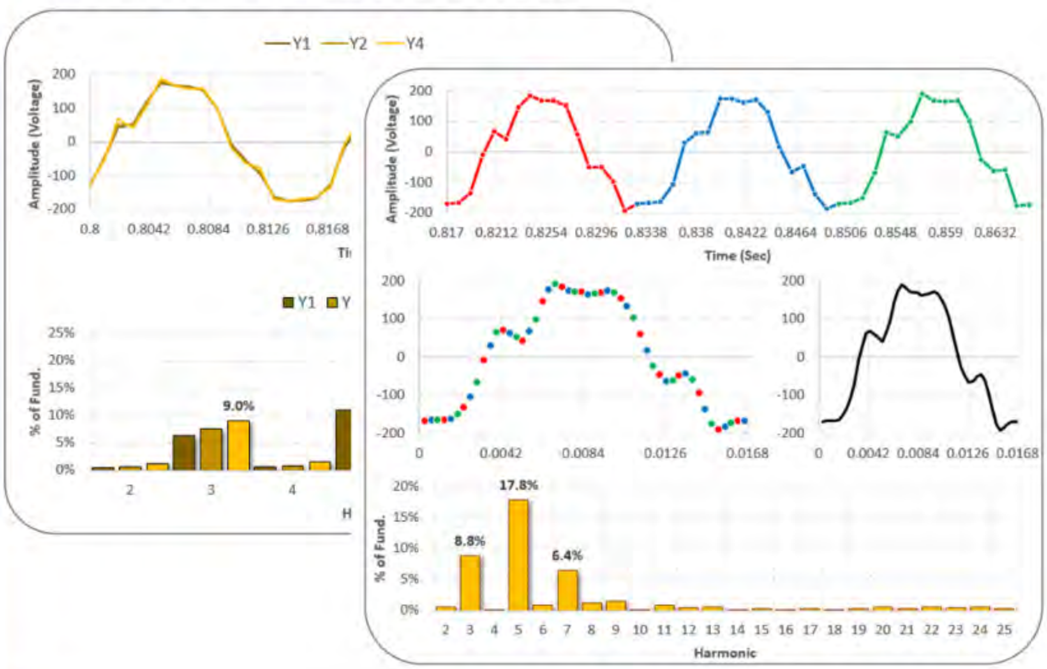


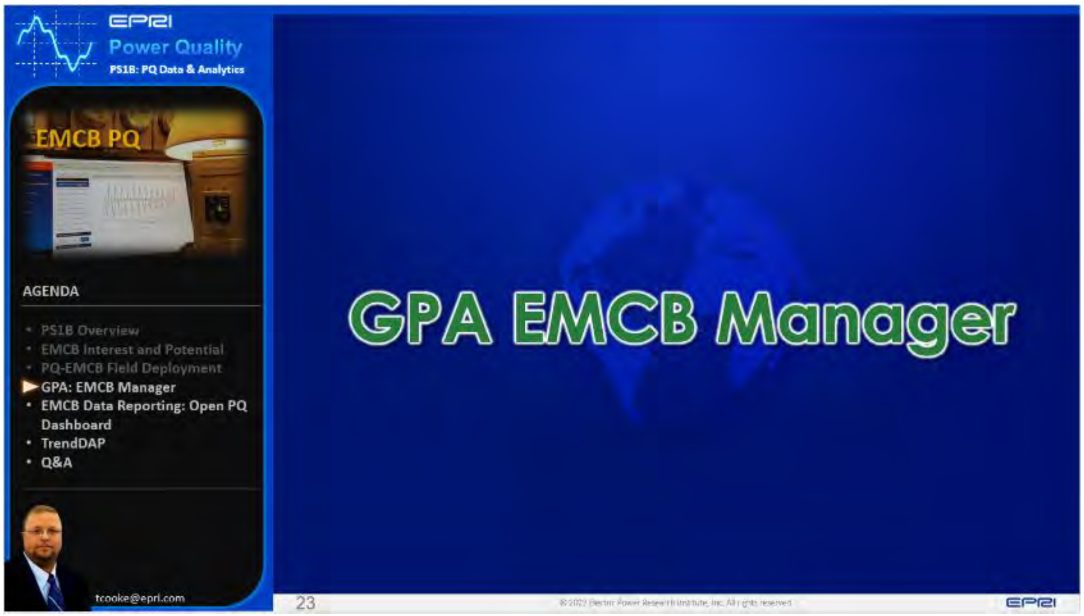
20 EPRI

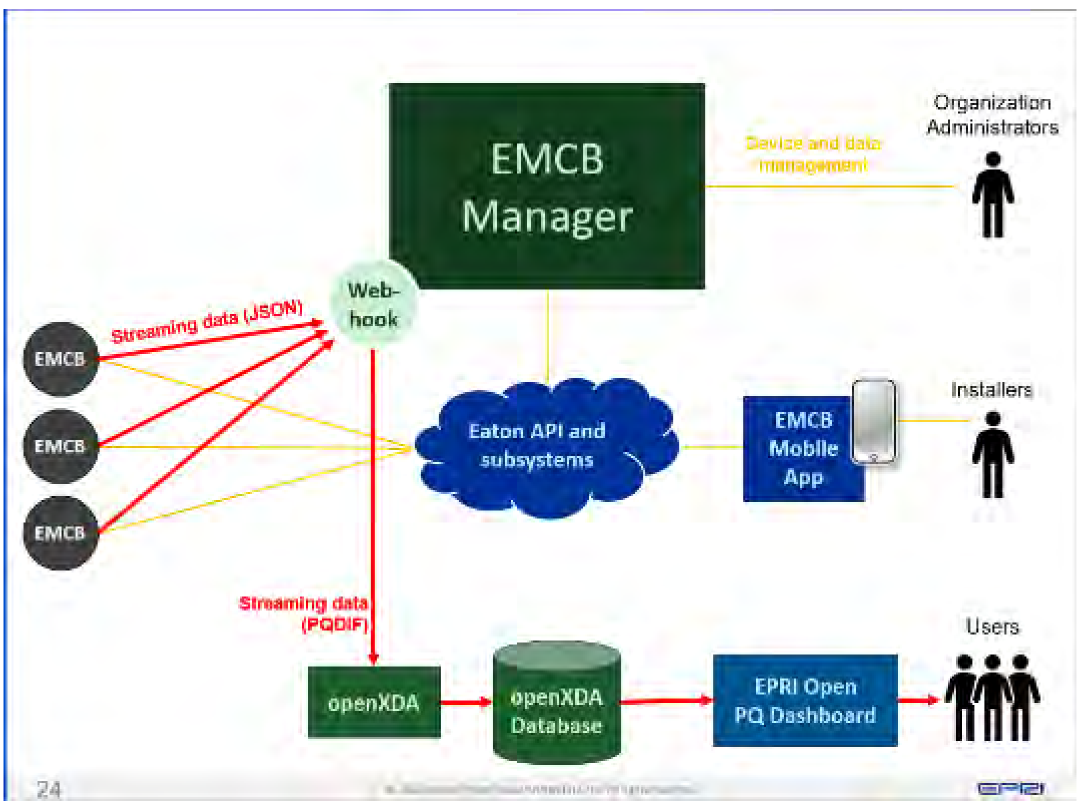
Fault Voltage Signatures



Harmonic Measurements




EPRI
Power Quality
PS1B: PQ Data & Analytics
EMCB PQ
AGENDA
PS1B Overview
EMCB Interest and Potential
PQ-EMCB Field Deployment
GPA: EMCB Manager
EMCB Data Reporting: Open PQ Dashboard
TrendDAP
Q&A
tcooke@epri.com
GPA EMCB Manager
23
EPRI


EMCB Manager
Device and data management
Organization Administrators
Web-hook
Streaming data (JSON)
EMCB
EMCB
EMCB
Eaton API and subsystems
EMCB Mobile App
Installers
Streaming data (PQDIF)
Users
openXDA
openXDA Database
EPRI Open PQ Dashboard
24
EPRI

Eaton API Application Hierarchy

- Application: EMCB Manager
  - Organizations page to manage organizations
  - Locations page to view/edit the location hierarchy
  - Installers page to manage who can use the EMCB mobile app to install devices
  - Users page to manage who has access to each organization
  - Settings page to manage EMCB Manager application settings

From the Eaton API docs:

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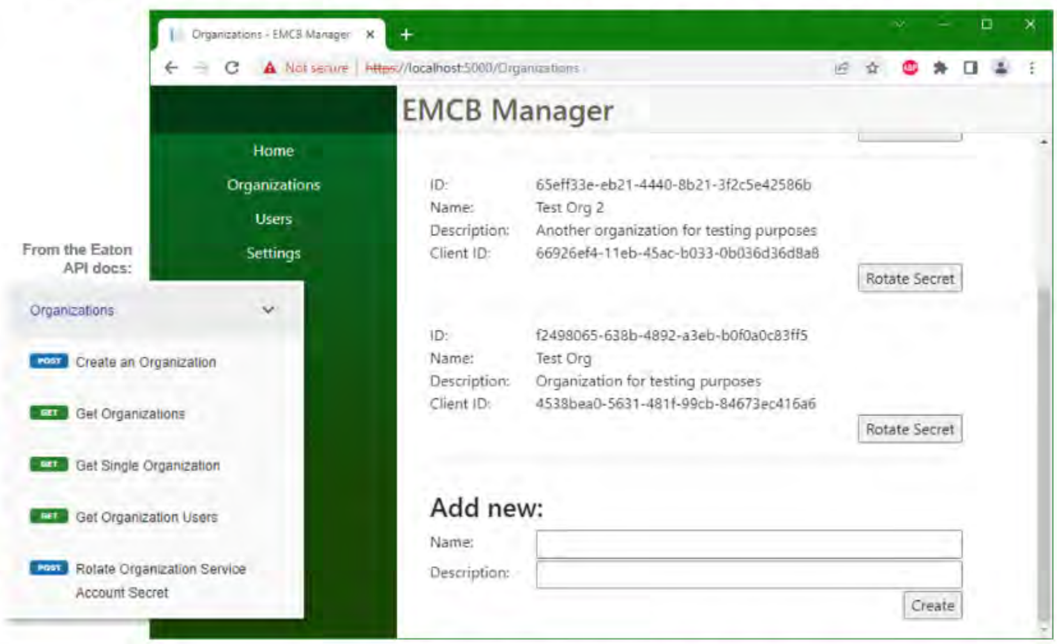
EMCB Manager – Organizations Page



Note – the application is still under development

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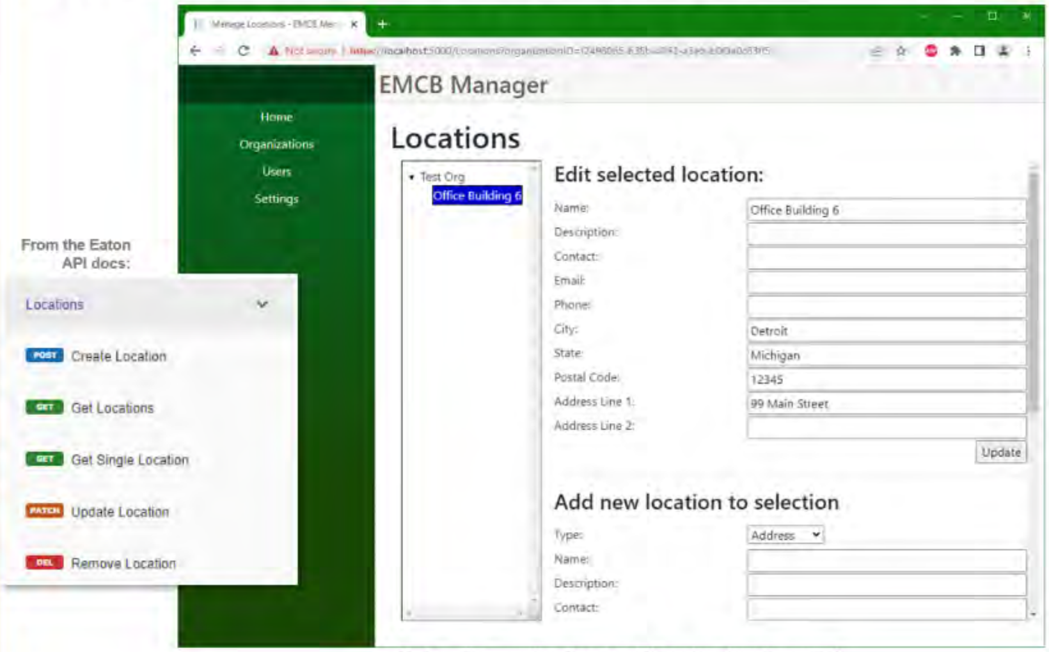
EMCB Manager – Locations Page

From the Eaton API docs:



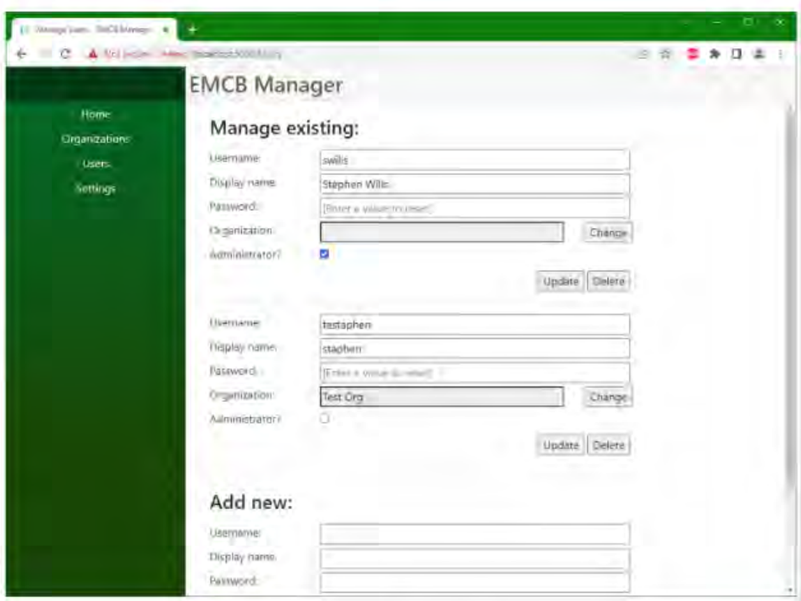
Note – the application is still under development

27

EPRI

EMCB Manager – Users Page

- Application administrators
  - Manage any organization's locations, installers and devices
  - User management
    - Invite new users and administrators
    - Assign organizations
    - Reset passwords
  - Manage application settings
- Organization administrators
  - Assigned to a single organization
  - Manage locations, installers, and devices for that organization



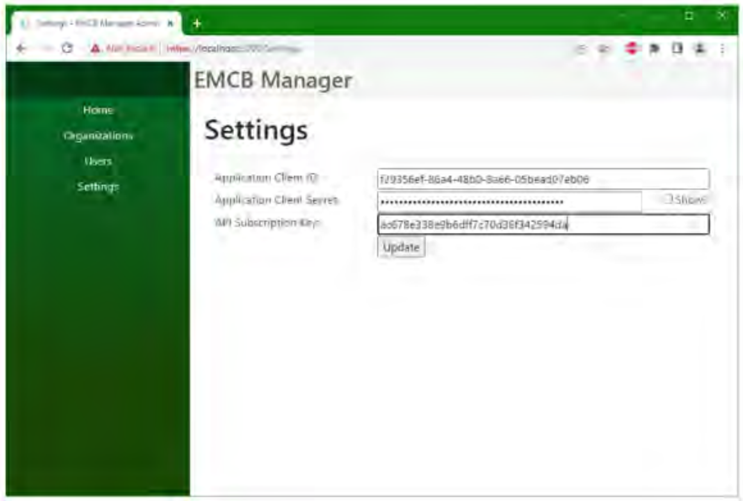
Note – the application is still under development

28

EPRI

EMCB Manager – Settings Page

- Manage settings for the application itself
- Links the application to the Eaton API developer subscription

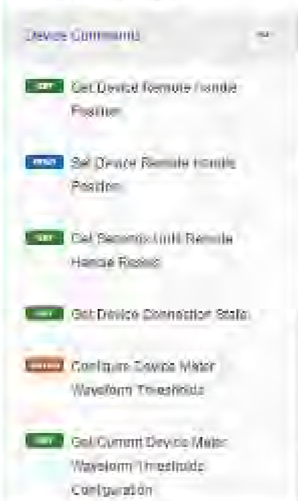


Note – the application is still under development

29

EMCB Manager – Still more to come…

From the Eaton API docs:



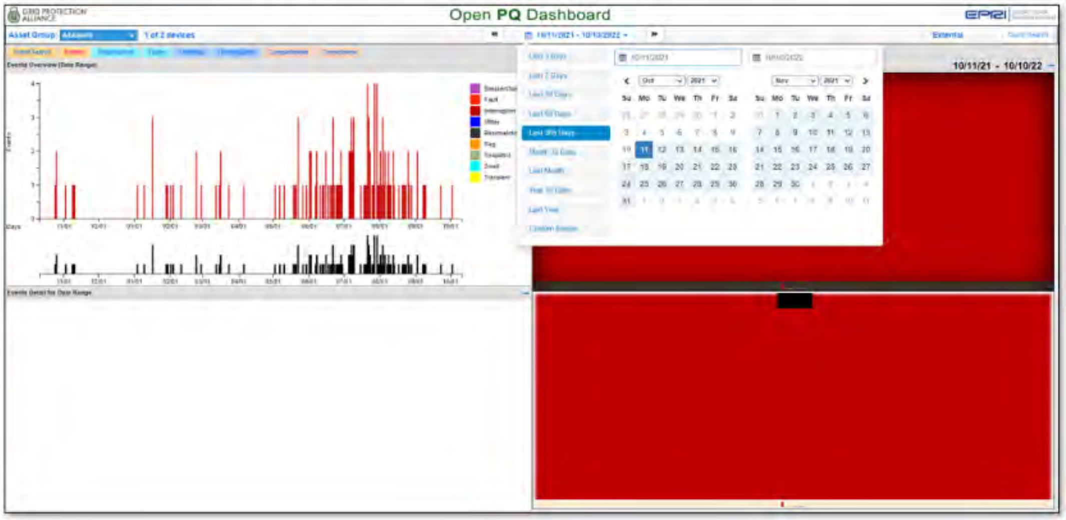
- Organization administrators need to be able to invite installers who can use the EMCB mobile app to commission devices
- Additional features to manage the devices themselves as well as their data
- Webhook to receive streaming data and events from devices automatically
- Integration with EPRI's Open PQ Dashboard for data visualization

30

Grid Protection Alliance

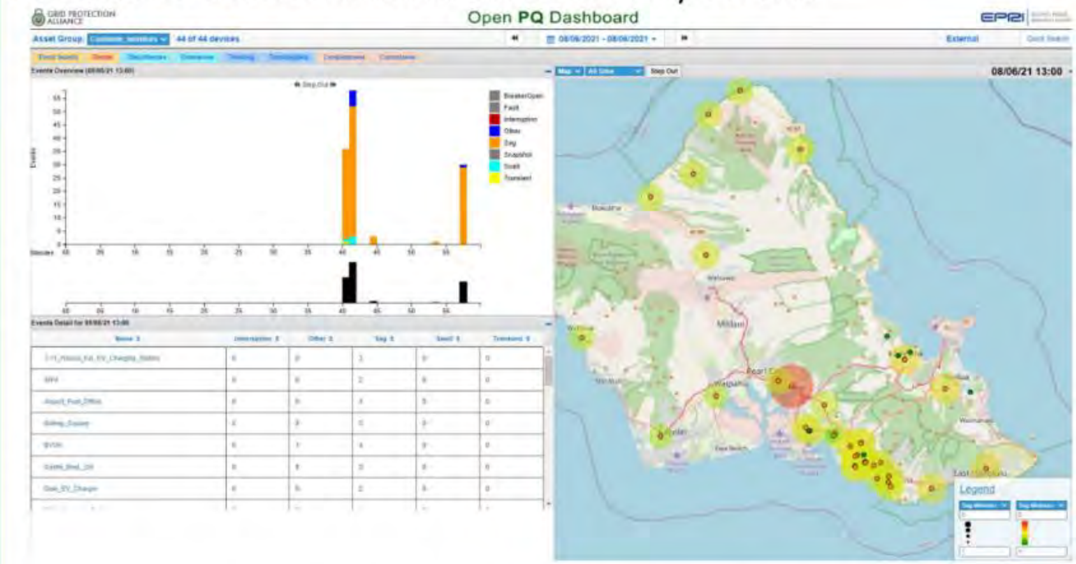
- Grid Protection Alliance (GPA) is developing the EMCB Manager as an option for users of EMCB devices to manage their data
- Access to EMCB Manager will be provided as a service by GPA
- Demo system to be available through February 2023 once development and testing has been completed
- More information is available upon request (clackner@gridprotectionalliance.org)

