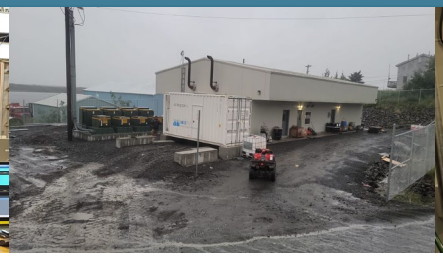
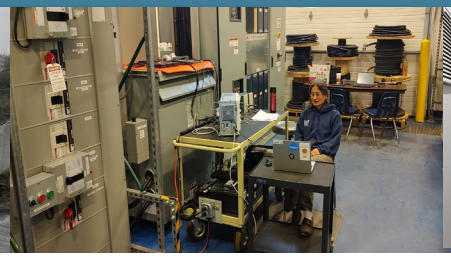
Sandia National Laboratories

Energy Storage Demonstration Projects – OE-ES Peer Review 10/24/23

Project: 2170654

Energy Storage Control for Maximum Remote Alaskan Microgrid Benefit





William Thomson PE (Ak) P.Eng (BC)

2023 DOE Office of Electricity Peer Review – Deployment Projects

AVEC

ACEP
Alaska Center for Energy and Power

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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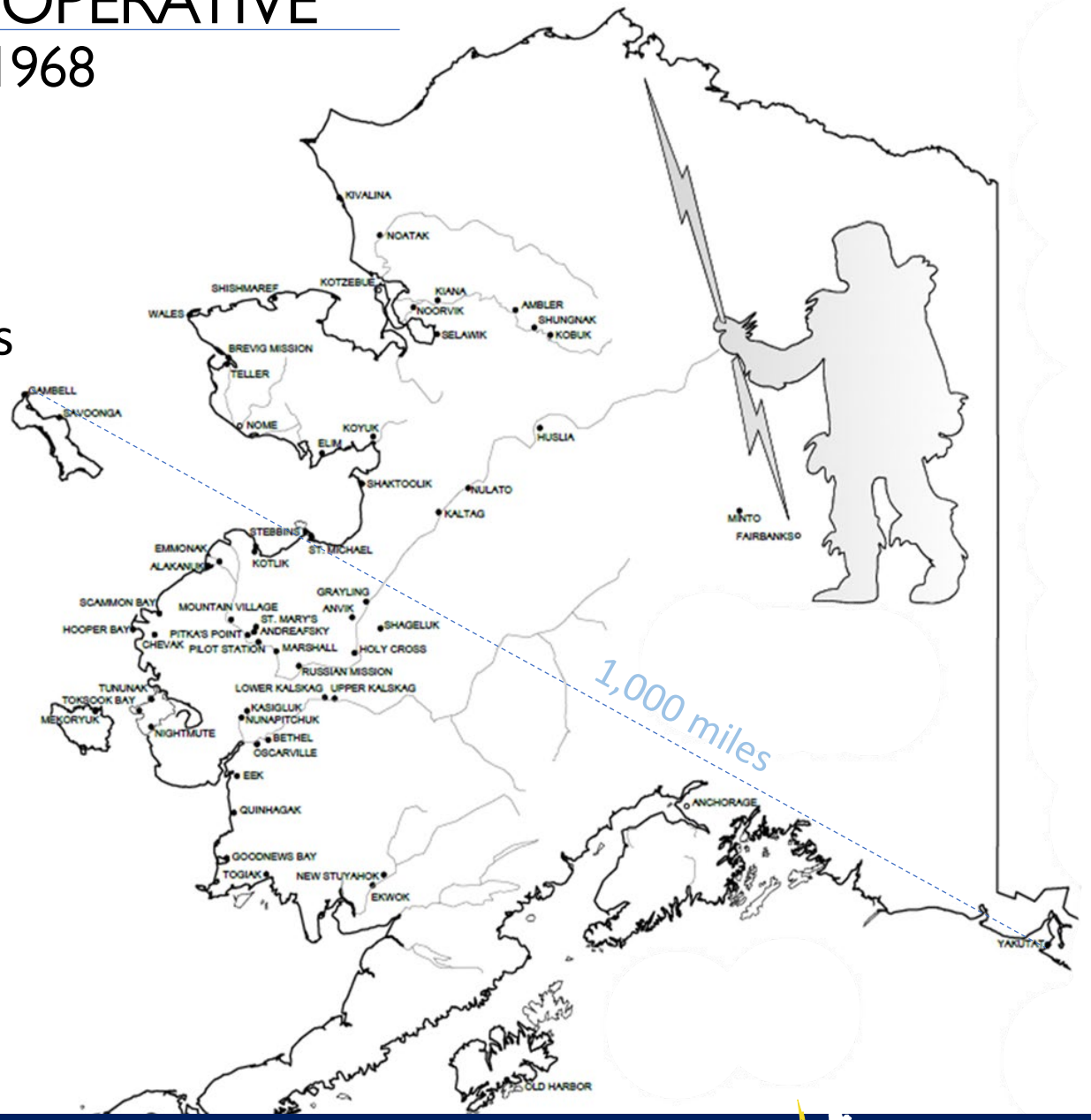
ALASKA VILLAGE ELECTRIC COOPERATIVE