Summary Fleet Status Information



Drill-Down to Raw Data Visualization

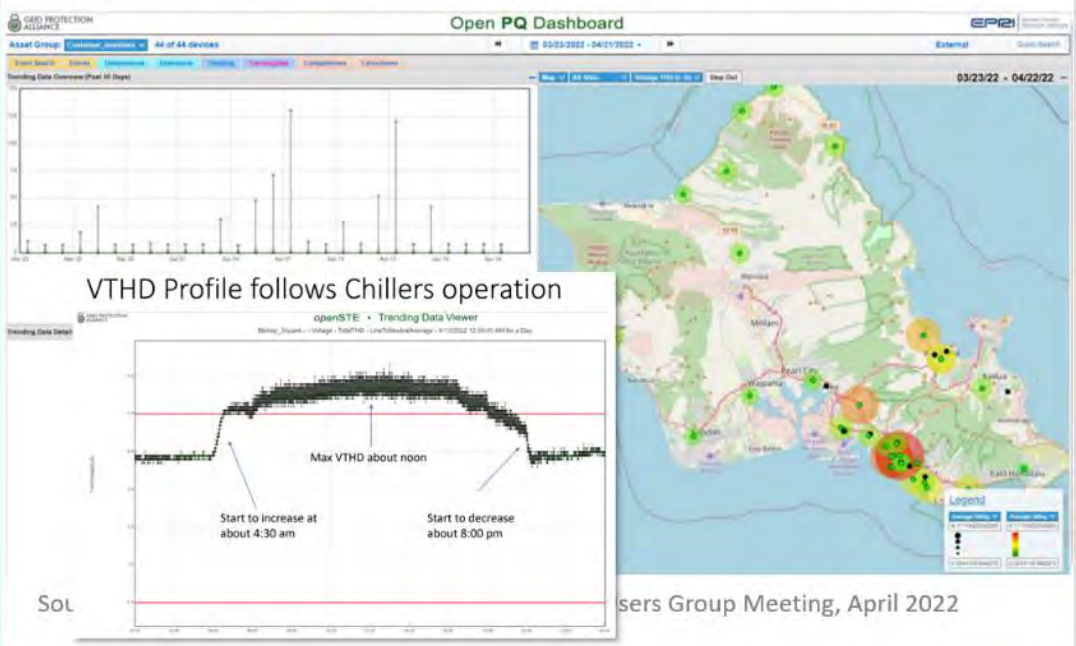
138kV Transmission event red circle with all other monitors across island affected by event



Source: Hawaiian Electric Company, PQ Dashboard Users Group Meeting, April 2022

EPRI

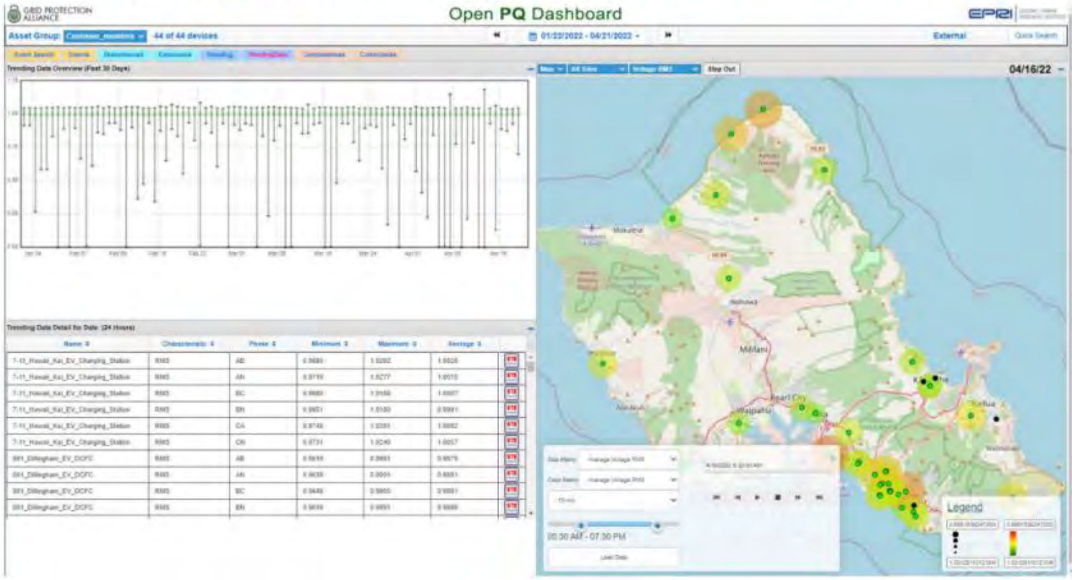
Customer monitors for month – showing sites with higher "Average Voltage THD"



Sou sers Group Meeting, April 2022

EPRI

Voltage Trending for All customer sites across island

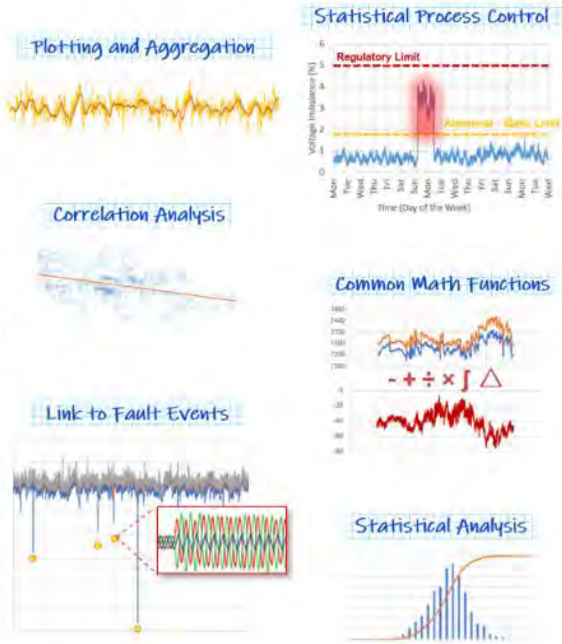


Source: Hawaiian Electric Company, PQ Dashboard Users Group Meeting, April 2022

TrenDAP

open-source trending-data analytics platform

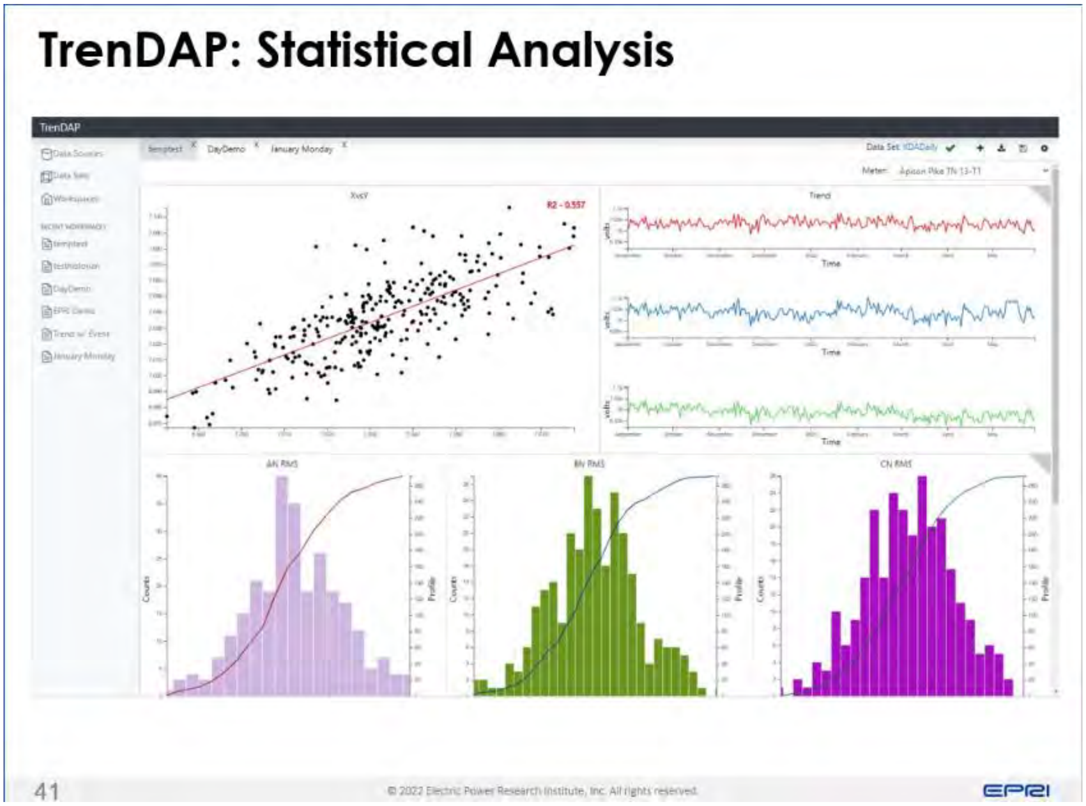
- An open-source software component as part of the Open PQ Dashboard suite of products.
- Design requirements from collaborative utility funders and EPRI
- Developed by Grid Protection Alliance
- Objective of the tool is to integrate, analyze, and report trend data from a multitude of PQ and other data parameters to enable quick and informed decision-making.
- Flexible and Extensible Design: Customizable workspace with various analytical widgets.
- For more information:
  - EPRI PM: Tom Cooke, tcooke@epri.com
  - TVA PM: Tony Murphy, ammurphy@tva.gov



EPRI

TrenDAP: Statistical Analysis

EPRI



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C USING SMART DEVICES AT THE BUILDING LEVEL

Using Smart Devices at the Building Level

Use Cases of System Integration

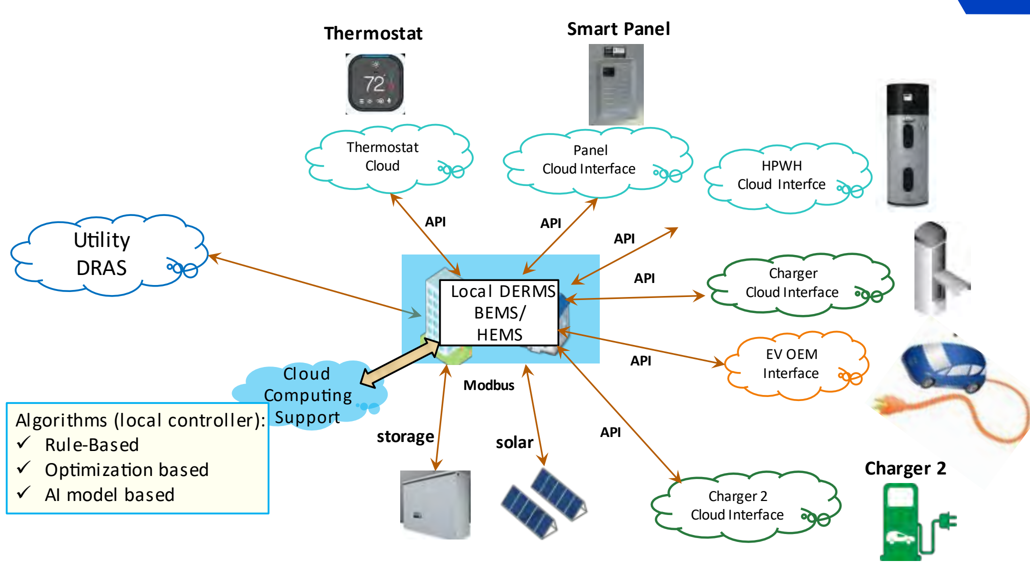
Penn Zhao, PhD
Technical Leader

October 12, 2022

www.epri.com

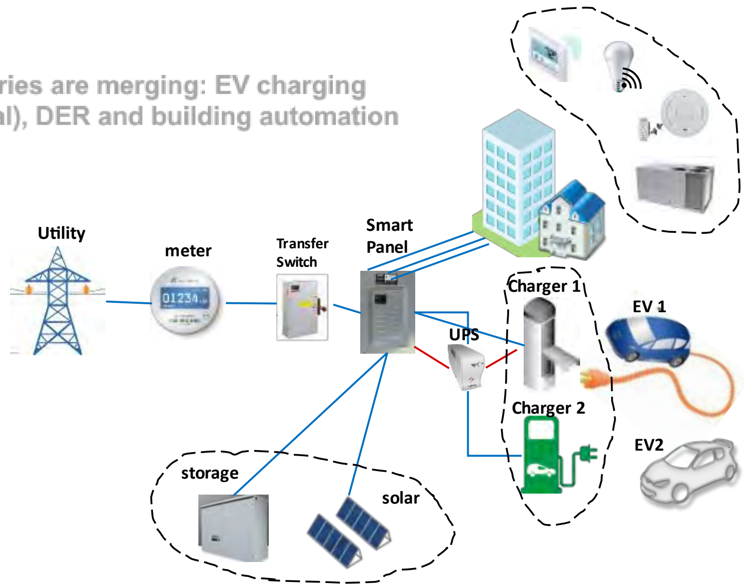
EPRI 50th ANNIVERSARY

Smart Devices at the Building Level

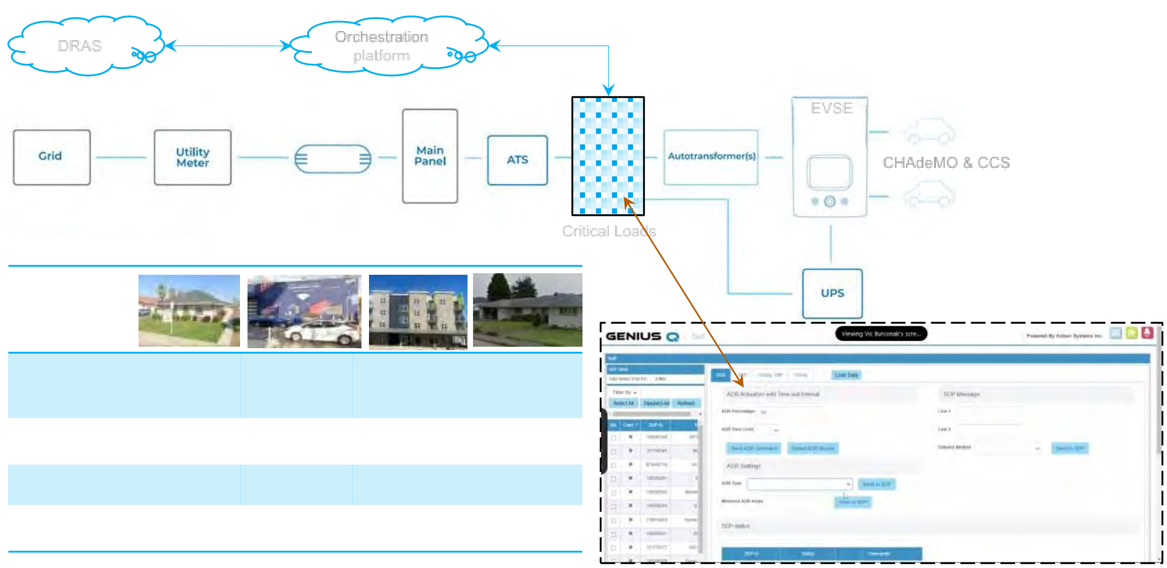


Smart Devices at the Building Level

Three industries are merging: EV charging (bi-directional), DER and building automation

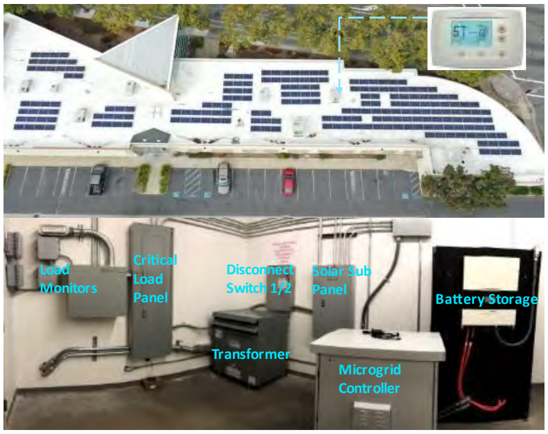


Vehicle to Building Use Cases



Courtesy of Koben Systems

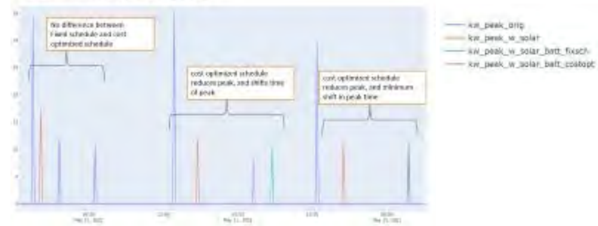
DER + Building Flexible Loads Use Cases



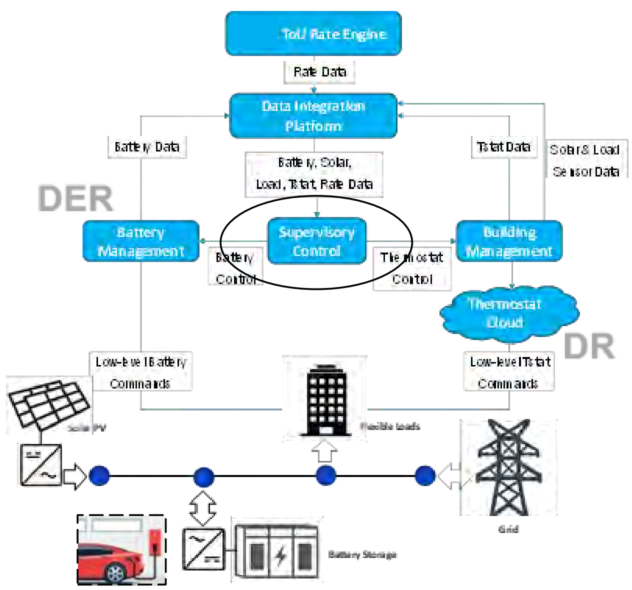
Office Building at San Francisco Bay Area
23,000 sq.ft. of office + retail

Optimization with the Control of Battery and Thermostats

Peak Load Reductions



Discussion of Opportunities and Challenges



Challenges to Aggregate Building's Flexible DER + DR for Utility DSM Programs

- Getting reliable data
- Advanced controls only show incremental benefits relative to rule-based controls
- Changeable equipment state, incomplete info, lack of sufficient data, complex systems to model and need domain knowledge.
- Can't completely close the feedback loop and still need human in the loop. Therefore, stuck with monetization and scaling

Opportunities

- Reliable circuit level data
- Direct load controls
- V2B Resiliency (independent of economics of demand charge)

Next Step: Extending the Aggregation and Controls in Response to Wholesale Markets

Building-Scale Heterogeneous Aggregation of DERs + DR for Grid Services through FO2222 Compliance

- Understanding the requirements for heterogeneous behind -the-meter aggregation of DERs + DR at buildings as the center of integration
- Joint EPRI funded project with EPRI's P39 Grid Ops
  - Phase 1 to understand FO2222 rules
  - Phase 2 focus on simulations of use cases

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D LOCAL CONTROL OF EMCB DEVICES

EMCB Local Control

Viswanath (Vis) Ananth
Electric Power Research Institute
Palo Alto, CA

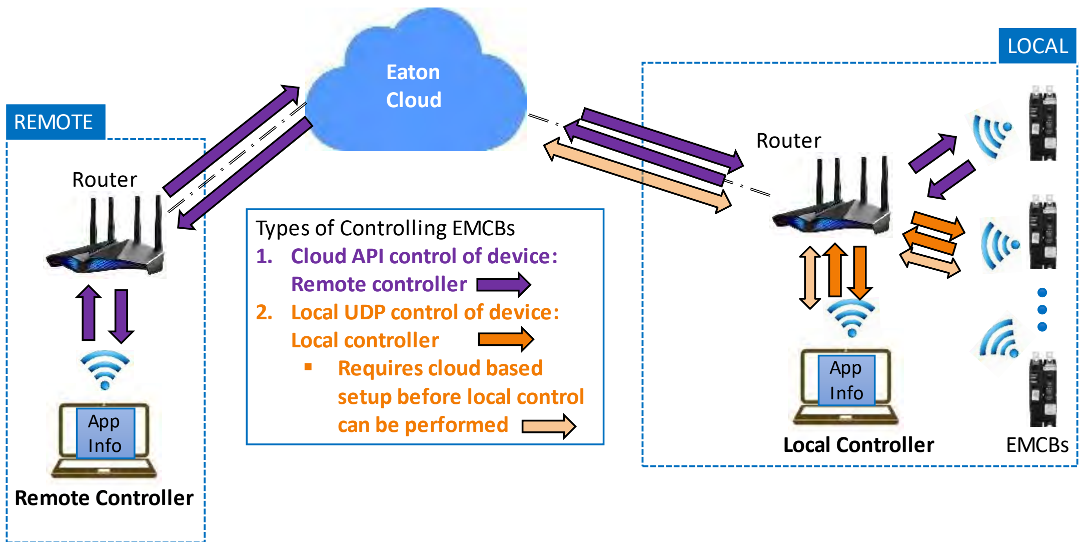
October 12, 2022

www.epri.com

Summary

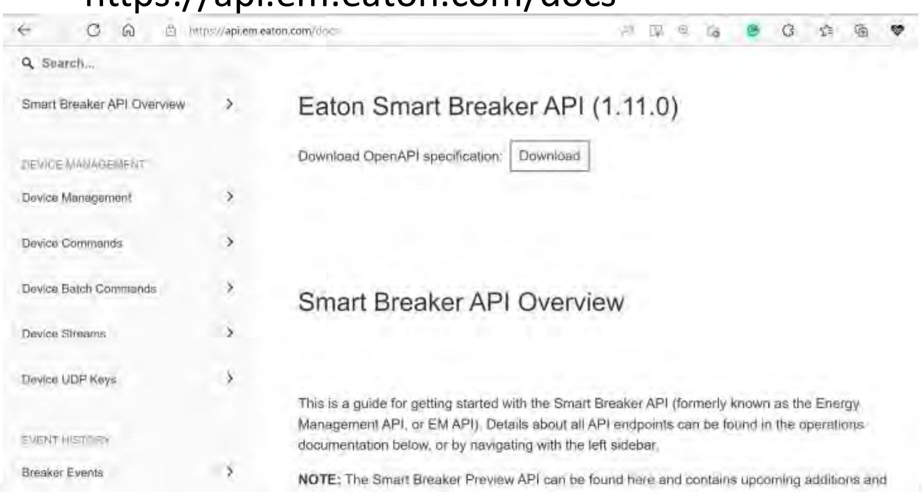
- Overview of EMCB controls Architecture
- Cloud based Control of EMCBs (a brief)
- Local Control of EMCBs
- Demonstration of local access to EMCB

Overview of EMCB controls



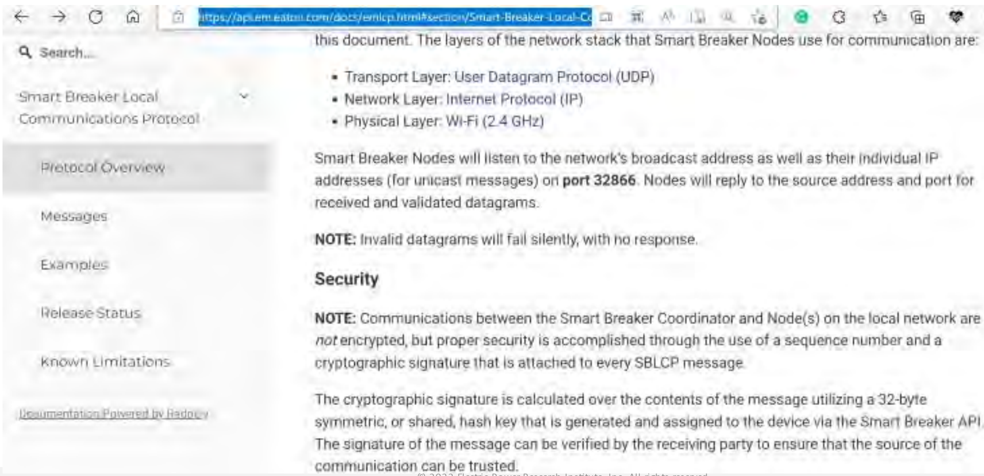
Cloud Based Control of EMCBs

- Complete details of setup and API messaging available at https://api.em.eaton.com/docs



Local Control of EMCBs

- Local control documentation at Eaton is
  https://api.em.eaton.com/docs/emlcp.html



https://api.em.eaton.com/docs/emlcp.html#section/Smart-Breaker-Local-C

Search...

Smart Breaker Local Communications Protocol

Protocol Overview

Messages

Examples

Release Status

Known Limitations

Documentation Powered by Redocly

this document. The layers of the network stack that Smart Breaker Nodes use for communication are:

- Transport Layer: User Datagram Protocol (UDP)
- Network Layer: Internet Protocol (IP)
- Physical Layer: Wi-Fi (2.4 GHz)

Smart Breaker Nodes will listen to the network's broadcast address as well as their individual IP addresses (for unicast messages) on **port 32866**. Nodes will reply to the source address and port for received and validated datagrams.

NOTE: Invalid datagrams will fail silently, with no response.

Security

NOTE: Communications between the Smart Breaker Coordinator and Node(s) on the local network are *not* encrypted, but proper security is accomplished through the use of a sequence number and a cryptographic signature that is attached to every SBLCP message.

The cryptographic signature is calculated over the contents of the message utilizing a 32-byte symmetric, or shared, hash key that is generated and assigned to the device via the Smart Breaker API. The signature of the message can be verified by the receiving party to ensure that the source of the communication can be trusted.

Local Control of EMCBs

- Requires a local controller to execute in the same LAN as the nodes
  - Discover nodes in the local network
  - Control and status messages to be initiated by controller, and responses provided by nodes
- Communication by the nodes are based on:

  Transport Layer: User Datagram Protocol (UDP)

  Network Layer: Internet Protocol (IP)

  Physical Layer: Wi-Fi (2.4 GHz)

  Nodes will listen to the network's broadcast address as well as their individual IP addresses (for unicast messages) on **port 32866**. Nodes will reply to the source address and port for received and validated datagrams. Invalid datagrams will fail silently, with no response.

Local Control of EMCBs

- Security of the local messaging is controlled by
  - sequence number (chosen randomly by a node at bootup time)
  - cryptographic signature that is attached to every message
  - Allocation of unicast and broadcast symmetric keys called “UDPKeys” in documentation in the devices (requires cloud API access for setup)
- Setup of UDPKeys in the device
  - Generate UDPKeys using cloud API (unicast and broadcast) expires in 7 days
  - Allocate generated keys to devices using cloud API
  - Regenerate and re-allocate UDPKeys before they expire to continue to use the local controller.

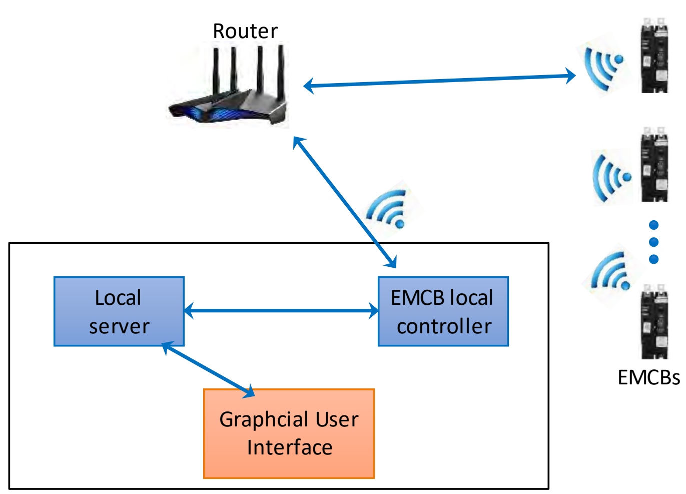
Local controller implementation architecture

Architecture

✓ Three Tier architecture

✓ Language: javascript using Nodejs

✓ Graphical User Interface: React web framework



Local Control of EMCBs

- **Implementation Suggestions**

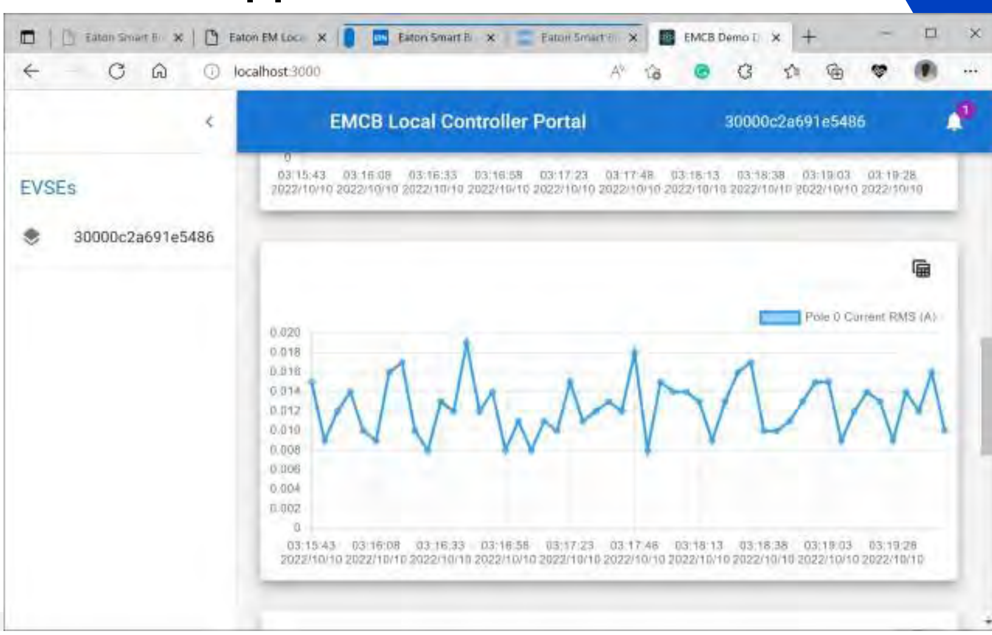
✓ Proper creation and assignment of UDPKeys for broadcast and unicast communication at the local controller

✓ Do not send rapid successive requests, wait for response before sending a new request

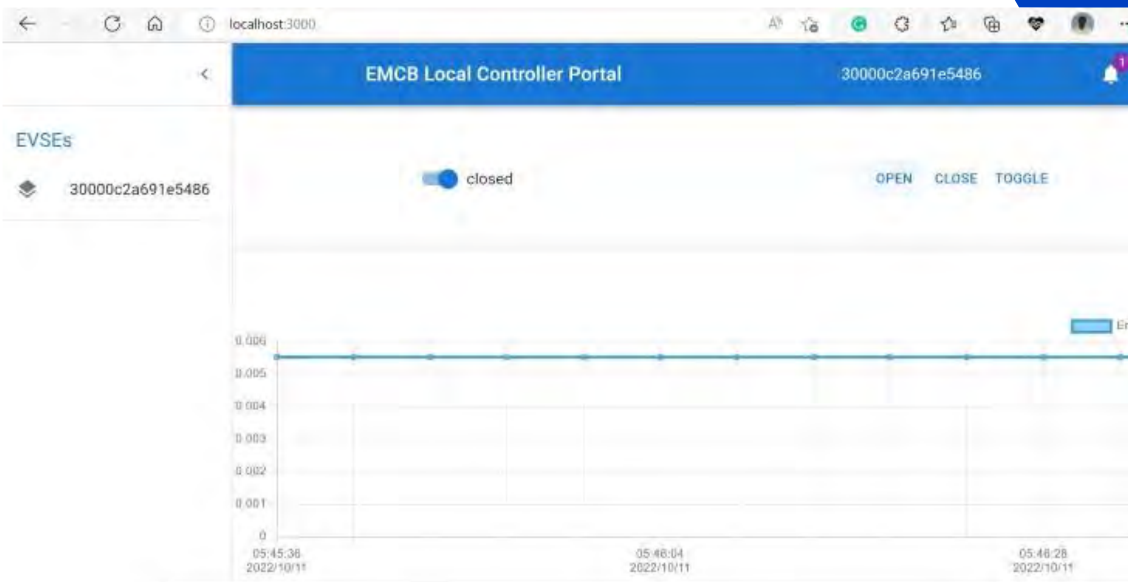
✓ Keeping track of UDPKeys expiration and regeneration and assignment of keys to devices

✓ Ensure all parameters are correct before sending request, since the node drops the packets without response

Screenshot of application



Screenshot of application: control functions



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E WHAT IS NEEDED FOR THE "SMART CONSUMER?"

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What is needed for the "Smart Consumer?"

What is next Big Thing!

Tom Reddoch
Principal Technical Executive

October 12, 2022

www.epri.com

What are some of the Options for a Smart Consumer

Management Choices

- Passive control versus Active control (rates/incentives or pricing vs direct control) or testing price elasticity vs managed outcomes for effectiveness to manage loads
- Central versus local control (utility/third party control vs local consumer control)
- Just using local control (energy management, smart thermostat, on/off via timer, etc.)
- Hybrid configurations

Questions

- Is resilience important
- Is lowest cost paramount
- Is comfort the highest value
- Are features preferred

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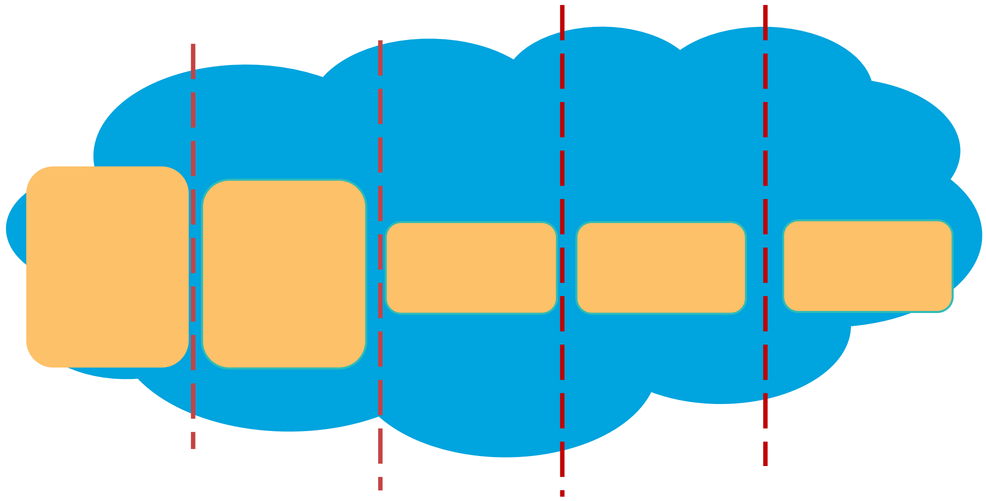
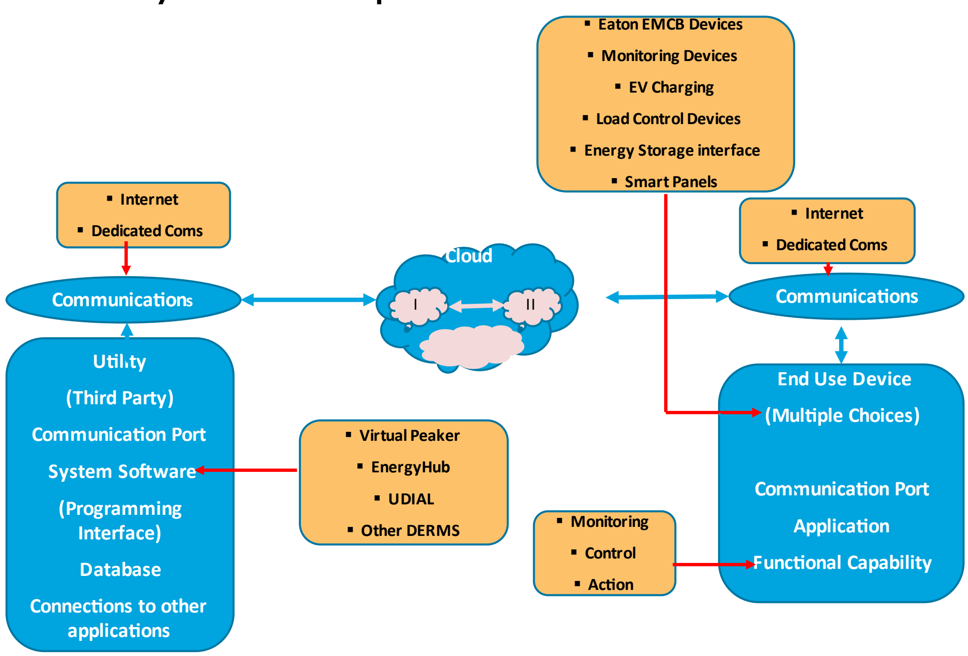
What are the Market needs



Generic Systems Concept

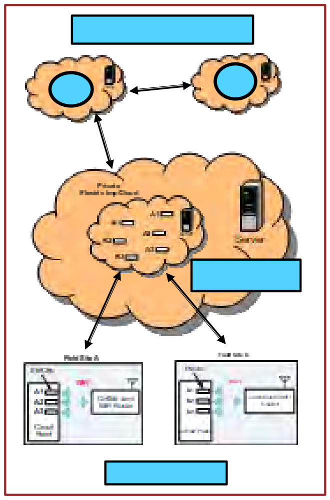


The Energy Management Circuit Breaker System

EMCB manufactured by Eaton Corporation with the System powered by Virtual Peaker

Common Circuit Breaker Panel

EMCB EV Version



EMCB Standard Version

System Software by Virtual Peaker

EPRI Contacts
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865-456-3708
treddoch@epri.com

www.epri.com

F PROPOSED SMART CHARGING ALGORITHM DEVELOPMENT

ELECTRIC POWER RESEARCH INSTITUTE

Energy Management Circuit Breaker

Palo Alto Charge Management Algorithm

John Halliwell
Senior Technical Executive

October 9, 2020
DRAFT

www.epri.com

Overview

- There are 19 charge stations served by the transformer on the site
  - CS1-1 through CS17 (7-each) are offline at this time
    - I would like algorithm to be able to handle these if they were to come online
  - CS3-1 through CS312 (12each)
    - There are the ones we want to control in this project
    - CS3-12 is offline at this time
  - Offline units likely to remain inactive until later in 2021
- User chooses max loading for transformer
- User can set a time -based derating to manage the peak power profile versus time
- System manages programmed charge currents to limit power below max loading in near real time based on 5-minute accumulated energy data
- EMCB provides 4-quadrant energy data – must convert to power and derive current
- Charge stations are distributed across the 3-phases, so phase balance must be considered in control algorithm
- We will only know the system state from 5-minutes in the past
- Stations in an unknown state are considered to be running at full power
- Priority for higher power is given to stations that were known to be actively charging at the last 5-minute interval

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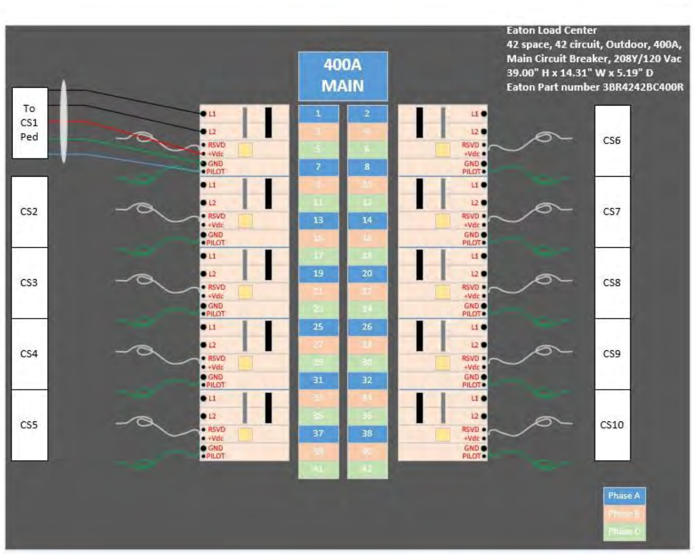
SITE Details

Site Layout

Pedestal Ref. #	Breaker Position	AE Parking Lot ID	EMCB Device ID	EMCB Agent ID	Pedestal Type	Pedestal Label	Notes
CS3-1 1	L	1-L	30000c2a690c76ff	VAZiZGzudtvc	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 2,4	
1	R	1-R	30000c2a690cc65e	jbOtegbLxsOc		PANEL EVCP2 DISCONNECT CKTS 2,4	
2	L	2-L	30000c2a690c75bb	8SynjEBlEo6T	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 6,8	
2	R	2-R	30000c2a690c759f	OZuhfdPU-PeG		PANEL EVCP2 DISCONNECT CKTS 6,8	
3	L	3-L	30000c2a690cc68c	oqERLzP-30fw	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 10,12	Pedestal has 120V convenience outlet added
3	R	3-R	30000c2a690c6e51	DEWbTI07yEnu		PANEL EVCP2 DISCONNECT CKTS 10,12	Pedestal has 120V convenience outlet added
4	L	4-L	30000c2a690c75aa	x3K6s_Cb4mhv	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 14,16	
4	R	4-R	30000c2a690c72be	BiFMPyRR-c14		PANEL EVCP2 DISCONNECT CKTS 14,16	
5	L	5-L	30000c2a690c75a8	PdLDYd9XmO4N	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 18,20	
5	R	5-R	30000c2a690cc67a	SYdOVa3OnQpT		PANEL EVCP2 DISCONNECT CKTS 18,20	
6	L	6-L	30000c2a690c5975	zrfilclq5eZ0	Dual-Head	PANEL EVCP2 DISCONNECT CKTS 22,24	
CS3-12 6	R	6-R	TBD			PANEL EVCP2 DISCONNECT CKTS 22,24	Disconnected for start of field trial
		ADA-1	30000c2a690c7943	WtEnFYwO1HUo	Single-Head	PANEL EVCP3 DISCONNECT CKTS 5,7	
		ADA-2	30000c2a690c7a05	9xKY-QsmxUTM	Single-Head	PANEL EVCP3 DISCONNECT CKTS 6,8	

Stations CS1-1 through CS1-7 Panel Layout



CS1-8 through CS1-10 are not installed

Station/MAC/Agent List for CS3-x Stations

- CS3-1: 30000c2a690c76ff
  - VAZiZGzudtvc
- CS3-2: 30000c2a690cc65e
  - jbOtegbLxsOc
- CS3-3: 30000c2a690c75bb
  - 8SynjEBlEo6T
- CS3-4: 30000c2a690c759f
  - OZuhfdPU-PeG
- CS3-5: 30000c2a690cc68c
  - oqERLzP-30fw
- CS3-6: 30000c2a690c6e51
  - DEWbTl07yEnu
- CS3-7: 30000c2a690c75aa
  - x3K6s_Cb4mhv
- CS3-8: 30000c2a690c72be
  - BiFMPyRR-c14
- CS3-9: 30000c2a690c75a8
  - PdLDYd9XmO4N
- CS3-10: 30000c2a690c794e
  - 4GpjlW_h2WF2
  - [Note: CS3 -10 was 30000c2a690cc67a; SYdOVa3OnQpT – replaced March 9, 2020]
- CS3-11: 30000c2a690c5975
  - zrfilcIq5eZ0
- CS3-12: TBD
  - TBD
- ADA-1: 30000c2a690c7943
  - WtEnFYwO1HUo
- ADA-2: 30000c2a690c7a05
  - 9xKY-QsmxUTM

Site Power Capacity and Phase Loading

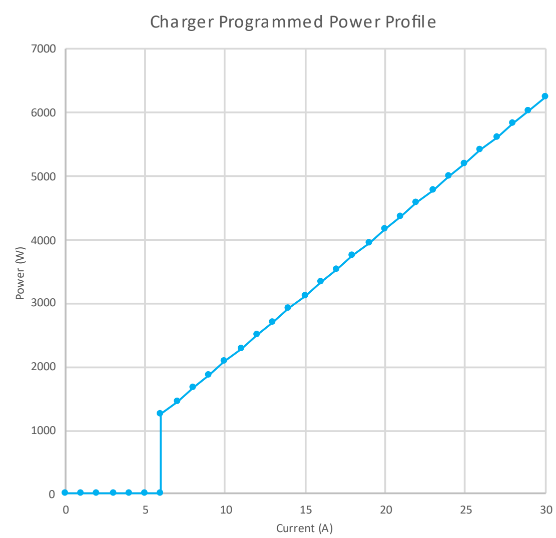
- 75kVA transformer
  - 208V, 3-phase AC
  - 208.2A max per phase
- 19 EVSE, served in two sections:
  - CS1-1 through CS1-7; 30A max charge current each; these are all offline
  - CS3-1 through CS3-12; 30A max charge current each; all online except CS3-12
- Phase loading
  - AB – 7 stations
  - BC – 7 stations
  - CA – 5 stations