Energizing Rural Alaska Since 1968

- Nonprofit 501(c)12 -Electric Cooperative
- 59 Member Communities, 31,000+ Residents
- 48 Power Plants, 160 Diesel Generators
- 9.1M Gallons of Diesel in 2022 ($35.3M)
- 515 miles of Distribution Lines
- 12 Wind Sites, 32 Wind Turbines, Serving 20 Communities
- $60.7M Annual Revenue
- 2022 Total Electricity Sold 124.5 MWh



St. Mary's Family of Projects

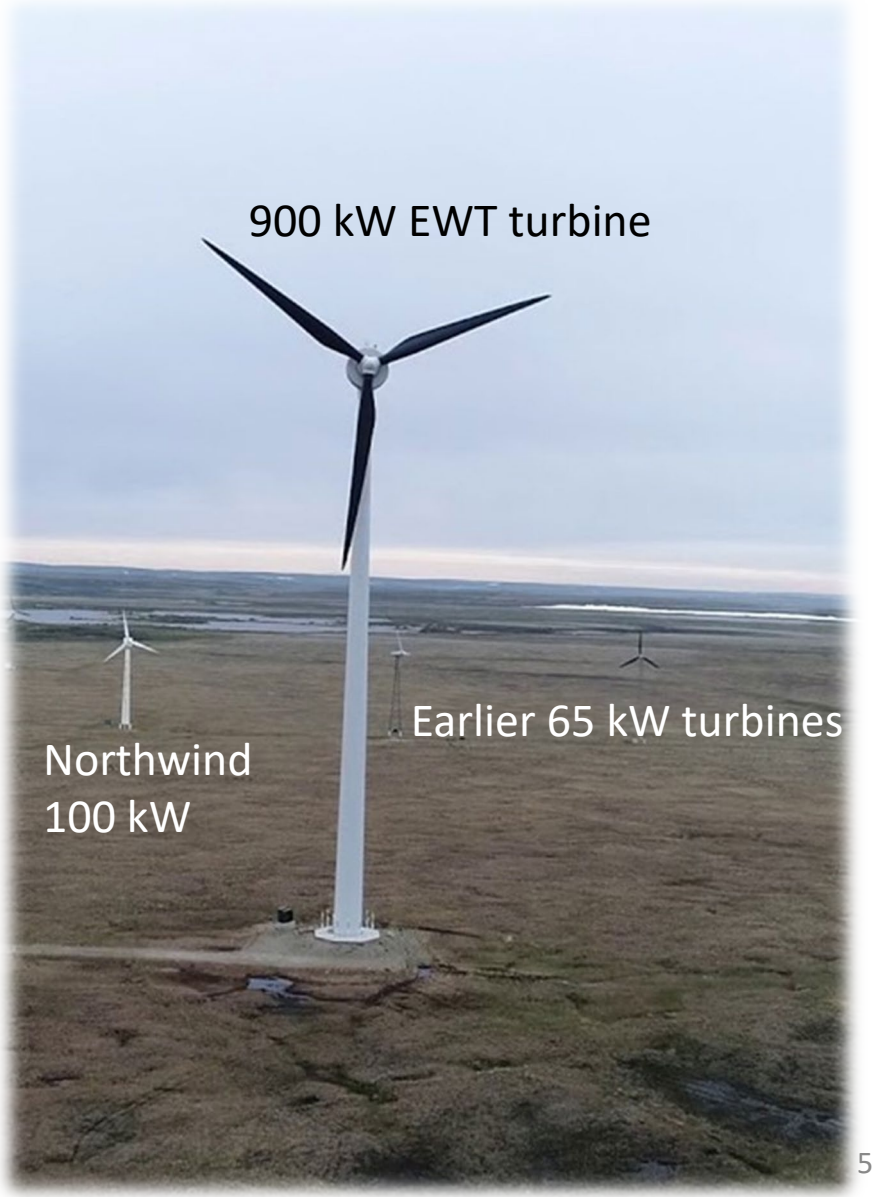
- 900kW EWT Wind Turbine and Distribution Upgrades
- 20 Mile Intertie to Mt. Village
- 3MW Power Plant
- 35-40% Annual Diesel Displacement (without energy storage)
- GBS Energy Storage (2023)