- CS1-1 phase AB
- CS1-2 phase BC
- CS1-3 phase CA
- CS1-4 phase AB
- CS1-5 phase BC
- CS1-6 phase AB
- CS1-7 phase BC

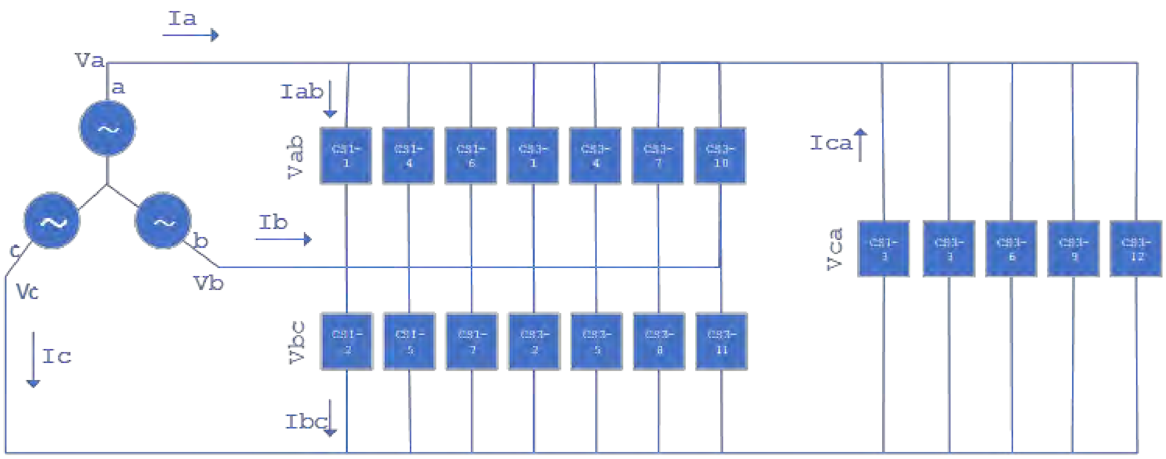
- CS3-1 phase AB
- CS3-2 phase BC
- CS3-3 phase CA
- CS3-4 phase AB
- CS3-5 phase BC
- CS3-6 phase CA
- CS3-7 phase AB
- CS3-8 phase BC
- CS3-9 phase CA
- CS3-10 phase AB
- CS3-11 phase BC
- CS3-12 phase CA

EV Charging is Current Controlled

- User specifies max Power Loading, but control at charger is done by setting maximum charge current
- Maximum programmed current per charger is 30A
- Minimum programmed current per charger is 6A (this is a lower limit specified by J1772)
- Chargers can be disabled to have a zero power setting
- Actual power will vary with line voltage (since we are controlling current)
- Example curve at right assumes 208Vac



One Line Diagram



Three Phase Calculations

3-phase Y - Current Relationships

$$I_a = I_{ab}\cos(30) - (-I_{ca}\cos(30))$$
$$I_b = I_{bc}\cos(30) - (-I_{ab}\cos(30))$$
$$I_c = I_{ca}\cos(30) - (-I_{bc}\cos(30))$$

$$I_a = 0.866 * (I_{ab} + I_{ca})$$
$$I_b = 0.866 * (I_{bc} + I_{ab})$$
$$I_c = 0.866 * (I_{ca} + I_{bc})$$

Phase a Current

$$\begin{aligned} I_a &= 0.866 * (I_{ab} + I_{ca}) \\ &= 0.866 * [(I_{CS1-1} + I_{CS1-4} + I_{CS1-6} + I_{CS3-1} + I_{CS3-4} + I_{CS3-7} + I_{CS3-10}) + (I_{CS1-3} + I_{CS3-3} + I_{CS3-6} + I_{CS3-9} + I_{CS3-12})] \end{aligned}$$

$$I_a(max) = 12 * 30A * 0.866 = 311.8A$$

Note that a single phase can be overloaded before exceeding the transformer's power capacity
Current limit is 208.2A per phase – or per station if all are active

Phase b Current

$$Ib = 0.866 * (Ibc + Iab)$$
$$= 0.866 * [(I_{CS1-2} + I_{CS1-5} + I_{CS1-7} + I_{CS3-2} + I_{CS3-5} + I_{CS3-8} + I_{CS3-11}) + (I_{CS1-1} + I_{CS1-4} + I_{CS1-6} + I_{CS3-1} + I_{CS3-4} + I_{CS3-7} + I_{CS3-10})]$$

$$Ib(max) = 0.866 * (14 * 30A) = 363.7A$$

Note that a single phase can be overloaded before exceeding the transformer's power capacity
Current limit is 208.2A per phase – or 14.9A per station if all are active

Phase c Current

$$Ic = 0.866 * (Ica + Ibc)$$
$$= 0.866 * [(I_{CS1-3} + I_{CS3-3} + I_{CS3-6} + I_{CS3-9} + I_{CS3-12}) + (I_{CS1-2} + I_{CS1-5} + I_{CS1-7} + I_{CS3-2} + I_{CS3-5} + I_{CS3-8} + I_{CS3-11})]$$

$$Ic(max) = 12 * 30A * 0.866 = 311.8A$$

Note that a single phase can be overloaded before exceeding the transformer's power capacity
Current limit is 208.2A per phase – or 17.3A per station if all are active

Algorithm

Algorithm Task Flow

- {Discover Active Stations}

Repeat this steps once every 24 hours

- {Power Allocation}
- {Assign Phase Power}
- {Read Energy Data}
- {Calculate Remaining Per Phase Power}
- {Allocate Power Limits to Stations}
- {Convert to Current Limits}
- {Current Limit Under 6A}
- {Program Station Current Limits}

Repeat these steps at 5-minute intervals

{Discover Active Stations}

- Using Eaton API Tools, get list of commissioned devices
- Using Eaton API, poll devices to make sure they are online
- We can limit the discovery to once every 24 hours
- Combine discovered status with known station states
  - Stations that are out of service – currently CS1-1 through CS1-7; and CS3-12

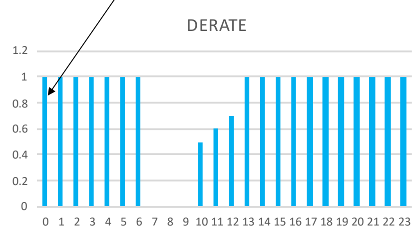
{Power Allocation}

{Power Allocation}

- Read User defined $P_{SITEMAXA}$ in kVA
  - 0 kVA – system offline, do not allow charging
  - 75 kVA is maximum
- Read user defined DERATE(time), where time is 1-hour slot in 24-hour day; value from 0 (no charging) to 1 (follow $P_{SITEMAXA}$)
- Compute Maximum Power allowed in any given hour:

$$P_{SITEMAX} = P_{SITEMAXA} * \text{DERATE(time)}$$

Example – this first slot is DERATE value for 0000 to 0100 time window



{Assign Phase Power}

{Assign Phase Power}

- $P_{PHaMAXA} = 1/3 * P_{SITEMAX}$
- $P_{PHbMAXA} = 1/3 * P_{SITEMAX}$
- $P_{PHcMAXA} = 1/3 * P_{SITEMAX}$

Example: if $P_{SITEMAXA}$ = 25kW, then each phase would be limited to 8.33kW

{Read Energy Data}

{Read Energy Data}

- Read EMCB energy data from previous 5-minute window
- Process energy data into individual station power and current values
- Tally total power and compare with planned power management limit; report as ERROR – POWER EXCEEDS LIMIT if total power exceed planned limit

Energy Data in EMCB Telemetry

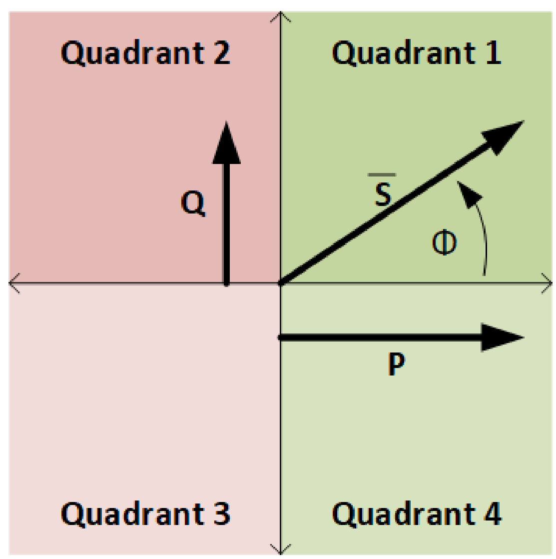
telemetry.rawEnergy.q1mJpA	number	Lifetime total real milliJoules in Quadrant 1, Phase A.	milliJoules
telemetry.rawEnergy.q1mJpB	number	Lifetime total real milliJoules in Quadrant 1, Phase B.	milliJoules
telemetry.rawEnergy.q1mVARspA	number	Lifetime total milliVARs in Quadrant 1, Phase A.	milliVARs
telemetry.rawEnergy.q1mVARspB	number	Lifetime total milliVARs in Quadrant 1, Phase B.	milliVARs
telemetry.rawEnergy.q2mJpA	number	Lifetime total real milliJoules in Quadrant 2, Phase A.	milliJoules
telemetry.rawEnergy.q2mJpB	number	Lifetime total real milliJoules in Quadrant 2, Phase B.	milliJoules
telemetry.rawEnergy.q2mVARspA	number	Lifetime total milliVARs in Quadrant 2, Phase A.	milliVARs
telemetry.rawEnergy.q2mVARspB	number	Lifetime total milliVARs in Quadrant 2, Phase B.	milliVARs
telemetry.rawEnergy.q3mJpA	number	Lifetime total real milliJoules in Quadrant 3, Phase A.	milliJoules
telemetry.rawEnergy.q3mJpB	number	Lifetime total real milliJoules in Quadrant 3, Phase B.	milliJoules
telemetry.rawEnergy.q3mVARspA	number	Lifetime total milliVARs in Quadrant 3, Phase A.	milliVARs
telemetry.rawEnergy.q3mVARspB	number	Lifetime total milliVARs in Quadrant 3, Phase B.	milliVARs
telemetry.rawEnergy.q4mJpA	number	Lifetime total real milliJoules in Quadrant 4, Phase A.	milliJoules
telemetry.rawEnergy.q4mJpB	number	Lifetime total real milliJoules in Quadrant 4, Phase B.	milliJoules
telemetry.rawEnergy.q4mVARspA	number	Lifetime total milliVARs in Quadrant 4, Phase A.	milliVARs
telemetry.rawEnergy.q4mVARspB	number	Lifetime total milliVARs in Quadrant 4, Phase B.	milliVARs
telemetry.rawEnergyDelta.deltaTime	number	The delta time, in seconds, over which the energy was accumulated.	seconds

Power Calculation – Per Station

- EMCB provides 4 -quadrant energy data
- EMCB provides the number of seconds over which energy was calculated (rawEnergyDelta.deltaTime)
- Energy data is used to calculate total power for each 2-pole EV-EMCB

Complex Energy (per interval) = [q1mJpA + q4mJpA – q2mJpA – q3mJpA + q1mJpB + q4mJpB – q2mJpB – q3mJpB] + j[q1mVARspA + q2mVARspA – q3mVARspA – q4mVARspA + q1mVARspB + q2mVARspB – q3mVARspB – q4mVARspB]

- Convert Energy in mJ to kWh
- Convert deltaTime in s to h
- Power = Energy (kWh) / Time (h)



Power Calculation Per Station, continued

- Complex Power (average over interval) = [q1kWA + q4kWA – q2kWA – q3kWA + q1kWB + q4kWB – q2kWB – q3kWB] + j[q1kVARA + q2kVARA – q3kVARA – q4kVARA + q1kVARB + q2kVARB – q3kVARB – q4kVARB]
- Real Power = q1kWA + q4kWA – q2kWA – q3kWA + q1kWB + q4kWB – q2kWB – q3kWB
- Magnitude of Current (per charger) = SQRT{[(q1kWA + q4kWA – q2kWA – q3kWA + q1kWB + q4kWB – q2kWB – q3kWB) / (Vphase)]^2 + [(q1kVARA + q2kVARA – q3kVARA – q4kVARA + q1kVARB + q2kVARB – q3kVARB – q4kVARB) / (Vphase)]^2}
  - This considers VAR current (expect EVs to have near unity power factor but need to check this)

Power by Phase - measured

- Power (phase a) = Real [$P_{CS1-1} + P_{CS1-4} + P_{CS1-6} + P_{CS3-1} + P_{CS3-4} + P_{CS3-7} + P_{CS3-10}$]
- Power (phase b) = Real [$P_{CS1-2} + P_{CS1-5} + P_{CS1-7} + P_{CS3-2} + P_{CS3-5} + P_{CS3-8} + P_{CS3-11}$]
- Power (phase c) = Real [$P_{CS1-3} + P_{CS3-3} + P_{CS3-6} + P_{CS3-9} + P_{CS3-12}$]
- Power (total) = Power (phase a) + Power (phase b) + Power (phase c)

NOTE: may be missing data if a station fails to communicate; failed communicators get labeled as “state S1”

{Calculate Remaining Per Phase Power}

{Calculate Remaining Phase Power}

- Calculate phase remaining available power based on EMCB states (S0, S1, and S2C only) (see next slide for state definitions)
  - $P_{PHaREM} = P_{PHaMAXA}$ – (0.0kW for all S0) – (0.0kW for all S1) – (6.6kW for all S2C)
  - $P_{PHbREM} = P_{PHbMAXA}$ – (0.0kW for all S0) – (0.0kW for all S1) – (6.6kW for all S2C)
  - $P_{PHcREM} = P_{PHcMAXA}$ – (0.0kW for all S0) – (0.0kW for all S1) – (6.6kW for all S2C)

Electric Vehicle Supply Equipment (EVSE) States

- OUT OF SERVICE (S0)
  - No device assigned; Permanently offline
- OFF-LINE (S1)
  - Device assigned but no communications (could be comm link, power outage, feed breaker open)
- ON-LINE (communicating) (___)
  - Powered off (EMCB handle open) (S2A)
  - Idle (powered on, no vehicle connected) (S2B)
  - Disabled (powered on, no vehicle connected, charging not allowed) (S2C)
  - Active
    - Vehicle connected, not charging (S3A)
    - Vehicle connected with active charging (S3B)

Power by Phase limit

- $P_{PHaREM} = P_{PHaMAXA}$ – Real [$Plim_{CS1-1} + Plim_{CS1-4} + Plim_{CS1-6} + Plim_{CS3-1} + Plim_{CS3-4} + Plim_{CS3-7} + Plim_{CS3-10}$]
- $P_{PHbREM} = P_{PHbMAXA}$ – Real [$Plim_{CS1-2} + Plim_{CS1-5} + Plim_{CS1-7} + Plim_{CS3-2} + Plim_{CS3-5} + Plim_{CS3-8} + Plim_{CS3-11}$]
- $P_{PHcREM} = P_{PHcMAXA}$ – Real [$Plim_{CS1-3} + Plim_{CS3-3} + Plim_{CS3-6} + Plim_{CS3-9} + Plim_{CS3-12}$]

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Known Station States (until mid 2021)

- The following stations are in state S0 (OFFLINE)
  - CS2-1 through CS2-7
  - CS3-12

Thus:

- $P_{PHaREM} = P_{PHaMAXA} - \text{Real}\ [\cancel{Plim_{CS1\text{-}1}} + \cancel{Plim_{CS1\text{-}4}} + \cancel{Plim_{CS1\text{-}6}} + Plim_{CS3\text{-}1} + Plim_{CS3\text{-}4} + Plim_{CS3\text{-}7} + Plim_{CS3\text{-}10}\ ]$
- $P_{PHbREM} = P_{PHbMAXA} - \text{Real}\ [\cancel{Plim_{CS1\text{-}2}} + \cancel{Plim_{CS1\text{-}5}} + Plim_{CS1\text{-}7} + Plim_{CS3\text{-}2} + Plim_{CS3\text{-}5} + Plim_{CS3\text{-}8} + Plim_{CS3\text{-}11}\ ]$
- $P_{PHcREM} = P_{PHcMAXA} - \text{Real}\ [\cancel{Plim_{CS1\text{-}3}} + Plim_{CS3\text{-}3} + Plim_{CS3\text{-}6} + Plim_{CS3\text{-}9} + \cancel{Plim_{CS3\text{-}12}}\ ]$

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{Allocate Power Limits to Stations}

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{Allocate Power Limits to Stations}

- Allocate P_{PHxREM} across remaining phase x stations
  - If station handle is off (S2A) in last 5-minute interval, set Ilim to 6A and tally to (number of idle stations)
  - If station was idle (S2B) in last 5-minute interval, set Ilim to 6A and tally to (number of idle stations)
  - If station was connected but inactive (S3A), set Ilim to 6A and tally to (number of idle stations)
  - If station was active (vehicle connected) (S3B) in last 5-minute interval, add it to the active count – (number of active stations)
  - Allocate power to active station as: $Plim_{CSx-x}$ = [P_{PHaREM} – (220 * 6 * (number of idle stations))]/(number of active stations)
- List to be set: $Plim_{CS3-1}$; $Plim_{CS3-2}$; $Plim_{CS3-3}$; $Plim_{CS3-4}$; $Plim_{CS3-5}$; $Plim_{CS3-6}$; $Plim_{CS3-7}$; $Plim_{CS3-8}$; $Plim_{CS3-9}$; $Plim_{CS3-10}$; $Plim_{CS3-11}$

Per Station Contribution to Limits Based on State

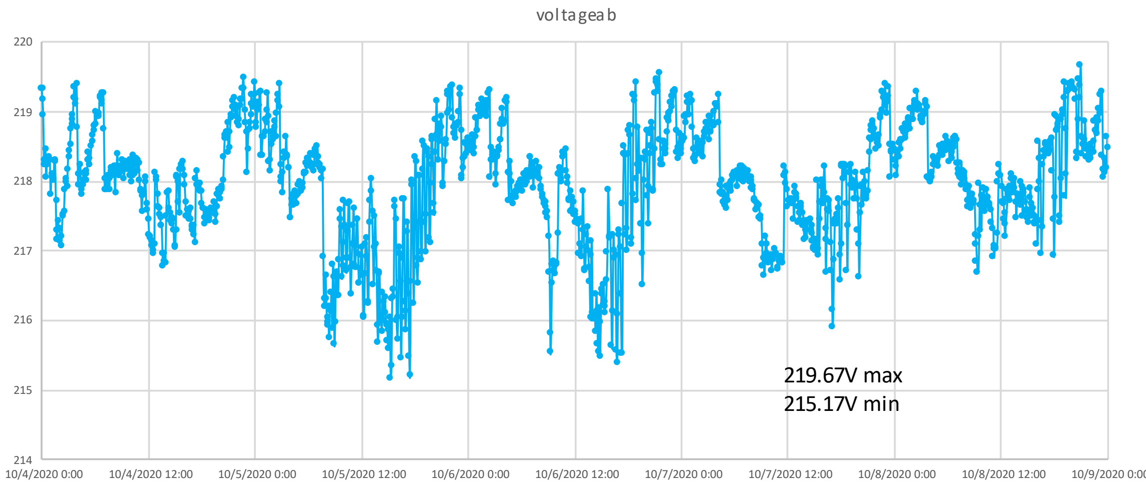
- OUT OF SERVICE (S0) = 0.0kW and 0.0A
  - Assumes control software state would be updated prior to putting a device in service
- OFF-LINE (S1) = 6.6kW and 30A
  - Must assume worst case contribution since state is unknown
- ON-LINE: Powered off (S2A), Idle (S2B) , or Active (S3A or S3B) = programmed A limit, calculated kW limit
  - Since system sets the current limits
- ON-LINE: Disabled (S2C) = 0.0kW and 0.0A
  - Since system has control of unit being disabled

{Convert to Current Limits}

{Convert to Current Limits}

- Convert the per station power limit to a current limit based on nominal line voltage (~ 220V for Palo Alto)
  - $Ilim = P_{CSX-X} / 220$
- Verify that the sum of currents on a phase is less than 208.2A (limit for 75kVA transformer)
- If less than 6A, go to {Current Limit Under 6A}

Typical Site Voltage Variation (typical about 4.5V variation)



{Current Limit Under 6A}

{Current Limit Under 6A}

- Disable one station (Ilim = 0) (start with highest CSX-X number)
- Recalculate Current Limits
- If > or = 6A, go to {Program Station Current Limits}
- Disable a second station (Ilim = 0)
- Recalculate Current Limits
- If > or = 6A, go to {Program Station Current Limits}
- Repeat process as needed
- If all stations must be disabled – return as ERROR - SYSTEM LIMIT TOO LOW

{Program Station Current Limits}

{Program Station Current Limits}

- Program and confirm station current limits from lowest assigned limit to highest

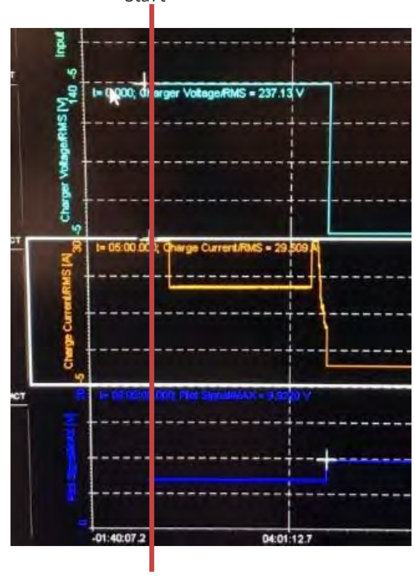
G SELECT HIGHLIGHTS FROM BIWEEKLY PROJECT MEETINGS

June 28, 2019 – Successful Test of EV-EMCB for Demand Response Charge Throttling

From the Lab

- Demand Response Load Shapes
  - Funded through P170 (Energy Efficiency)
- Discharge using the new EV test stand
- Uses the EV-EMCB to program DR events
- 7.2 kW Nominal
- After 1 hour, decrease to 66% of nominal for 4 hours
- Successful use of the EV-EMCB for DR event