- AVEC has discovered that for our microgrids, larger turbines are more maintainable and better behaved than smaller turbines.

- Larger turbines leapfrog us into high penetration very quickly.

- Unfortunately, the unpredictable nature of wind requires that we provide essentially 100% spinning reserve for the turbine, forcing us to run a large diesel with light load whenever the wind is blowing.

- An Energy Storage System can be configured to behave as a Grid Bridging System (GBS). The primary purpose of a GBS is to provide synthetic spinning reserve, allowing either a smaller diesel to be run, or even diesels-off operation.



GBS BENEFIT STREAMS

1. Provides spinning reserve, allowing less diesel capacity on-line
2. Creates a more solid and stable microgrid, allowing less downtime and maintenance.
3. Allows Arbitrage by saving surplus wind energy for later use.


St Marys Alaska

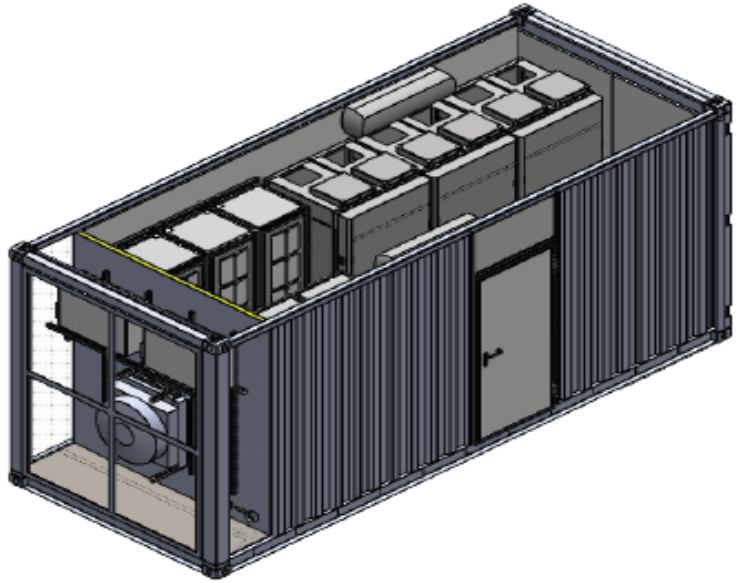
4. Improves Service Quality by reducing outages. The GBS can Compensate for unit outages until additional resources are brought on-line.

AVEC Grid Bridge Project – Battery Choice

Only need 10 minutes of Battery Power! In order to supply enough spinning reserve for another diesel to go on-line, A BESS whose major use is spinning reserve and microgrid stability only requires perhaps 10 minutes of storage.

How to obtain such a high power to Energy Ratio?
High power to energy ratios of at least C6 can be provided by Lithium Titanate batteries or Ultracapacitors.

The best price was with a 1 hour battery. We choose 1 hour of storage in order to keep within the budget, and also have more flexibility to explore actual benefit opportunities in operation.



500 KW INVERTER AND BATTERY MODULE (ONE OF TWO)

AVEC Grid Bridge Project – Vendor Decision

A German vendor, **FREQCON** was chosen for the GBS purchase and the contract signed May 2021.

Pros:

- Emergya Wind Technologies (EWT) uses FREQCON as one of two vendors for the EWT turbine inverters, so we felt their equipment would be reliable and maintainable.
- Their price was among the lowest received.
- All other bidders required an isolation transformer between the output of the inverter and the powerplant 480V bus.

The transformer was not only a significant expense, but it would increase system loss, and most importantly, there was no available real estate to site two 500 kVA transformers at the plant

Cons:

- They are an overseas vendor and we knew this increased the risk. Already in 2021 there were COVID related supply chain issues and marine congestion at North American ports.

AVEC Grid Bridge Project - Chronology

May 2021

- Contracted with FREQCON for two 500 KW GBS Systems

Summer 2021

- Approval of drawings and start of construction
- Shipping by October 27th was the original schedule
- No schedule delay was communicated at the time.