Start



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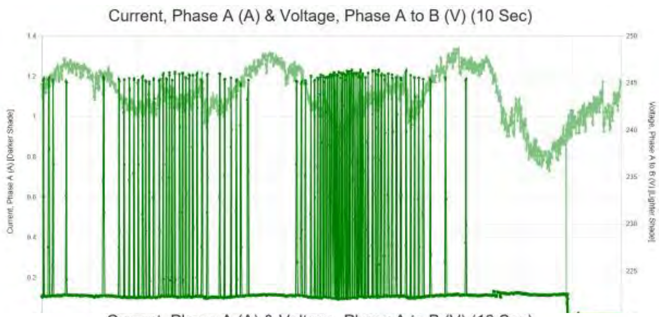
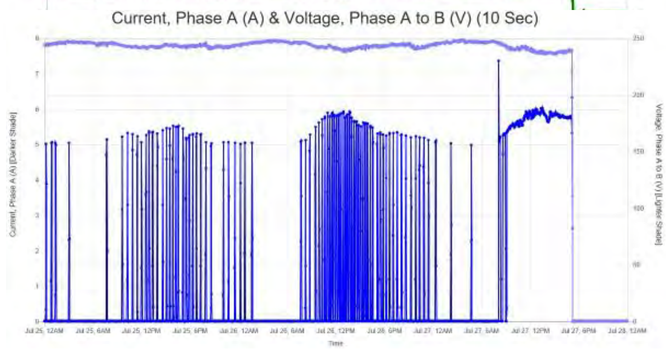
August 1, 2019 – EMCB Data from a Failed HVAC Blower Motor

HVAC Failure Data



Blower Motor

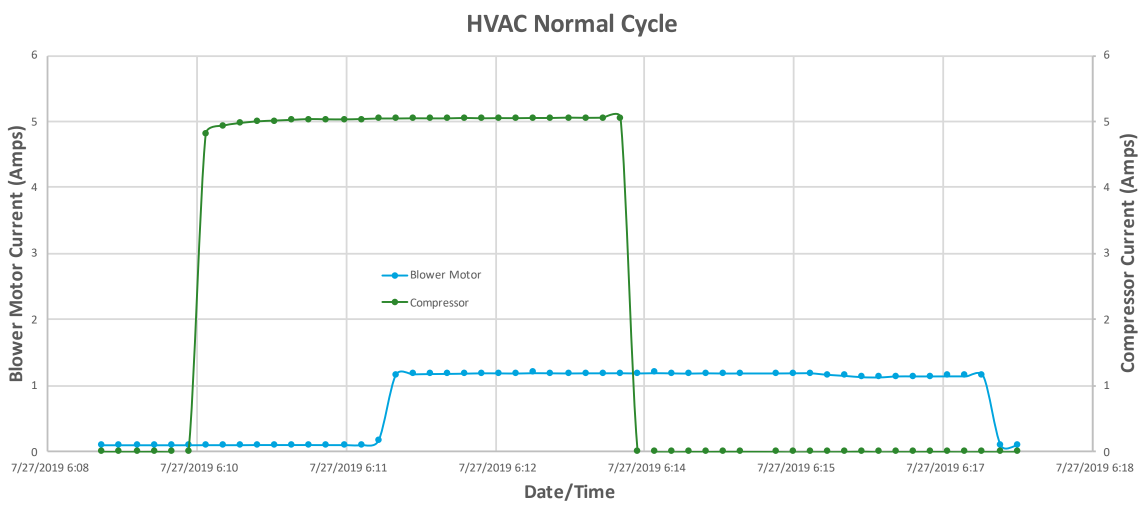
Top trace is Voltage



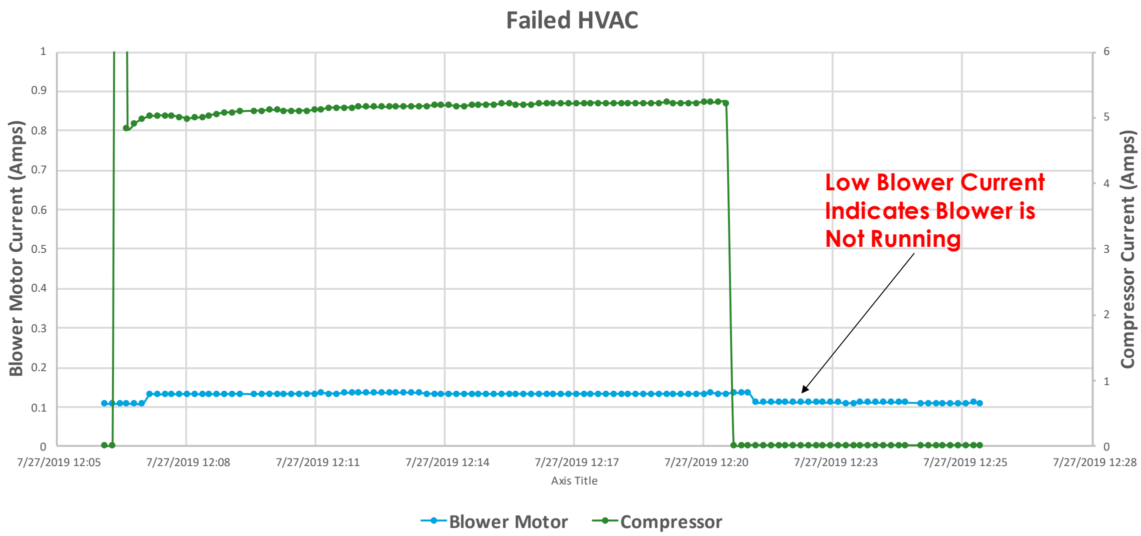
Compressor

Duke Energy Data

Data from Prior to HVAC Failure –Normal Cycle



Failure of HVAC



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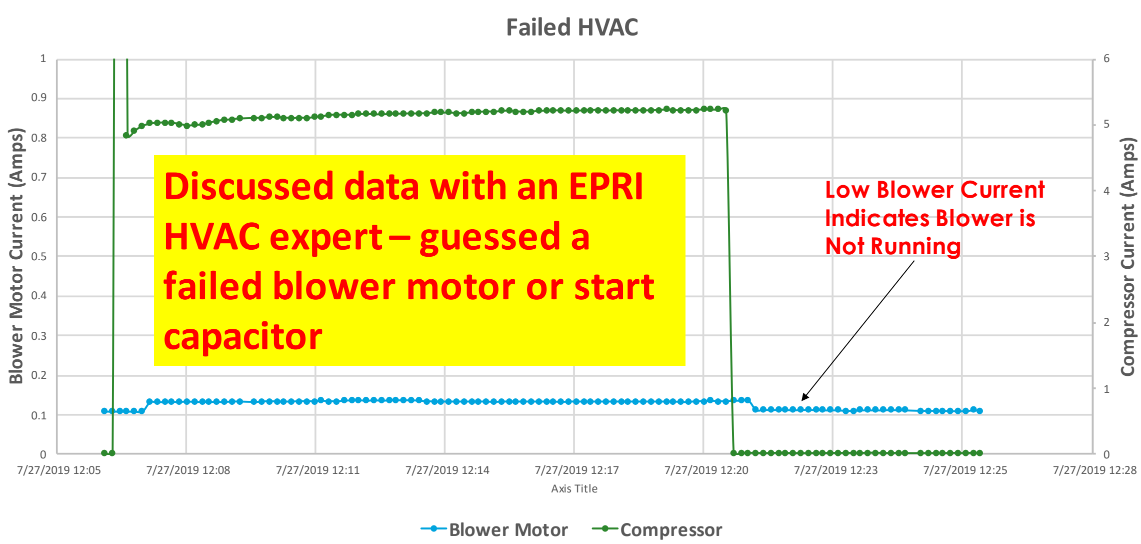
Failure of HVAC



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August 12, 2019 – Comparison of First and Second Generation EMCB Devices

New Meets Old…

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New Meets Old, continued

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New Meets Old, continued

Received Inventory -~40 devices

MAC ID	Part Number	Type	Amperage	Location	In/Out Date
0C2A690E1C9F	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1801	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1862	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E283A	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1D04	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e2ec1	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E2E8F	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e32bb	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e2bb6	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e2bfa	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E2EC8	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e1a66	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0c2a690e1860	BREM2040	Plug In	40	EPRI Shelf	8/12/2019
0c2a690e190e	BREM2030	Plug In	30	EPRI Shelf	8/12/2019
0c2a690e198b	BREM1015	Plug In	15	John H.	8/8/2019
0C2A690E1C8F	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1912	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1960	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1D11	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1843	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1D01	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E2873	BREM1015	Plug In	15	EPRI Shelf	8/12/2019
0C2A690E1995	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1A6E	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1A6C	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1CF1	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1A94	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1889	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1918	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E19EC	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E198A	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1AFC	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1886	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1AF8	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1AAB	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1CD8	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E3251	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E2BCD	BREM1020	Plug In	20	EPRI Shelf	8/12/2019
0C2A690E1939	BREM1020	Plug In	20	EPRI Shelf	8/12/2019

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January 21, 2021 – Installation of EV-EMCBs at EPRI's Palo Alto, CA Offices

Palo Alto EV EMCB Testing

Used a new Eaton Dual Port EVSE Pedestal that integrates the EV EMCB device in the pedestal.

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Palo Alto EV EMCB Testing, continued

UL Field Evaluation Completed
Wee of January 6th.

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March 3, 2020 – First Demonstration of Local Control of an EMCB Device

This work was done with Eaton's first generation API and had to be repeated for the second generation API – see section 5 and Appendix F for the more recent work.

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EMCB Local Control

Documentation and Demonstration

Eric Auel
Engineer/Scientist I

3/2/2020

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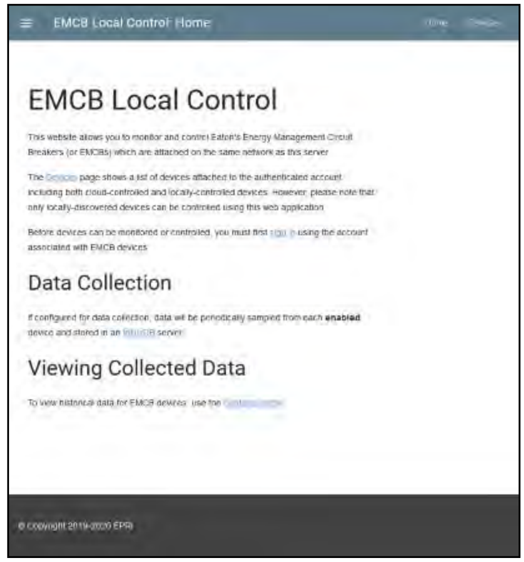
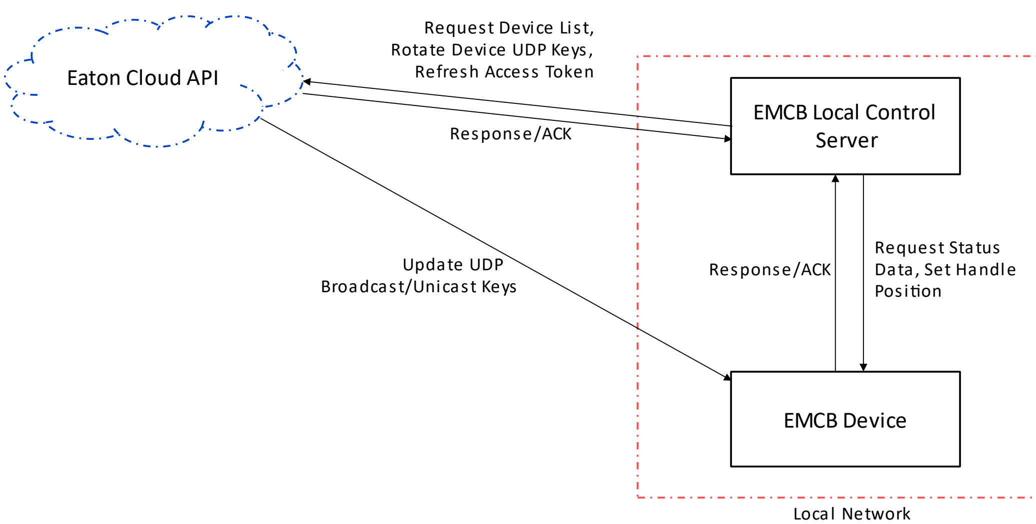
EMCB Local Control Server

- Allows for status querying and handle control of Eaton Energy Management Circuit Breaker (EMCB) devices
- Automatically handles authentication with:
  - The Eaton Cloud API server
  - The individual EMCB devices located on the local network
- Leverages Eaton's UDP API for local control
- Collected EMCB status data can optionally be stored on an InfluxDB server and visualized using Grafana



Connection Diagram



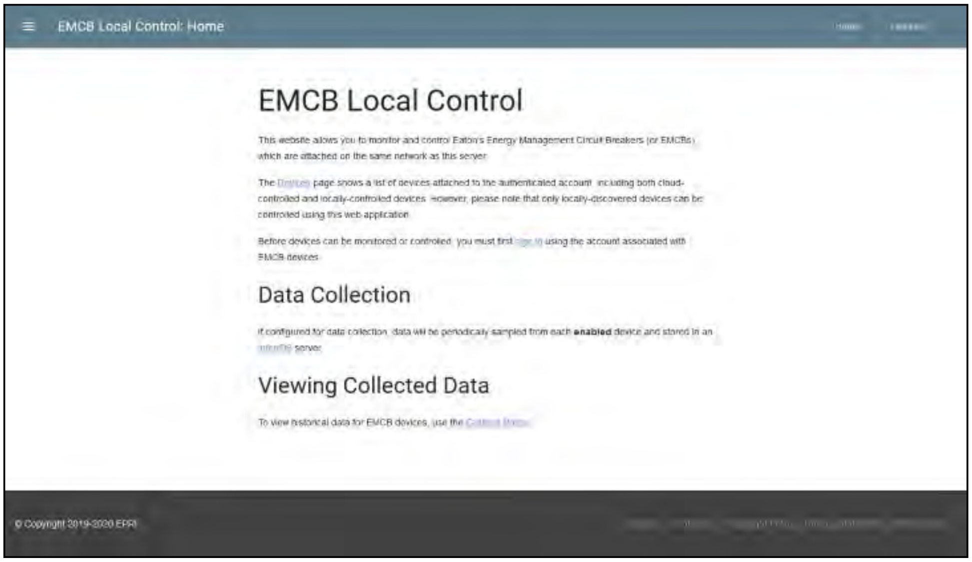
Steps for EMCB Local Communication

1. User signs in to Eaton API using Microsoft account

- The local control server then:
  2. Acquires an access token for API authentication
  3. Requests a list of devices associated with the authenticated account
  4. Requests a list of UDP keys currently being used by EMCBs
  5. Sends UDP broadcast messages on local network to discover EMCBs
  6. Enables local control for the EMCB on the webpage (if a local EMCB is found and is additionally added to the server's whitelist)
  7. Periodically rotates UDP keys for each discovered EMCB

Local Control Interface - Screenshots

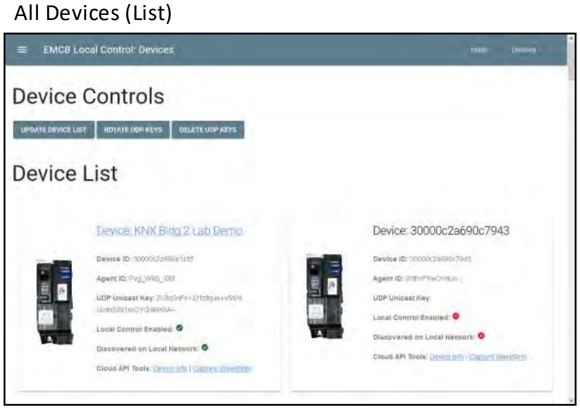
Web Interface – Home Page



Web Interface – Devices Page

Individual Device– Status and Control

All Devices (List)



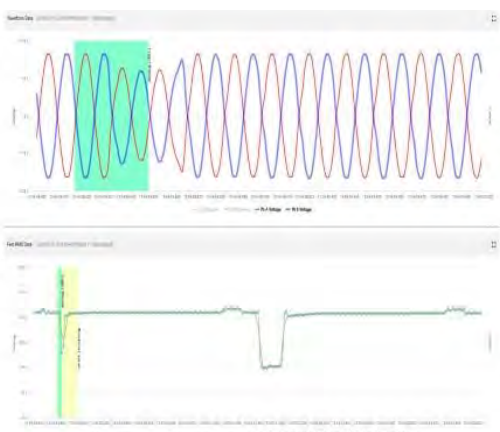
Web Interface – Grafana Data Visualization

InfluxDB/Grafana Allows for Historical Data Visualization

May 5, 2020 – Discussion of EMCB Waveform Capture Capabilities

EMCB Waveform Capability

- 200 mS Waveform Capture
  - Configurable triggers for voltage or current
  - 1 kHz Sampling (~16 points per cycle)
  - Sags, Swell, Lower-Order Harmonics
- 4 second Fast-RMS Capture
  - For extended analysis of events, such as recloser operation.



Agent API Calls – Waveform Setup

Configure Waveform Settings.

PUT Configure Waveform Settings.

Description

Configure Waveform Settings.

The structure of the request body is as follows:

Parameter	Type	Required	Description
p0OvercurrentDuration	number	Optional	Phase 0 Overcurrent Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous current must be above the overcurrent level to cause a trigger.
p0OvercurrentEnabled	boolean	Optional	Boolean indicating whether or not Phase 0 Overcurrent trigger is enabled.
p0mAOvercurrent	number	Optional	Phase 0 Overcurrent Level in milliAmps (instantaneous).
p0SagDuration	number	Optional	Phase 0 Voltage Sag Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous voltage must be below the voltage sag level to cause a trigger.
p0SagEnabled	boolean	Optional	Boolean indicating whether or not Phase 0 Voltage Sag trigger is enabled.
p0mVSag	number	Optional	Phase 0 Voltage Sag Level in milliVolts (instantaneous).
p0SwellDuration	number	Optional	Phase 0 Voltage Swell Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous voltage must be above the voltage swell level to cause a trigger.
p0SwellEnabled	boolean	Optional	Boolean indicating whether or not Phase 0 Voltage Swell trigger is enabled.

Get Waveform Configuration

GET Get Waveform Configuration

Description

Get Waveform configuration settings.

The structure of the response body is as follows:

p0mVSwell	number	Optional	Phase 0 Voltage Swell Level in milliVolts (instantaneous).
p1OvercurrentDuration	number	Optional	Phase 1 Overcurrent Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous current must be above the overcurrent level to cause a trigger.
p1OvercurrentEnabled	boolean	Optional	Boolean indicating whether or not Phase 1 Overcurrent trigger is enabled.
p1mAOvercurrent	number	Optional	Phase 1 Overcurrent Level in milliAmps (instantaneous).
p1SagDuration	number	Optional	Phase 1 Voltage Sag Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous voltage must be below the voltage sag level to cause a trigger.
p1SagEnabled	boolean	Optional	Boolean indicating whether or not Phase 1 Voltage Sag trigger is enabled.
p1mVSag	number	Optional	Phase 1 Voltage Sag Level in milliVolts (instantaneous).
p1SwellDuration	number	Optional	Phase 1 Voltage Swell Duration - this is the number of samples (relative to the 4kHz front-end sampling rate) that the instantaneous voltage must be above the voltage swell level to cause a trigger.
p1SwellEnabled	boolean	Optional	Boolean indicating whether or not Phase 1 Voltage Swell trigger is enabled.
p1mVSwell	number	Optional	Phase 1 Voltage Swell Level in milliVolts (instantaneous).
samplesAfterTrigger	number	Optional	Number of samples after waveform trigger to be captured (between 0-199).
samplesAfterTriggerFastRMS	number	Optional	Number of samples after fast RMS trigger to be captured (between 0-254).

Agent API Calls – Waveform Data

Get Waveform List

GET Get Waveform List

Description

Returns a list of waveform paths.

The request query parameters are described as follows:

Parameter	Type	Required	Description
startTime	String	Yes	Represents the earliest epoch timestamp (in seconds) to query.
endTime	String	No	Represents the latest epoch timestamp (in seconds) to query.
triggers	String	No	List of waveform trigger types, separated by ",". If left blank, will query all trigger types. e.g. "phase0undervoltage,phase1undervoltage"

The possible list of waveform trigger types to include in a triggers query parameter are as follows:

- immediate
- phase1overvoltage
- phase0overvoltage
- phase1overcurrent
- phase0overcurrent
- phase1undervoltage
- phase0undervoltage

The response body will contain an array of Waveform Description Objects. A Waveform Description Object is structured as follows:

Key	Value
trigger	Waveform trigger type
ts	Waveform timestamp in ISO 8601 format.

Get Waveform Data

GET Get Waveform Data

Description

Returns waveform data.

The trigger in the path must be one of the trigger types returned by the Get Waveforms List operation. The values can be:

- immediate
- phase1overvoltage
- phase0overvoltage
- phase1overcurrent
- phase0overcurrent
- phase1undervoltage
- phase0undervoltage

The timestamp in the path must be an ISO-6801 timestamp, as returned by the Get Waveforms List operation.

The response body is structured as follows:

Parameter	Type	Description
numSamples	Integer	Number of samples, per channel in data.
triggers	Array[String]	An array describing the triggers that caused the waveform capture.
shortestTrigger	String	The shortest configured trigger duration, and the initial trigger that caused the waveform capture.
captureWindowEndTime	Integer	The epoch timestamp at which the overall waveform capture ended, measured in seconds.
triggerWindowDurationMS	Integer	The duration of the trigger window within the waveform capture, in milliseconds.
timeAfterTriggerMS	Integer	The number of milliseconds between the end of the trigger window and the end of the overall capture.
sampleDeltaMS	Integer	Time between samples, in milliseconds.
data	Object	On object containing the sample data.
data.mVpA	Array[Integer]	Phase A Voltage measurements, measured in non-RMS milliVolts.
data.mVpB	Array[Integer]	Phase B Voltage measurements, measured in non-RMS milliVolts.
data.mApA	Array[Integer]	Phase A Current measurements, measured in non-RMS milliAmperes.
data.mApB	Array[Integer]	Phase B Current measurements, measured in non-RMS milliAmperes.

Agent API Calls – Fast RMS Data

Get Fast RMS Capture List

GET Get Fast RMS Capture List

Description

Returns a list of Fast RMS capture paths.

The request query parameters are described as follows:

Parameter	Type	Required	Description
startTime	String	Yes	Represents the earliest epoch timestamp (in seconds) to query.
endTime	String	No	Represents the latest epoch timestamp (in seconds) to query.
triggers	String	No	List of waveform trigger types, separated by ",". If left blank, will query all trigger types. e.g. "phase0undervoltage,phase1undervoltage"

The possible list of waveform trigger types to include in a triggers query parameter are as follows:

- immediate
- phase1overvoltage
- phase0overvoltage
- phase1overcurrent
- phase0overcurrent
- phase1undervoltage
- phase0undervoltage

The response body will contain an array of Fast RMS Capture Description Objects. A Fast RMS Capture Description Object is structured as follows:

Key	Value
trigger	Waveform trigger type.
ts	Waveform timestamp in ISO 8601 format.

Get Fast RMS Capture Data

GET Get Fast RMS Capture Data

Description

Returns Fast RMS capture data.

The trigger in the path must be one of the trigger types returned by the Get Fast RMS Capture List operation. The values can be:

- immediate
- phase1overvoltage
- phase0overvoltage
- phase1overcurrent
- phase0overcurrent
- phase1undervoltage
- phase0undervoltage

The timestamp in the path must be an ISO-6801 timestamp, as returned by the Get Fast RMS Capture List operation.

The response body is structured as follows:

Parameter	Type	Description
numSamples	Integer	Number of samples, per channel, in data.
triggers	Array[String]	An array describing the triggers that caused the fast RMS capture.
shortestTrigger	String	The shortest configured trigger duration, and the initial trigger that caused the fast RMS capture.
captureWindowEndTime	Integer	The epoch timestamp at which the overall fast RMS capture ended, measured in seconds.
triggerWindowDurationMS	Integer	The duration of the trigger window within the fast RMS capture, in milliseconds.
timeAfterTriggerMS	Integer	The number of milliseconds between the end of the trigger window and the end of the overall capture.
sampleDeltaMS	Integer	Time between samples, in milliseconds.
data	Object	On object containing the sample data.
data.mVpA	Array[Integer]	Phase A Voltage measurements, measured in non-RMS milliVolts.
data.mVpB	Array[Integer]	Phase B Voltage measurements, measured in non-RMS milliVolts.
data.mApA	Array[Integer]	Phase A Current measurements, measured in non-RMS milliAmperes.
data.mApB	Array[Integer]	Phase B Current measurements, measured in non-RMS milliAmperes.

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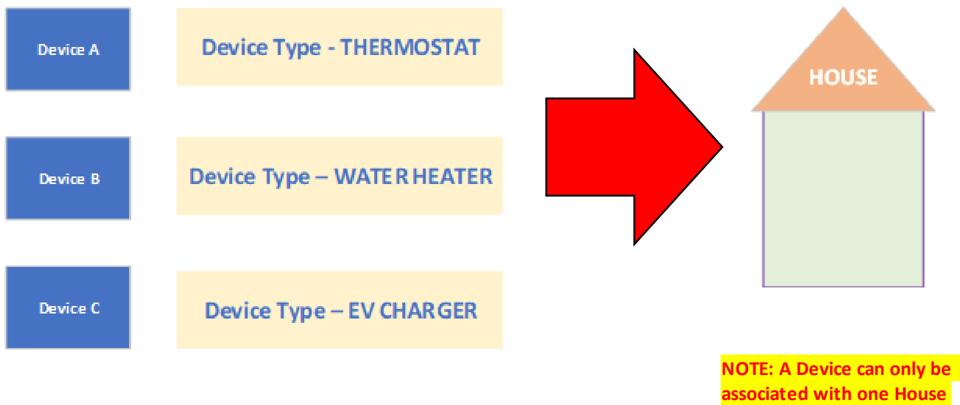
June 2, 2020 – **Discussion of Virtual Peaker's Web Portal Data Structure**

Section 1
Virtual Peaker's Web Portal Structure

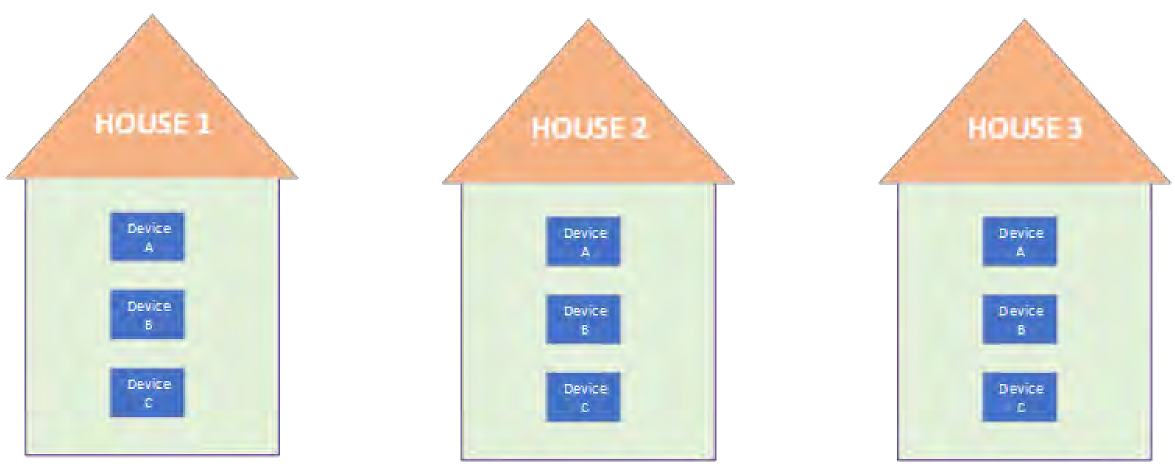
www.epri.com

Devices Enter the Virtual Peaker System and are Associated at the House Level

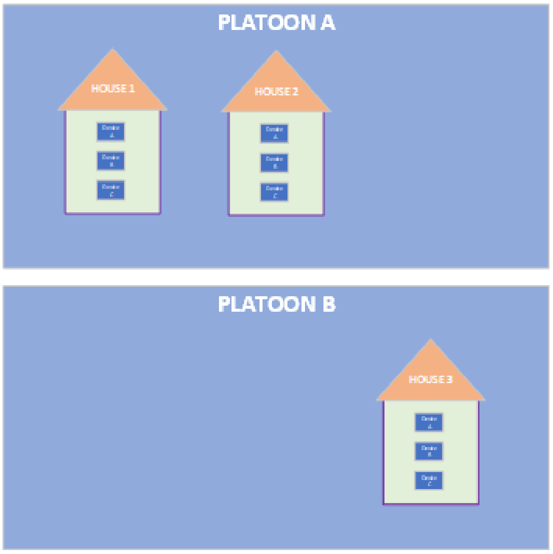
Assume we have houses with 3 types of devices:



A Deployment will have Multiple Houses



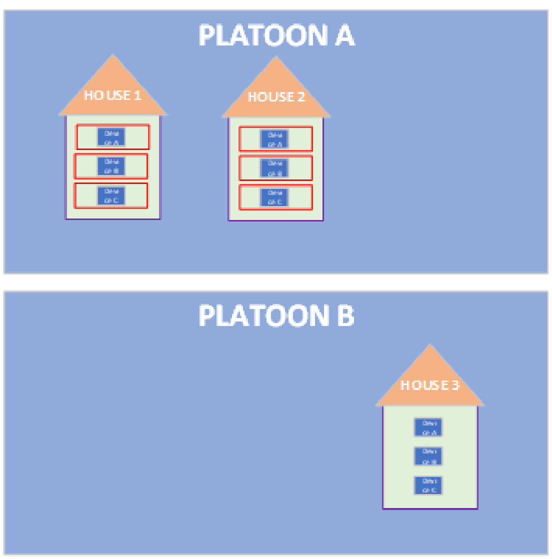
Houses can be Grouped in Platoons



In this example we've associated 2 houses with Platoon A and 1 house with Platoon B

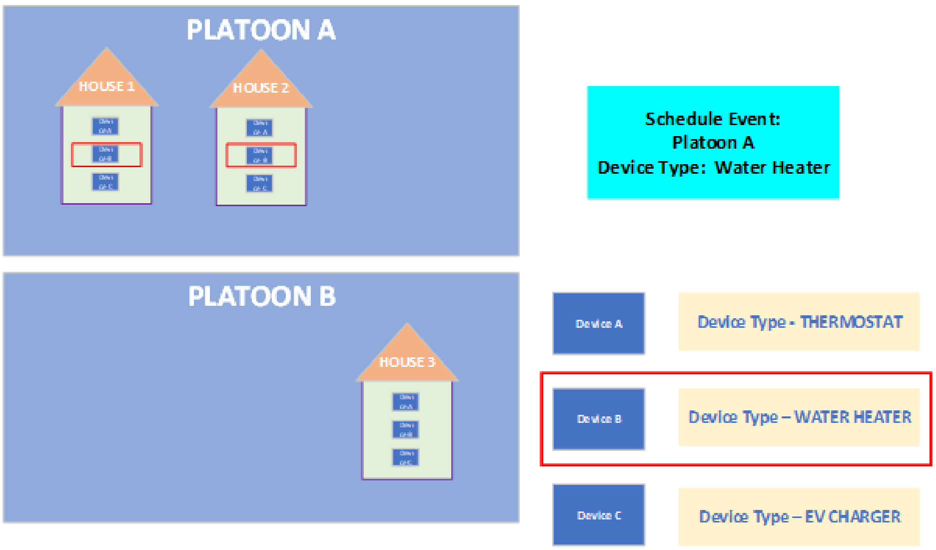
NOTE: A house can be associated with only one Platoon

Events Can Be Set Up by Platoon



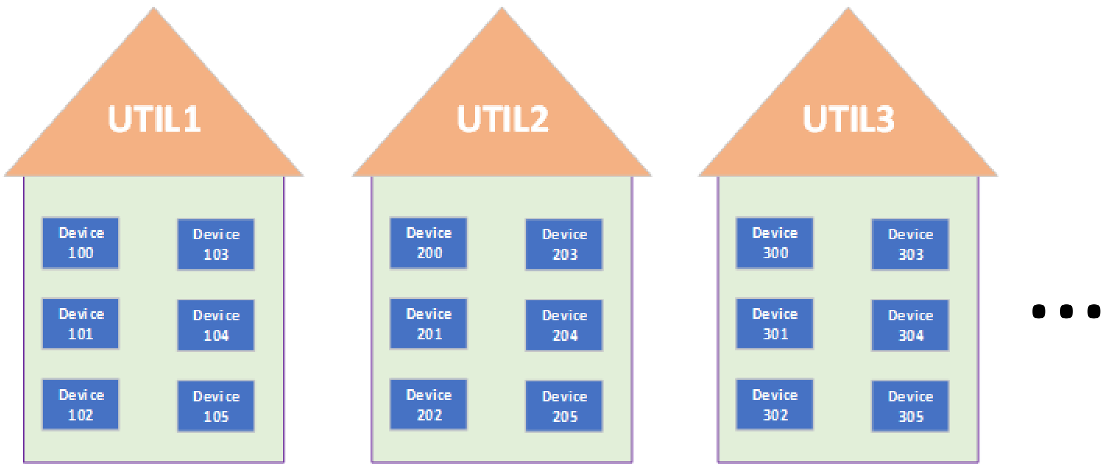
Schedule Event:
Platoon A

Events Can Be Set Up by Platoon and Device Type



Section 2
EPRI Project EMCB Integration with Virtual Peaker

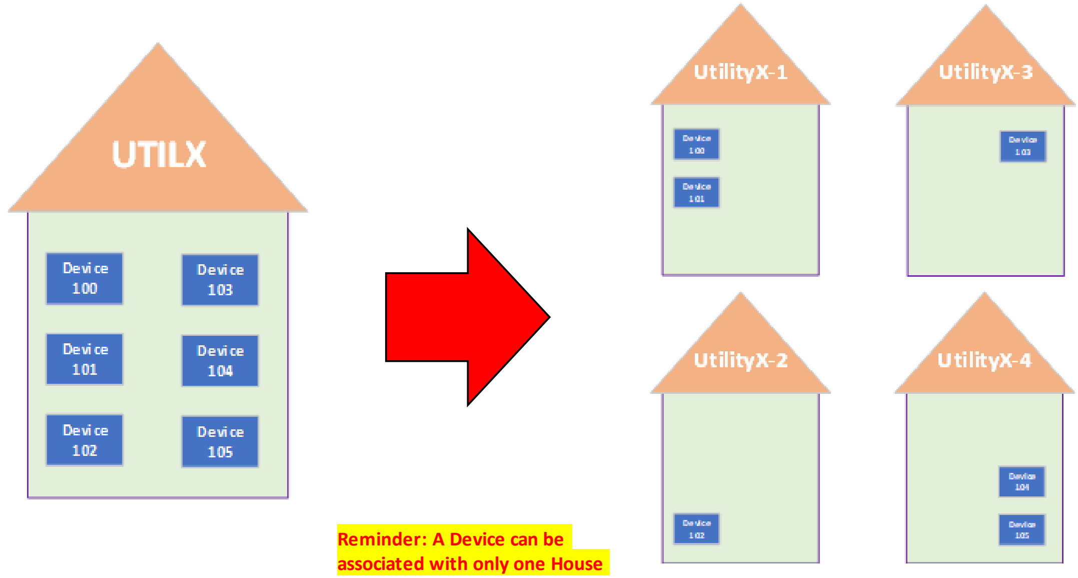
When Your EMCB Devices are Commissioned, They are Automatically Associated to Your Default House



Virtual Peaker has Opened Up Their Interface to Allow EPRI to Manually Reassign Devices to Houses

- We can create a custom set of houses for you that subdivide the EMCB devices as needed
- One limitation we have is that you can't subdivide an event by the device type, since all EMCB devices have the same "Circuit Breaker" device type
- In order to keep utilities anonymous, we'll need to keep a generic naming scheme
  - Your 'base' house will be UTILX, where X is your assigned number (1 -12)
  - Added houses will be named UtilityX-A, -B, -C, etc..

Example - Setting Up a Custom Set of Houses



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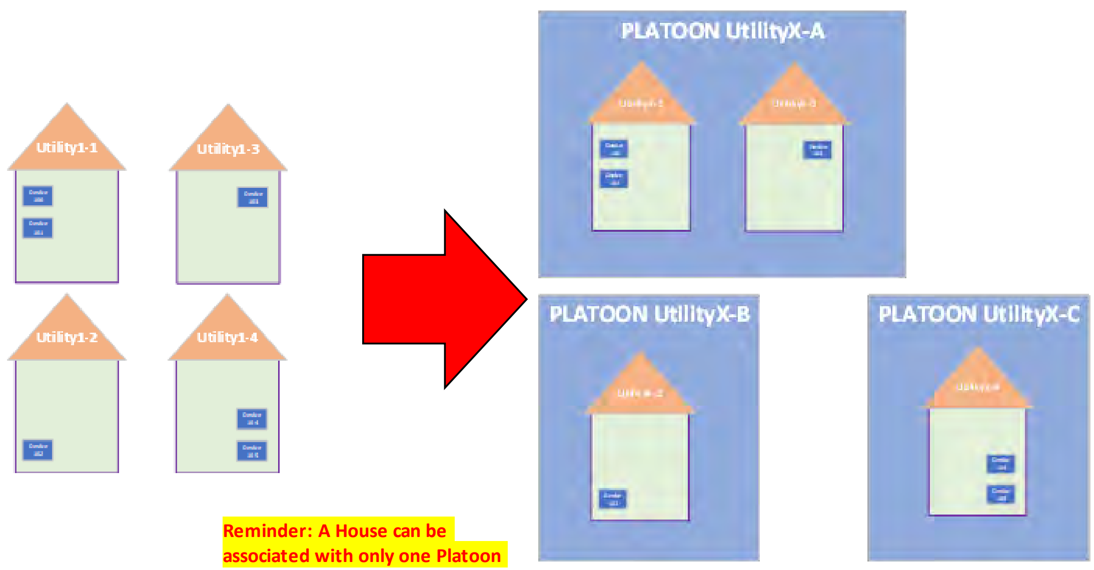
You Can Then Group These Houses in Platoons As Needed



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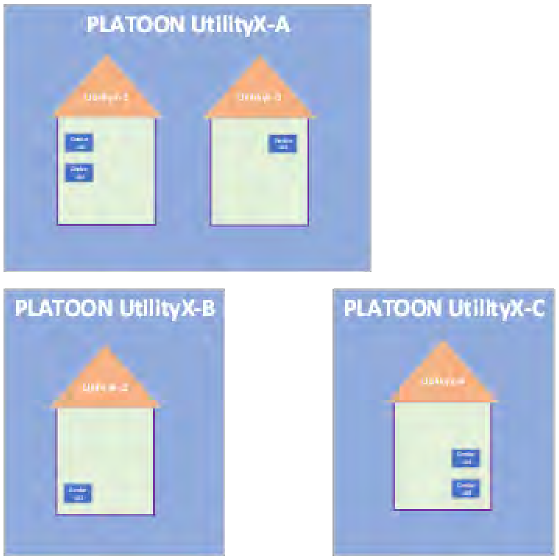
You Will Then Call Events at the Platoon Level



Just Remember that all EMCBs have a Device Type of "Circuit Breaker" so you can't sort by Device Type

www.epri.com

Section 3 – Unique Aspects of the EMCB to be Addressed

www.epri.com

How Will Devices Be Handled at Scale?

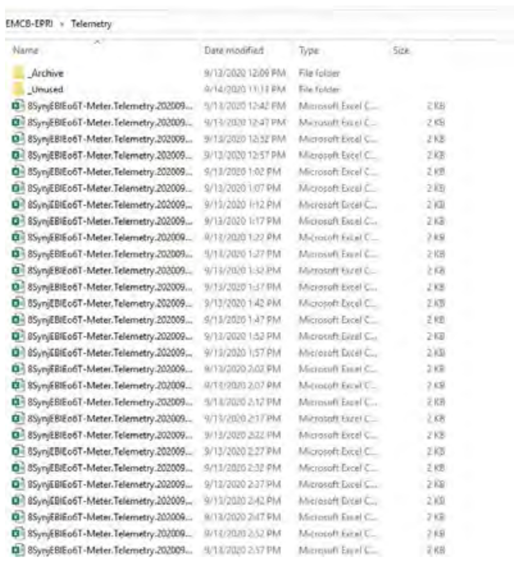
- Virtual Peaker assumes that each device in a house has its own unique authentication/authorization path
  - Eaton allows multiple EMCBs to be installed under a common authorization account – even at multiple physical sites
- Virtual Peaker assigns a device type at install
  - The EMCB can be upstream of a multitude of end uses (it could be a solar array, water heater, etc…)
  - End use type could be captured, but might be misreported by installer
    - Eaton commissioning app could ask for the end use type
    - Virtual Peaker onboarding process could capture end use

How Will Devices Be Handled at Scale? continued

- Virtual Peaker assumes a device has one function
  - The EMCB can be
    - A meter
    - A demand response control device
    - A power quality analyzer
    - A vehicle charger
  - Requires some thought as to how to display data from the EMCB suitable for a scale deployment

September 15, 2020 – EPRI Receiving Data from EMCB Devices and Moving into SQL Database

Data Files Arriving at EPRI

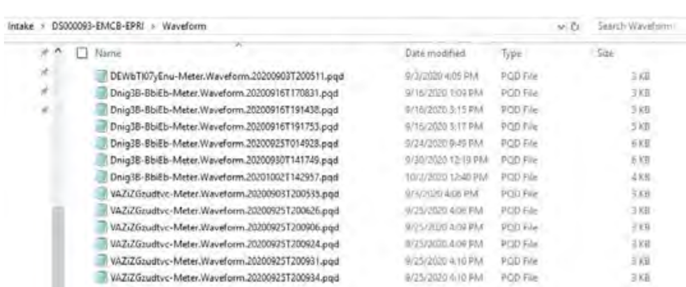


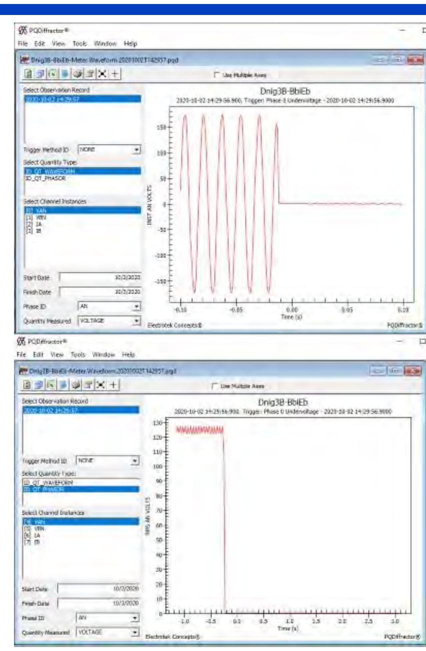
- Raw data shows up as a comma separated variable (CSV) file
- Files arrive from a device every 5 minutes
- One file for each data type
  - Meter
  - Accelerometer
  - Device
  - Thermometer
  - Waveform