Fall-Winter 2021:

- We were notified that Battery arrival in Germany had been delayed due to Chinese Covid issues.
- Inverters had successfully completed Factory Acceptance Testing using shop batteries. No written FAT report was ever received.
- We were told that due to late battery deliveries, shipping was delayed until Spring 2022. We choose not to receive modules without batteries

AVEC Grid Bridge Project - Chronology

January-February 2022:

- Little progress was made on the physical unit at Freqcon due due to many sickness absences.
- The design, engineering, and purchasing is finished.
- The FAT has taken longer than expected due to supply chain issues delaying the arrival of the batteries. (We thought this was already done)
- Many delays and false reports that the batteries had been delivered to FREQCON in Rethem.
- Delivery has now been extended to May 2022
- And then the Russian / Ukraine war starts.

FREQCON BATTERIES MODULES RACKED

AVEC Grid Bridge Project - Chronology

March-June 2022:

- The rest of the new St. Marys Powerplant installation continues on without the GBS. By August 2022 the new powerhouse is installed, commissioned, turned over for service and put into operation. The contractor starts packing up.
- FREQCON says the container design, electrical design of the GBS, PSC, and ESM are finished. The software is almost finished.
- To find out what the status of the project actually was, AVEC conducted an on-site visit at the FREQCON facilities in Rethem, Germany March 28-April 1st.
    - Supply Chain issues affecting chips used on the battery management boards needed to complete assembly of the battery modules
    - Batteries are arriving but still far behind schedule


BATTERY CELLS WAITING FOR BATTERY MANAGEMENT BOARDS

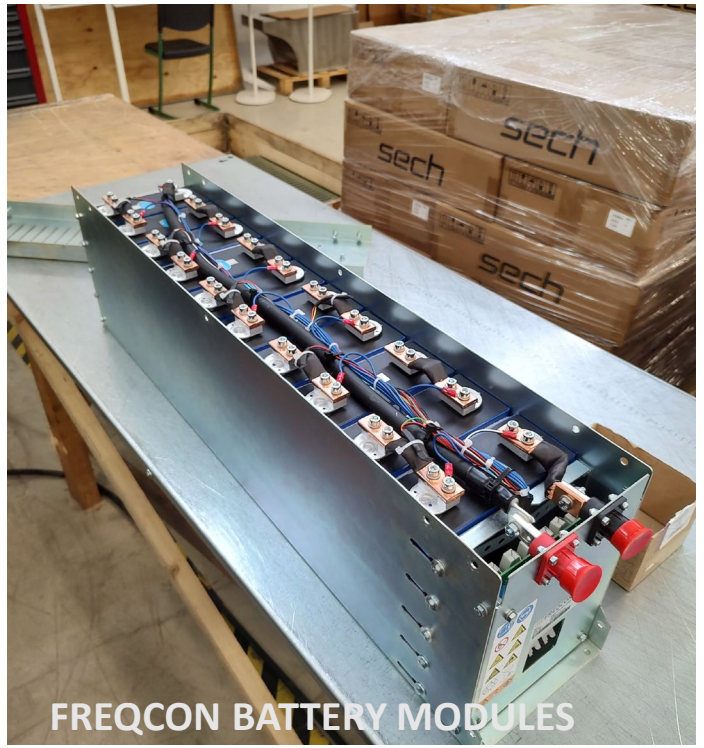
AVEC Grid Bridge Project - Chronology

Summer 2022:

- The project is declared to be delayed a full year, as FREQCON is unable to find any carrier to transport the batteries to North America in time for 2022 delivery to site.
- The new required delivery date has been communicated to FREQCON and will be the *first week of March 2023.*

Fall 2022:

- FREQCON has replaced the batteries in the modules with newer batteries and has tested them. Modules are supposedly ready for shipping. We have requested shipping information.
- Inconsistencies in the SCADA interfacing details were detected and corrections provided by FREQCON.
- We continue to request shipping information that will allow delivery in early March 2023



FREQCON BATTERY MODULES

AVEC Grid Bridge Project - Testing

January – February 2023:

- Batteries and modules are apparently in shipment, but precise information is impossible to obtain.
- Software was written that allows for manual control of the GBS in the test environment.