October 13, 2020 – Example of Waveform Data Being Received from EMCB Devices

Waveform Data

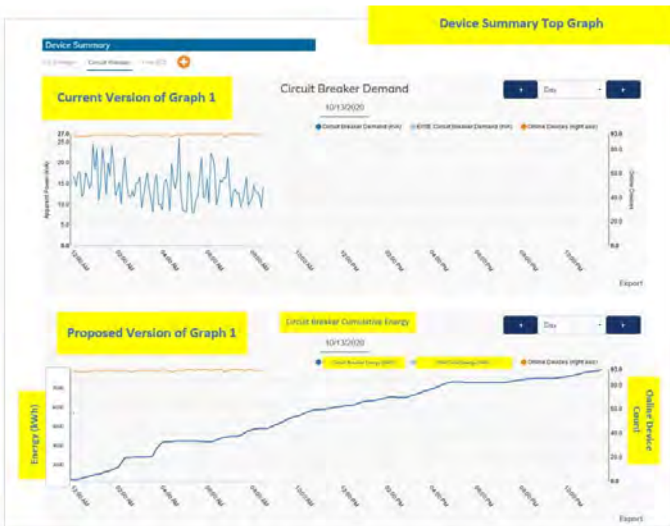
Includes:
Fast data (200ms of 1ms samples – V and I)
4-second RMS Voltage





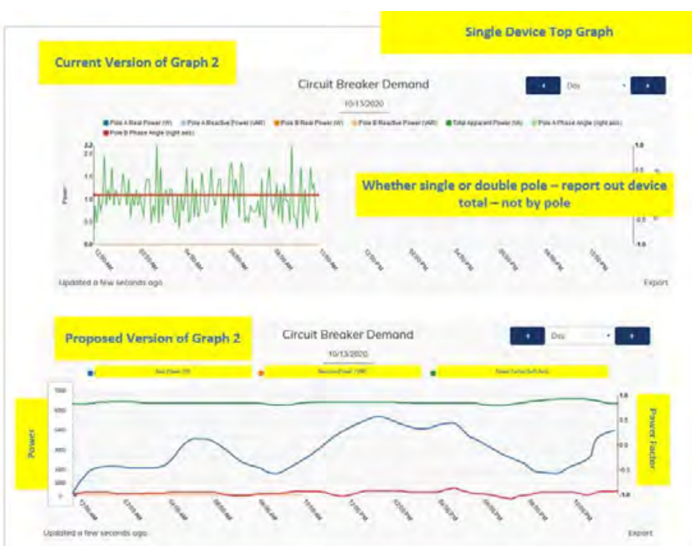
October 13, 2020 – Discussion of Virtual Peaker Graphing Layouts and Capability

Top Level – all devices summary graph



- Propose to move to display of Energy and not Power at top level
- Is power more important or number of online devices?
  - Do we need a summary power graph?
  - Feedback from group: yes – would like to see a power graph
  - Suggestion that we normalize the energy value to a zero reference at the start of the graph time window

Single Device – top level graph

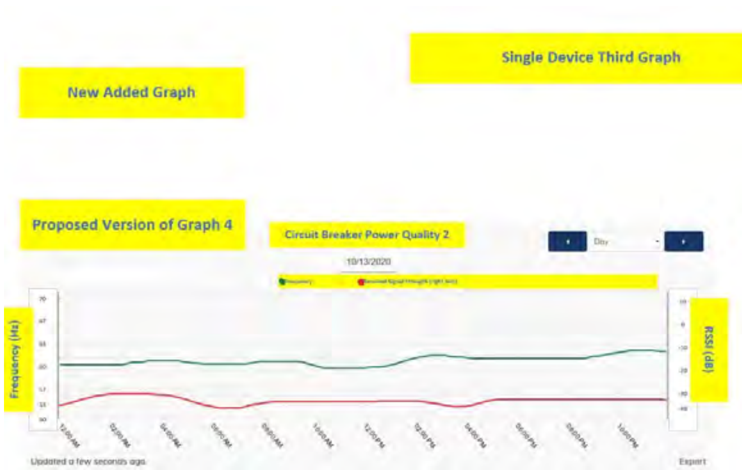


- Report only the totals for a device (do not single out poles on a 2-pole device)
- Drop apparent power (only adds confusion)
- Display power factor instead of angle

Single Device – second graph

- Is Power Quality the right label?
- Move frequency to another, new graph (see next slide)
- Add current for each pole

Single Device – proposed new third graph



- Move Frequency here
- Add signal strength reading as this is critical to breaker function

November 23, 2020 – Feedback on Virtual Peaker Tools

Virtual Peaker reviewed and corrected issues by early 2021.

Virtual Peaker - New Top Level – Device Summary Graphs

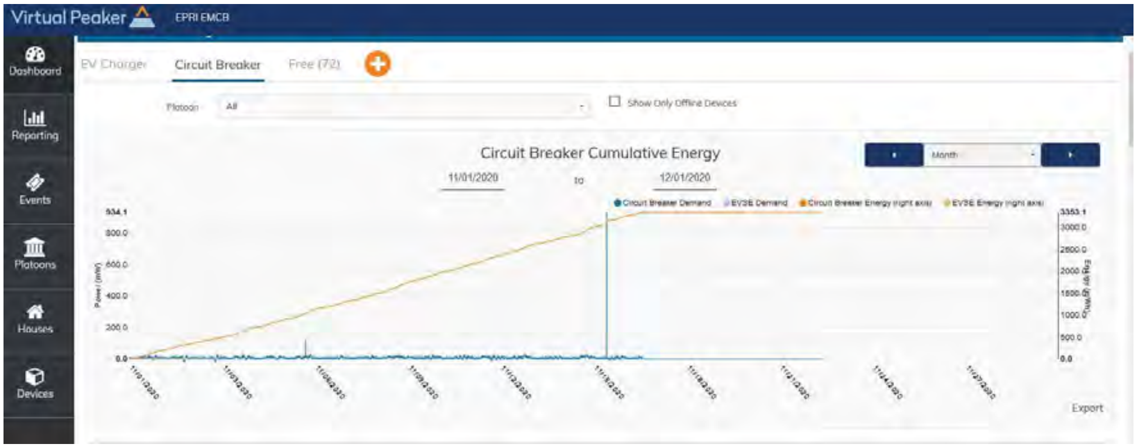
Top Level – Issues

- Selected “Week” then scrolled back 1-week – Data looks odd and drops off on 11/17/2020

Attachment B

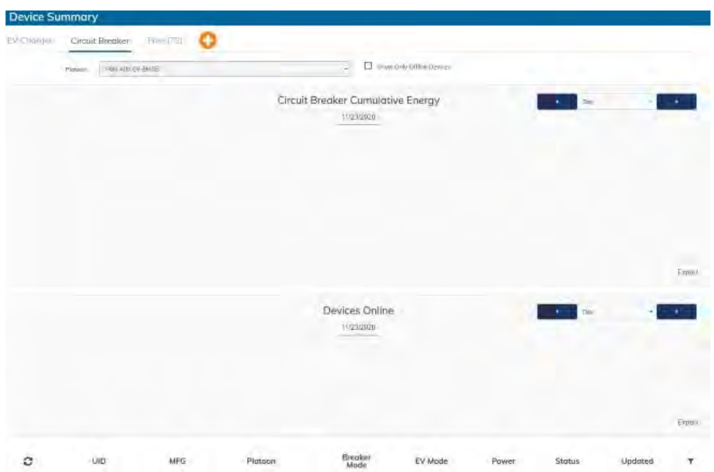
Top Level – Issues

- Selected “Month” – Data drops off on 11/17/2020



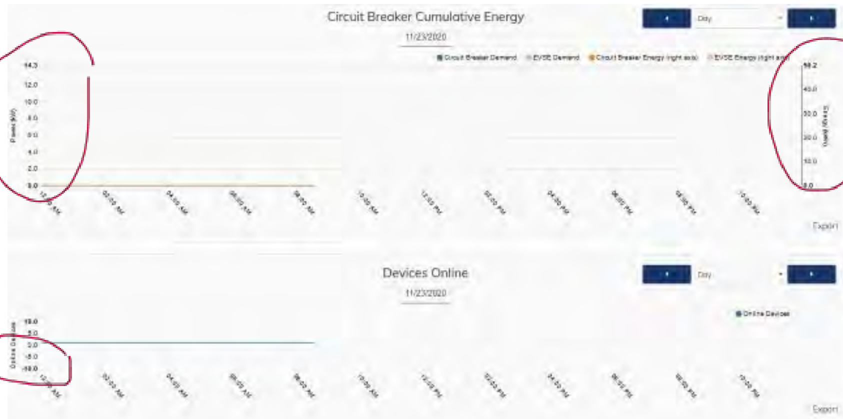
Top Level – Issues, continued

- Still seeing no data from EV-EMCBs in Palo Alto (may be Eaton issue)



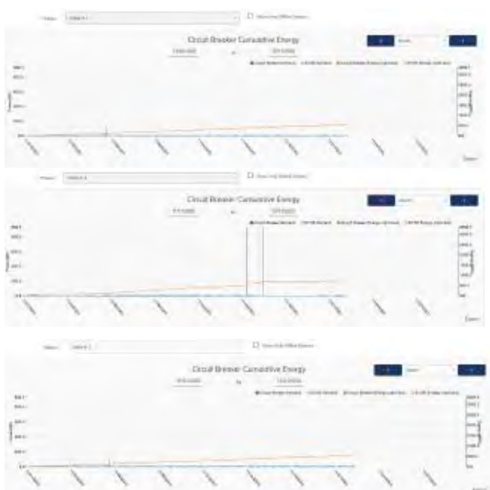
Platoon Level – issues

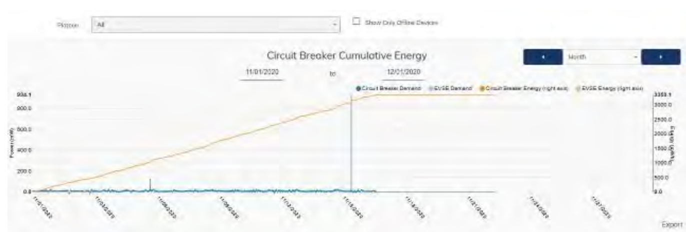
- When picking a platoon
  - Top graph doesn't auto -scale
  - Online devices includes negative numbers



Platoon Issues, Continued

- Spikes seen in Platoon data don't show up the same in ALL data

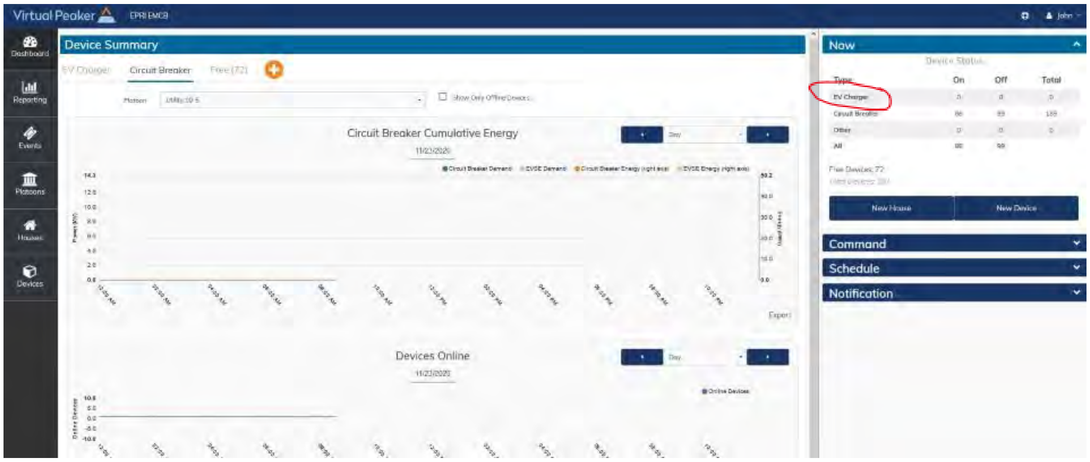




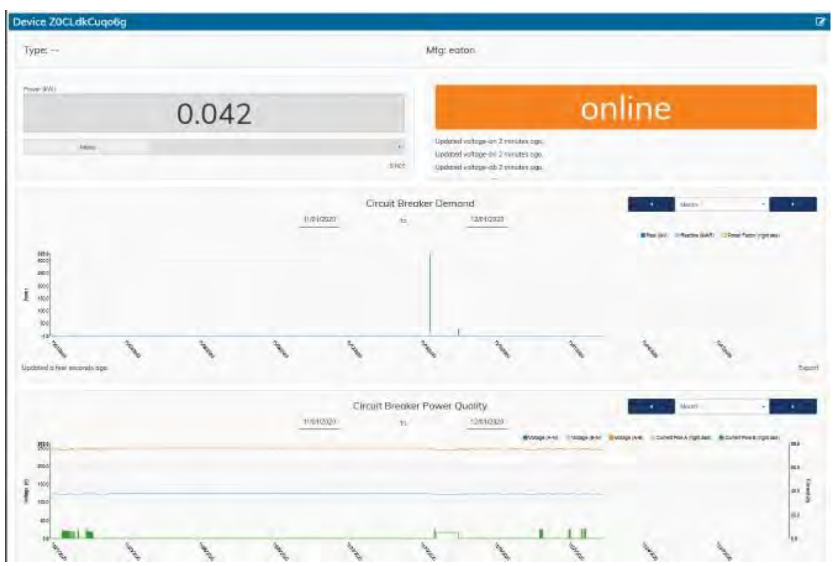
Platoon Level – Issues, continued

When looking at a Platoon's graphs:

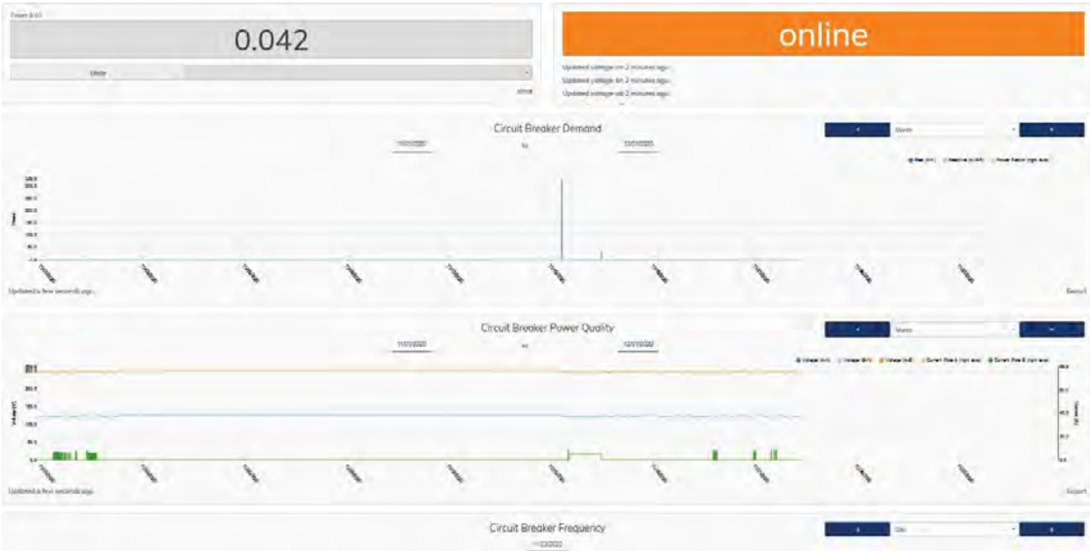
- Clicking on Circuit Breaker doesn't take you back to full list
  - No action occurs when you click Circuit Breaker in Device Status list
  - Browser back arrow takes you to a blank page (since it defaults to the EV Charger tab)
  - Only way back is to use the Platoon dropdown and select "ALL"



Device with VERY large Power Reading (329kW)



Device with VERY large Power Reading (329kW)

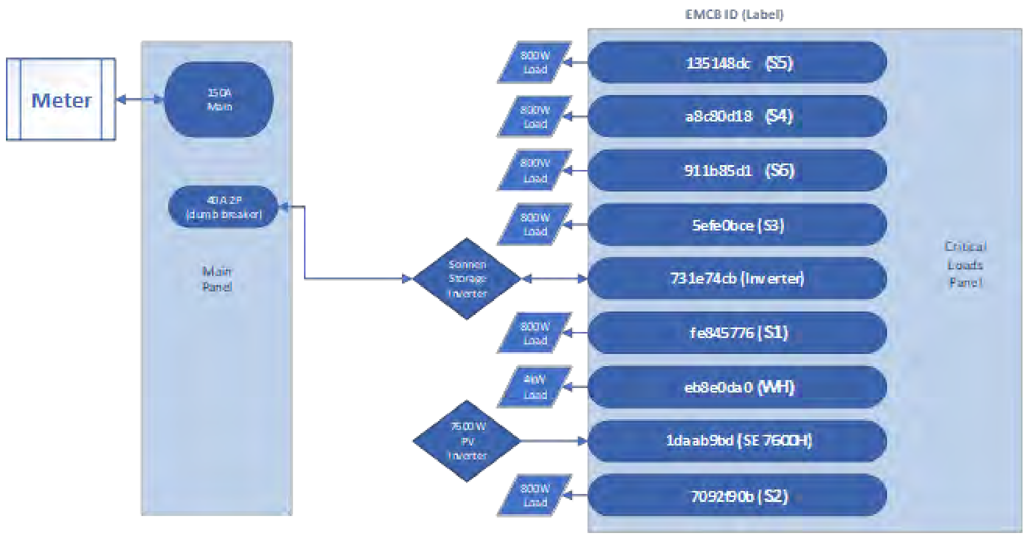


October 19, 2021 – EPRI Setup at SolarTAC facility to Demonstrate EMCBs with Storage and Solar

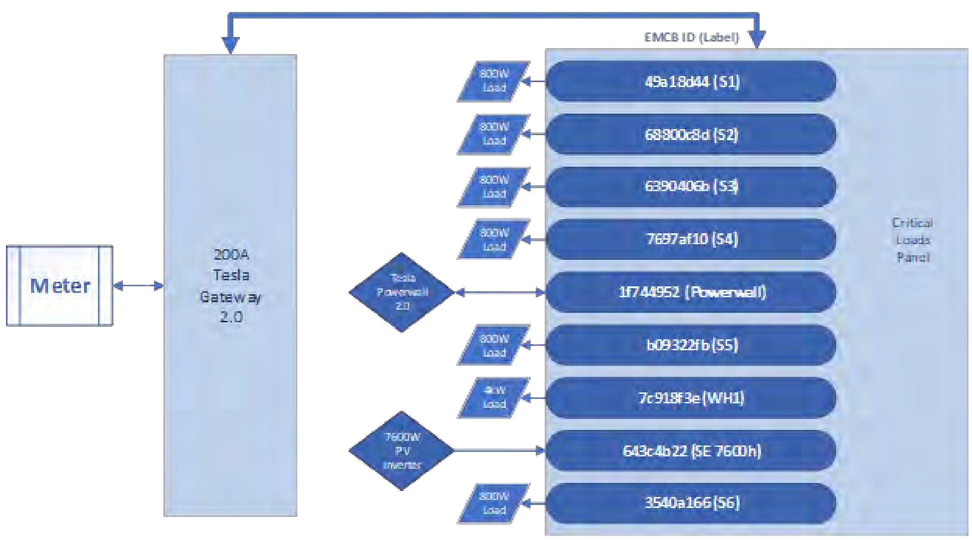
PV and Storage Demo (SolarTAC) – EMCB Info