April 2023:

- Both 500 kW modules arrived in Fairbanks. Most of the batteries are still on route (Hazmat).
- Twenty eight batteries were shipped with the two modules, sufficient for most testing requirements. Two half-strings were installed in the module under test, relying on the DC-DC converter to bring half battery voltage up to the full AC bridge requirements.

OUR MODULES READY FOR SHIPMENT

AVEC Grid Bridge Project - Testing

April 2023:

- A modified test plan based on the power limitations of a partial battery set was written.
- One of the two modules was connected to the Laboratory bus.
- HVAC equipment starts being installed in the modules at Fairbanks.
- ACEP, AVEC, and FREQCON representatives were on site for preparations for testing during April 24th through May 2nd.
- Laboratory Acceptance Testing Starts!
- 2023 Delivery is more than a month late, but we can make 2023 shipping and only be a year late if everything from here on is smooth, including the testing to start April 24th.

AVEC Grid Bridge Project - Testing

PROBLEMS ARISE when Fairbanks Laboratory testing starts

- The inverter was shipped by accident without AC output inductors that are required when an inverter is used without an isolation transformer. We decide that testing can proceed without them, but we immediately have difficulties.

- The inductors would provide for better power quality, particularly lower harmonic levels. We cannot connect the GBS to the facility grid due to high harmonic levels.

- We found that the Factory Accceptance Testing (FAT) was done only for Grid Following functionality. The required Grid forming capabilities were not tested before shipping. This may explain why no documentation on FAT was ever received and no opportunity for customer witnessing of the FAT was ever provided.

ALASKA CENTER FOR ENERGY AND POWER (ACEP)

AVEC Grid Bridge Project - Testing

PROBLEMS ARISE when Fairbanks Laboratory testing starts

- As a consequence of the lack of FAT, the inverter was initially incapable of grid forming operation. Only by the heroic efforts of the Freqcon programmer, coupled with the presence of an excellent testing facility, did we obtain minimal functionality by May 2nd.

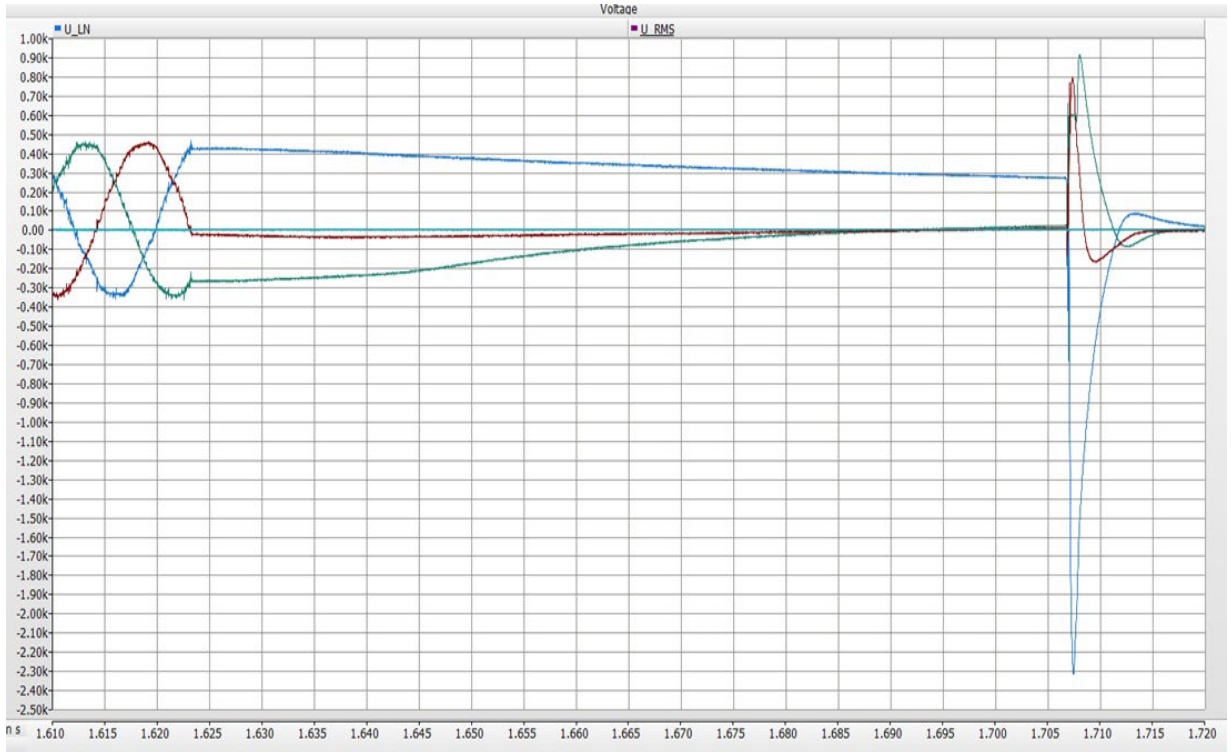
- The Freqcon technicians had to return to Germany on May 3rd, leaving the equipment not yet approved for shipping to site for the following reasons:
  1. Additional output filtering is required
  2. Erratically unable to start using black start and Faults when attempting a Black Start do not show up in the event log, nor where they seen as faults on the web interface.
  3. There is no written starting procedure. This may have caused some starting issues.
  4. There is a lack of written documentation, such as fault decoding.
  5. Operation is not yet reliable. The inverters shut down without warning or a fault showing.
  6. The small compliment of batteries prevents us from fully loading the inverter.
  7. The small compliment of batteries prevents us from checking parallel operation of the inverters.
  8. The sequence for Battery balancing/Equalizing has not been tested yet.

ALASKA CENTER FOR ENERGY AND POWER (ACEP)

AVEC Grid Bridge Project - Problems

MORE PROBLEMS as May testing continues without additional filtering

- The inverter was shipped without AC output inductors that would normally be expected when an inverter is used without an isolation transformer. We continue testing without them and have more difficulties.
- HVAC equipment was completed during the first two weeks of May.
- After the modules were available, testing continued using remote access by the FREQCON software programmer. Some success was obtained. Some additional documentation was obtained as well
- However on May 24. Fuses and surge arrestors blew in the inverter on test. The people doing the testing heard the surge when it happened. The inverter was running off-grid in stand-alone mode at the surge happened shortly ***AFTER*** the inverter shut down on a fault.
- We decided that testing had to stop until the cause was clearly identified. We suspected it was due to operating without the additional required filtering.



We are now looking at losing an additional year, since the last 2023 barge to site was scheduled in just a bit more than 2 months and we are missing essential filtering hardware necessary for final programming and hopefully completion of testing.

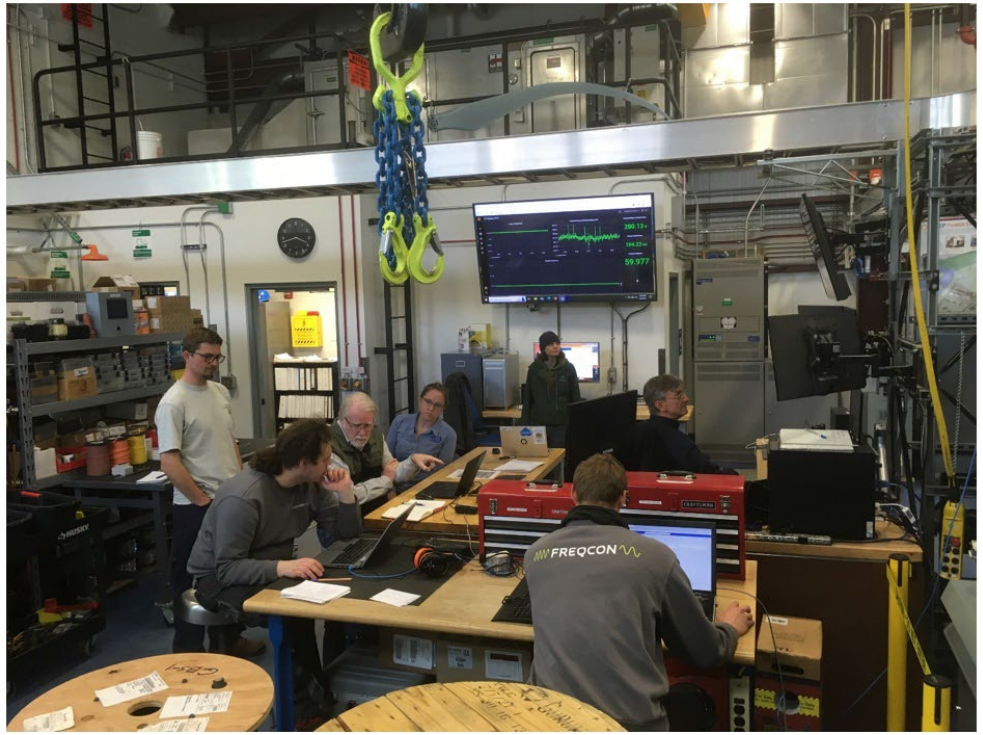
AVEC Grid Bridge Project - Waiting

June 2023

Freqcon explained the voltage spike that was observed during remote testing in May. This was another unintended result of the inverters being designed to expect isolation transformers.