http://www.solartac.org/

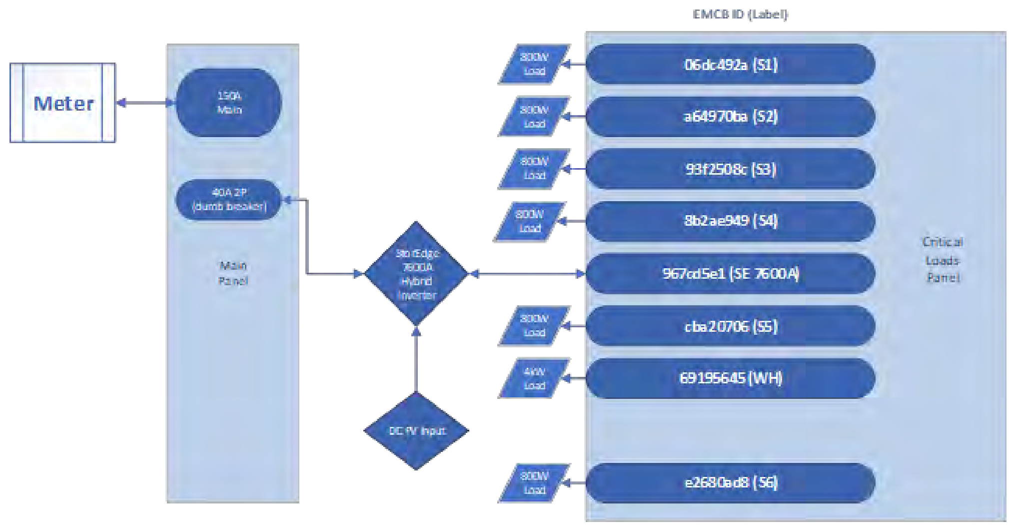
Sonnen EMCB Mapping



Tesla EMCB Mapping

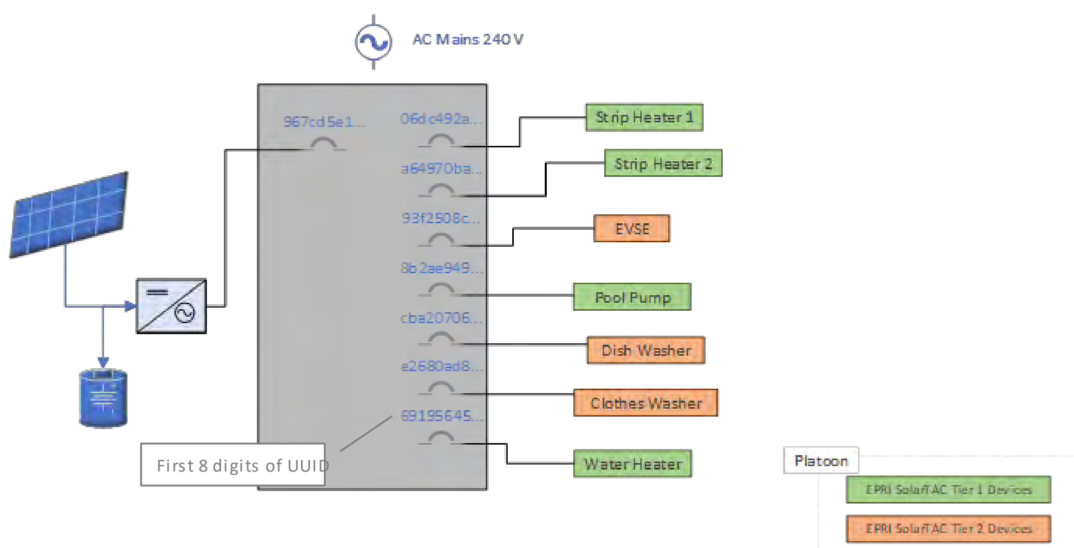


LG/SolarEdge EMCB Mapping

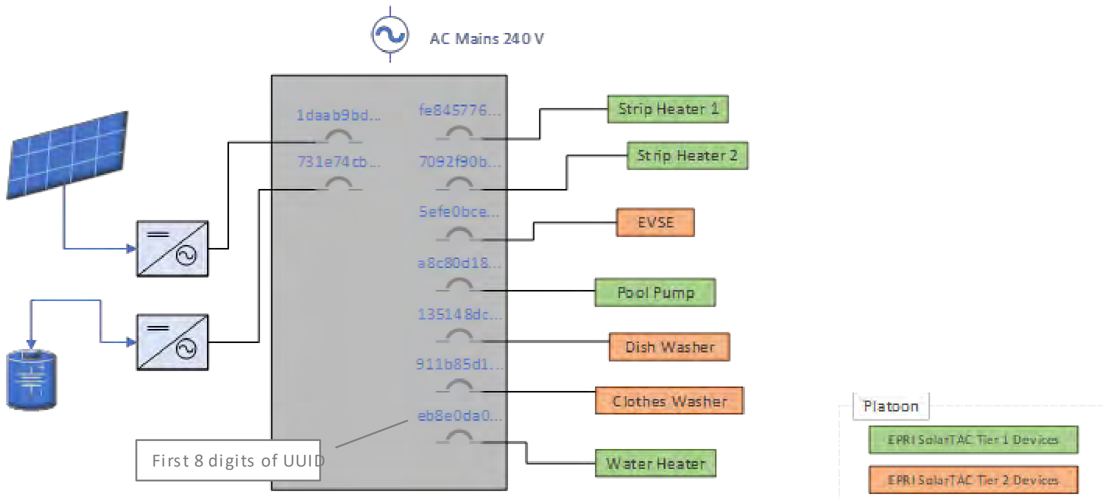


February 22, 2022 – Details of SolarTAC Setup

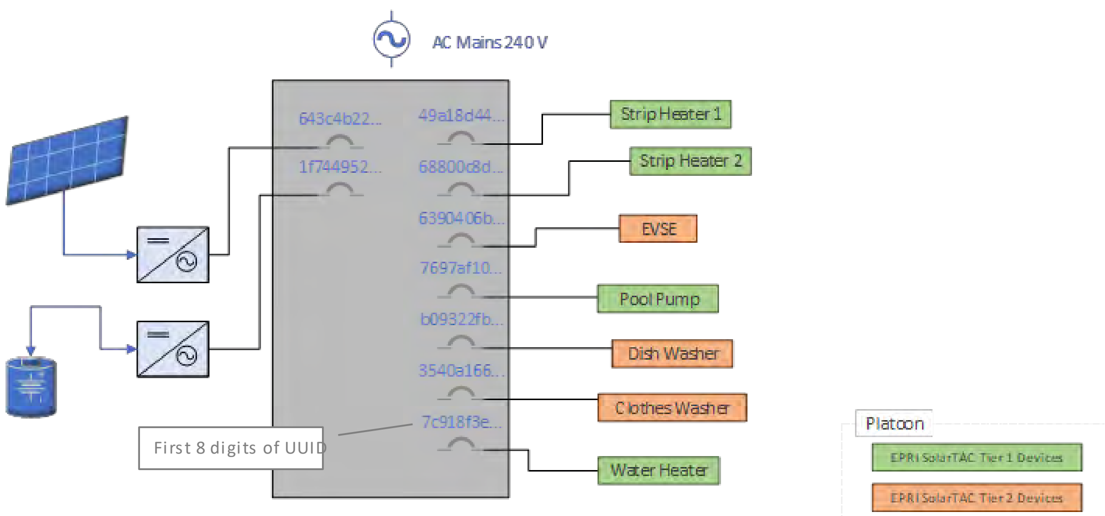
LG/SolarEdge House



Sonnen House



Tesla House



Platoon Setup in Virtual Peaker

Platoons

Inverters controlled separately

	Name	Description	Total Houses	Total Devices	Default Schedule
1	default	default platoon	0	0	-- none --
2	EPRI EMCB Breaker	EPRI EMCB Breaker	3	8	-- none --
3	EPRI SolarTAC LG-SolarEdge Inverter	EPRI SolarTAC LG-SolarEdge Inverter	1	1	-- none --
4	EPRI SolarTAC Sonnen Battery Inverter	EPRI SolarTAC Sonnen Battery Inverter	1	1	-- none --
5	EPRI SolarTAC Sonnen PV Inverter	EPRI SolarTAC Sonnen PV Inverter	1	1	-- none --
6	EPRI SolarTAC Tesla Battery Inverter	EPRI SolarTAC Tesla Battery Inverter	1	1	-- none --
7	EPRI SolarTAC Tesla PV Inverter	EPRI SolarTAC Tesla PV Inverter	1	1	-- none --
8	EPRI SolarTAC Tier 1 Devices	Strip heat, pool pumps, water heaters	3	12	-- none --
9	EPRI SolarTAC Tier 2 Devices	EVSE, dish washer, washing machine	3	9	-- none --

Loads in all 3 houses controlled together

House Setup in Virtual Peaker

	Billing Key	User(s)	Platoon	Date	Devices	Actions
☐	EPRI SolarTAC LG-SolarEdge House (Tier 1 devices)	Doni Nastasi	EPRI SolarTAC Tier 1 Devices	01/19/2022	4	⋮
☐	EPRI SolarTAC LG-SolarEdge House (Tier2 devices)	Doni Nastasi	EPRI SolarTAC Tier 2 Devices	01/19/2022	3	⋮
☐	EPRI SolarTAC LG-SolarEdge Inverter	Doni Nastasi	EPRI SolarTAC LG-SolarEdge Inverter	01/19/2022	1	⋮
☐	EPRI SolarTAC Sonnen Battery Inverter	Doni Nastasi	EPRI SolarTAC Sonnen Battery Inverter	01/19/2022	1	⋮
☐	EPRI SolarTAC Sonnen House (Tier1 devices)	Doni Nastasi	EPRI SolarTAC Tier 1 Devices	01/19/2022	4	⋮
☐	EPRI SolarTAC Sonnen House (Tier2 devices)	Doni Nastasi	EPRI SolarTAC Tier 2 Devices	01/19/2022	3	⋮
☐	EPRI SolarTAC Sonnen PV Inverter	Doni Nastasi	EPRI SolarTAC Sonnen PV Inverter	01/19/2022	1	⋮
☐	EPRI SolarTAC Tesla Battery Inverter	Doni Nastasi	EPRI SolarTAC Tesla Battery Inverter	01/19/2022	1	⋮
☐	EPRI SolarTAC Tesla House (Tier1 devices)	Doni Nastasi	EPRI SolarTAC Tier 1 Devices	01/19/2022	4	⋮
☐	EPRI SolarTAC Tesla House (Tier2 devices)	Doni Nastasi	EPRI SolarTAC Tier 2 Devices	01/19/2022	3	⋮
☐	EPRI SolarTAC Tesla PV Inverter	Doni Nastasi	EPRI SolarTAC Tesla PV Inverter	01/19/2022	1	⋮

LG/SolarEdge Physical House

Sonnen Physical House

Tesla Physical House

Export Control Restrictions

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Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

Program(s):

Insert Program Name

Insert Program Name

3020xxxxxx

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Demand Side Management Annual Report

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Neighborhood Energy Saver
Program Start Date: 2007 with modifications approved in 2015, 2018, 2020 and 2021
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants*	Projected Cumulative Penetration Level % [(d/c)x100]	Actual Annual Number of Program Participants*	Actual Cumulative Number of Program Participants*	Actual Cumulative Penetration Level % [(g/c)x100]	Actual Participation Over (Under) Projected Participants (g-d)
2020	1,647,440	443,161	5,000	1.13%	950	950	0.21%	-4,050
2021	1,673,995	450,305	10,000	2.22%	537	1,487	0.33%	-8,513
2022	1,700,215	457,358	15,250	3.33%	4,771	6,258	1.37%	-8,992
2023	1,726,425	464,408	20,500	4.41%				
2024	1,752,362	471,385	25,750	5.46%				

cols b,c,d,e are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator	
Winter kW Reduction	1.78	1.93	8,507	9,199	Program total @Meter divided by (1- Residential Loss Factor) equals the wkW reduction at the Generator
Summer kW Reduction	1.20	1.29	5,705	6,170	Program total @Meter divided by (1- Residential Loss Factor) equals the skW reduction at the Generator
Annual kWh Reduction	3,269.42	3,535.50	15,598,419	16,867,892	Program total @Meter divided by (1- Residential Loss Factor) equals the kWh reduction at the Generator

Utility Cost per Installation:	$1,108	Total Program Cost (F34) divided by Completions (F17) gives you the utility cost per installation
Total Program Cost of the Utility ($000):	$5,288	Provided in CT-2 P 2 of DEF's ECCR True Up Filing to be filed on May 3, 2023
Net Benefits of Measures Installed During Reporting Period ($000):	-$4,070	

**homes served*

Line No.	Jurisdiction	System Rollup of Jurisdiction's State	Product Code	Metric	Measure	Total
50	Florida	DE Progress Florida	HWLI	Annual KWH Gross FR, @ Meter Total	13182: Ceiling Insulation (R2 to R38) - NES	7,821,412
51	Florida	DE Progress Florida	HWLI	Annual KWH Gross FR, @ Meter Total	13183: Ceiling Insulation (R19 to R38) - NES	426
52	Florida	DE Progress Florida	HWLI	Annual KWH Gross FR, @ Meter Total	13184: Duct Repair - NES	1,214,122
53	Florida	DE Progress Florida	HWLI	Annual KWH Gross FR, @ Meter Total	13185: Central AC Tune Up - NES	452,455
54	Florida	DE Progress Florida	HWLI	Annual KWH Gross FR, @ Meter Total	13188: Whole House Measure - NES	6,110,004
					Subtotal Annual KWH Gross FR, @ Meter Total	**15,598,419**
57	Florida	DE Progress Florida	HWLI	Annual SKW Gross FR, @ Meter Total	13182: Ceiling Insulation (R2 to R38) - NES	3,432
58	Florida	DE Progress Florida	HWLI	Annual SKW Gross FR, @ Meter Total	13183: Ceiling Insulation (R19 to R38) - NES	0
59	Florida	DE Progress Florida	HWLI	Annual SKW Gross FR, @ Meter Total	13184: Duct Repair - NES	533
60	Florida	DE Progress Florida	HWLI	Annual SKW Gross FR, @ Meter Total	13185: Central AC Tune Up - NES	199
61	Florida	DE Progress Florida	HWLI	Annual SKW Gross FR, @ Meter Total	13188: Whole House Measure - NES	1,542
					Subtotal Annual SKW Gross FR, @ Meter Total	**5,705**
64	Florida	DE Progress Florida	HWLI	Annual WKW Gross FR, @ Meter Total	13182: Ceiling Insulation (R2 to R38) - NES	5,068
65	Florida	DE Progress Florida	HWLI	Annual WKW Gross FR, @ Meter Total	13183: Ceiling Insulation (R19 to R38) - NES	0
66	Florida	DE Progress Florida	HWLI	Annual WKW Gross FR, @ Meter Total	13184: Duct Repair - NES	787
67	Florida	DE Progress Florida	HWLI	Annual WKW Gross FR, @ Meter Total	13185: Central AC Tune Up - NES	199
68	Florida	DE Progress Florida	HWLI	Annual WKW Gross FR, @ Meter Total	13188: Whole House Measure - NES	2,453
					Subtotal Annual WKW Gross FR, @ Meter Total	**8,507**
71	Florida	DE Progress Florida	HWLI	Participants	13182: Ceiling Insulation (R2 to R38) - NES	2,417
72	Florida	DE Progress Florida	HWLI	Participants	13183: Ceiling Insulation (R19 to R38) - NES	1
73	Florida	DE Progress Florida	HWLI	Participants	13184: Duct Repair - NES	1,529
74	Florida	DE Progress Florida	HWLI	Participants	13185: Central AC Tune Up - NES	2,415
75	Florida	DE Progress Florida	HWLI	Participants	13188: Whole House Measure - NES	4,771
					Total Participants	**4,771**

RESIDENTIAL/COMMERCIAL INDUSTRIAL LOSS FACTOR	
Residential	7.53%
Commercial Industrial	5.13%

Demand Side Management - Annual Report*

Utility: DUKE ENERGY FLORIDA, LLC.
Program Name: Neighborhood Energy Saver
Program Start Date: 2007 with modifications approved in 2015, 2018, 2020 and 2021
Reporting Period: 2022

a	b	c	d	e	f	g	h	i
Year	Total Number of Customers	Total Number of Eligible Customers	Projected Cumulative Number of Program Participants*	Projected Cumulative Penetration Level % [(d/c)x100]	Projected Annual Number of Program Participants*	Projected Cumulative Number of Program Participants*	Projected Cumulative Penetration Level % [(g/c)x100]	Projected Participation Over (Under) Projected Participants (g-d)
2022	1,700,215	457,358	15,000	3.28%	5,000	5,000	4.31%	-10,000

all values are based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG

Annual Demand & Energy Savings (during the reporting period)	Per Installation @ Meter	Per Installation @ Generator	Program Total @ Meter	Program Total @ Generator	
Winter kW Reduction	1.91	2.02	9,542	10,101	Program total @Meter divided by (1- Residential Loss Factor) equals the wkW reduction at the Generator
Summer kW Reduction	1.31	1.38	6,536	6,919	Program total @Meter divided by (1- Residential Loss Factor) equals the skW reduction at the Generator
Annual kWh Reduction	3,540.13	3,747.31	17,700,669	18,736,531	Program total @Meter divided by (1- Residential Loss Factor) equals the kWh reduction at the Generator

Utility Cost per Installation:	$1,121	The Utility Cost Per Installation is the Total Program Cost (F35) divided by Completions (F17)
Total Program Cost of the Utility ($000):	$5,604	Total Program Cost based on DEF's 2020 Program Plan approved by the Commission in Docket 20200054-EG
Net Benefits of Measures Installed During Reporting Period ($000):	-$7,023	

**homes served*

Program Participation

Year	Total Number of Customers [1]	Total Number of Measure Eligible Customers [2]	Annual Number of Program Measure Participants [3]	Cumulative Penetration Level (%) [4]	Annual Participation Level (%)
2020	1,647,440	443,161	5,000	1.13%	1.13%
2021	1,673,995	450,305	5,000	2.22%	1.11%
2022	1,700,215	457,358	5,000	3.28%	1.09%
2023	1,726,425	464,408	5,000	4.31%	1.08%
2024	1,752,362	471,385	5,000	5.30%	1.06%
2025	1,777,519	478,153	0	5.23%	0.00%
2026	1,802,497	484,872	0	5.16%	0.00%
2027	1,826,913	491,440	0	5.09%	0.00%
2028	1,850,092	497,675	0	5.02%	0.00%
2029	1,873,271	503,910	0	4.96%	0.00%

HWLI	RIM	**1.00**	TRC	**3.91**	PCT	**4.15**

1.058521079 Line loss factor

Savings Estimates

At the Meter

Year	Per Customer KWh Reduction	Per Customer Winter KW Reduction	Per Customer Summer KW Reduction	Total Annual KWh Reduction	Total Annual Winter KW Reduction	Total Annual Summer KW Reduction
2020	3,540	1.91	1.31	17,700,669	9,542	6,536
2021	3,540	1.91	1.31	17,700,669	9,542	6,536
2022	3,540	1.91	1.31	17,700,669	9,542	6,536
2023	3,540	1.91	1.31	17,700,669	9,542	6,536
2024	3,540	1.91	1.31	17,700,669	9,542	6,536
TOTAL				88,503,346	47,711	32,682

At the Generator

Year	Per Customer KWh Reduction	Per Customer Winter KW Reduction	Per Customer Summer KW Reduction	Total Annual KWh Reduction	Total Annual Winter KW Reduction	Total Annual Summer KW Reduction
2020	3,747	2.02	1.38	18,736,531	10,101	6,919
2021	3,747	2.02	1.38	18,736,531	10,101	6,919
2022	3,747	2.02	1.38	18,736,531	10,101	6,919
2023	3,747	2.02	1.38	18,736,531	10,101	6,919
2024	3,747	2.02	1.38	18,736,531	10,101	6,919
TOTAL				93,682,657	50,504	34,595

Cost Effectiveness Tests

Cost-Effectiveness Test	NPV Benefits $(000)	NPV Costs $ (000)	NPV Net Benefits $(000)	B/C Ratio
Rate Impact Measure	$138,063	$137,801	$262	1.00
Participant	$135,091	$32,578	$102,514	4.15
Total Resource Cost	$138,063	$35,287	$102,776	3.91

RESIDENTIAL LINE LOSS FACTOR

Residential	1.058521079

PROGRAM: Neighborhood Energy Saver HWLI

Rate Impact Measure (RIM) Test

	BENEFITS				COSTS				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
YEAR	TOTAL FUEL & O&M SAVINGS $(000)	AVOIDED T&D CAP. COSTS $(000)	AVOIDED GEN. CAP. COSTS $(000)	**TOTAL BENEFITS** $(000)	UTILITY PROGRAM COSTS $(000)	INCENTIVE PAYMENTS $(000)	REVENUE LOSSES $(000)	**TOTAL COSTS** $(000)	**NET BENEFITS** $(000)
2020	516	1,182	0	1,697	619	4,985	2,130	7,734	-6,037
2021	1,008	2,405	0	3,413	619	4,985	4,285	9,888	-6,475
2022	1,470	3,581	0	5,051	619	4,985	6,471	12,074	-7,023
2023	1,967	4,815	0	6,783	619	4,985	8,767	14,370	-7,588
2024	2,699	6,110	0	8,808	619	4,985	11,203	16,807	-7,998
2025	3,195	6,145	0	9,340	0	0	11,666	11,666	-2,326
2026	3,448	6,182	0	9,629	0	0	12,149	12,149	-2,520
2027	3,897	6,330	7,809	18,036	0	0	12,758	12,758	5,278
2028	4,107	6,483	7,850	18,440	0	0	13,273	13,273	5,167
2029	4,254	6,596	10,455	21,305	0	0	13,575	13,575	7,730
2030	4,520	6,676	10,426	21,622	0	0	13,794	13,794	7,828
2031	4,337	6,296	9,695	20,328	0	0	13,025	13,025	7,303
2032	4,112	5,892	7,147	17,150	0	0	12,137	12,137	5,013
2033	3,838	5,444	7,022	16,304	0	0	11,034	11,034	5,271
2034	3,510	5,020	6,464	14,994	0	0	10,100	10,100	4,894
2035	2,986	4,591	7,153	14,731	0	0	9,046	9,046	5,684
2036	2,974	4,648	7,147	14,769	0	0	9,098	9,098	5,671
2037	3,118	4,704	6,025	13,848	0	0	9,288	9,288	4,560
2038	3,313	4,784	6,117	14,214	0	0	9,699	9,699	4,515
2039	3,544	4,864	6,123	14,532	0	0	10,103	10,103	4,429
2040	2,923	3,976	5,069	11,969	0	0	8,351	8,351	3,618
2041	2,266	3,047	3,878	9,192	0	0	6,459	6,459	2,733
2042	1,565	2,076	2,600	6,241	0	0	4,445	4,445	1,796
2043	810	1,060	1,346	3,216	0	0	2,294	2,294	922
2044	0	0	0	0	0	0	0	0	0
2045	0	0	0	0	0	0	0	0	0
2046	0	0	0	0	0	0	0	0	0
2047	0	0	0	0	0	0	0	0	0
2048	0	0	0	0	0	0	0	0	0
2049	0	0	0	0	0	0	0	0	0
2050	0	0	0	0	0	0	0	0	0
2051	0	0	0	0	0	0	0	0	0
2052	0	0	0	0	0	0	0	0	0
2053	0	0	0	0	0	0	0	0	0
2054	0	0	0	0	0	0	0	0	0
2055	0	0	0	0	0	0	0	0	0
2056	0	0	0	0	0	0	0	0	0
2057	0	0	0	0	0	0	0	0	0
2058	0	0	0	0	0	0	0	0	0
2059	0	0	0	0	0	0	0	0	0
NOMINAL	70,377	112,908	112,325	295,611	3,093	24,925	225,150	253,168	42,442
NPV	33,808	57,632	46,624	138,063	2,709	21,832	113,259	137,801	262

Utility Discount Rate = 7.10%
Benefit Cost Ratio = 1.002