A solution to prevent future spikes await the delivery and installation of additional componentry.

In the meanwhile, ACEP lab funding was based on GBS testing time, not to support a lengthly FREQCON development time. The cost of this development time must be paid and there is no contractual framework for that to happen yet.

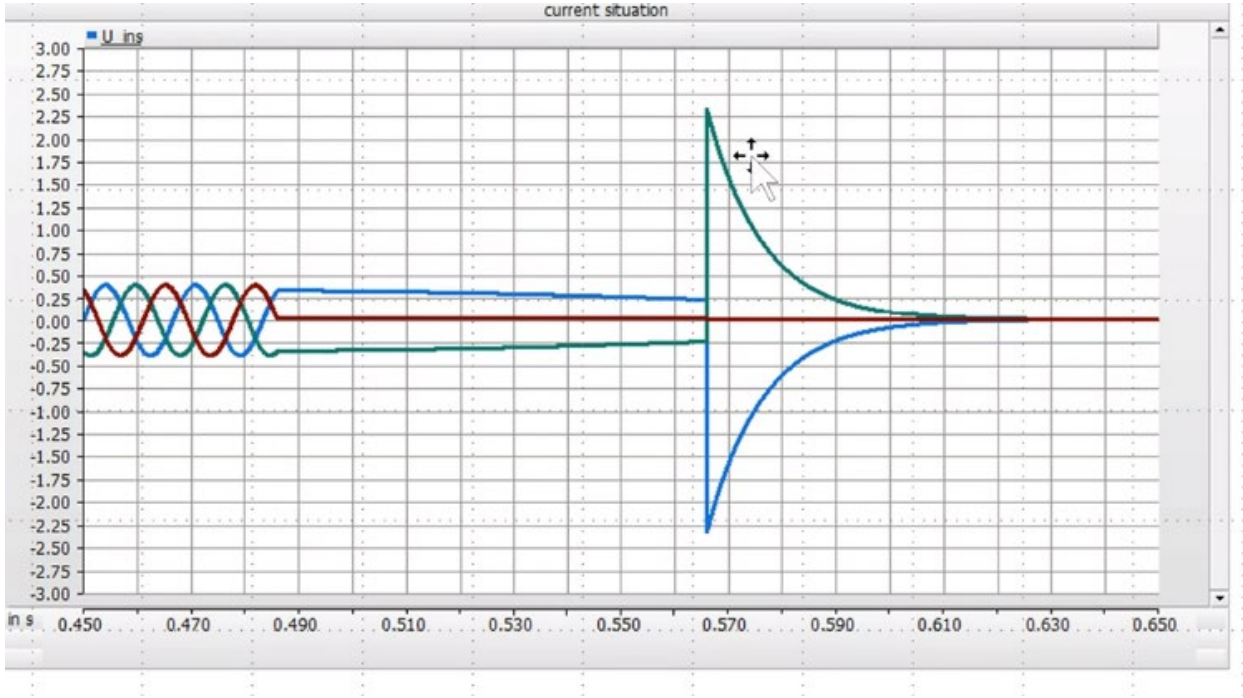


ALASKA CENTER FOR ENERGY AND POWER (ACEP)
A FULL CREW: ACEP, FREQCON AND AVEC PERSONNEL

AVEC Grid Bridge Project - Progress

July 2023

- Additional Components from FREQCON arrived on July 12th.
- Two FREQCON technicians arrived on July 17th to install them.
- FREQCON's CEO and founder, Norbert Hennchen arrived Thursday July 20th to oversee testing.
- Responsibility for ACEP additional costs was accepted by FREQCON (Friday).
- Working with the FREQCON software technician logged in from Germany, their work continued through the weekend.
- Acceptance testing proceeded immediately after their work was done, starting Tuesday July 25th.
- Testing was successfully completed on both inverter modules by Friday July 28th.
- Based on successful testing, the batteries and two inverter modules were approved for shipment to site at St. Mary's.



FREQCON SIMULATION OF THE MAY 24 EVENT

FAIRBANKS TESTING

AVEC Grid Bridge Project - Now

August-October 2023

- Modules were shipped from Fairbanks on August 4th.
- They arrived at St. Marys during September and were installed on concrete foundations
- At the end of September the full complement of batteries were installed in the module racks.
- Temporary heat was installed in the modules.
- A contract for interconnecting wiring has been awarded.
- Batteries are to be charged and equalized by the end of October.
- Commissioning should be completed by Year-End and then the project will be in full operation.

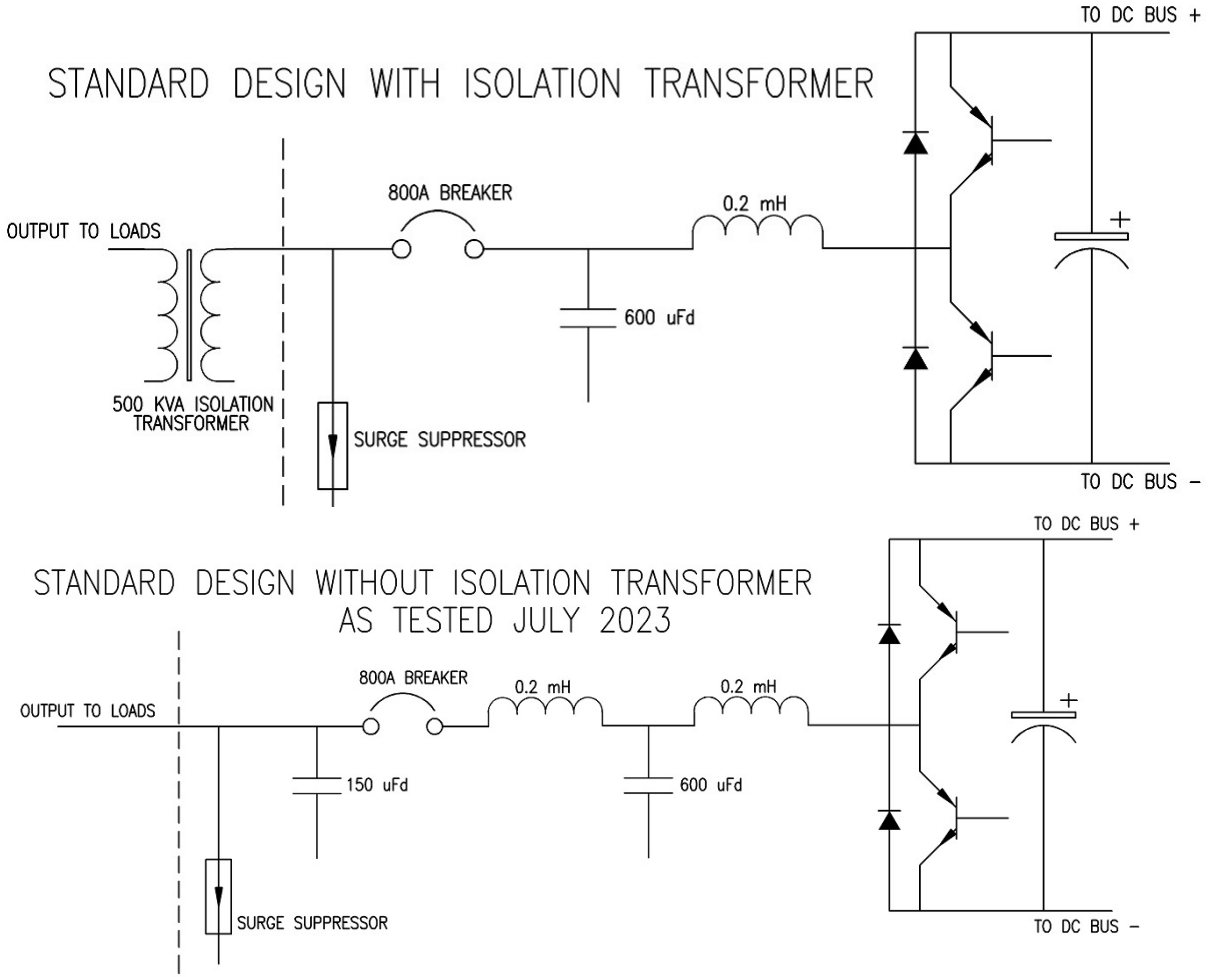
ONE OF TWO MODULES MOUNTED ON SITE AT ST. MARYS POWERPLANT

FAIRBANKS TESTING

AVEC Grid Bridge Project - Denouement

What caused the May 24 2023 Event?

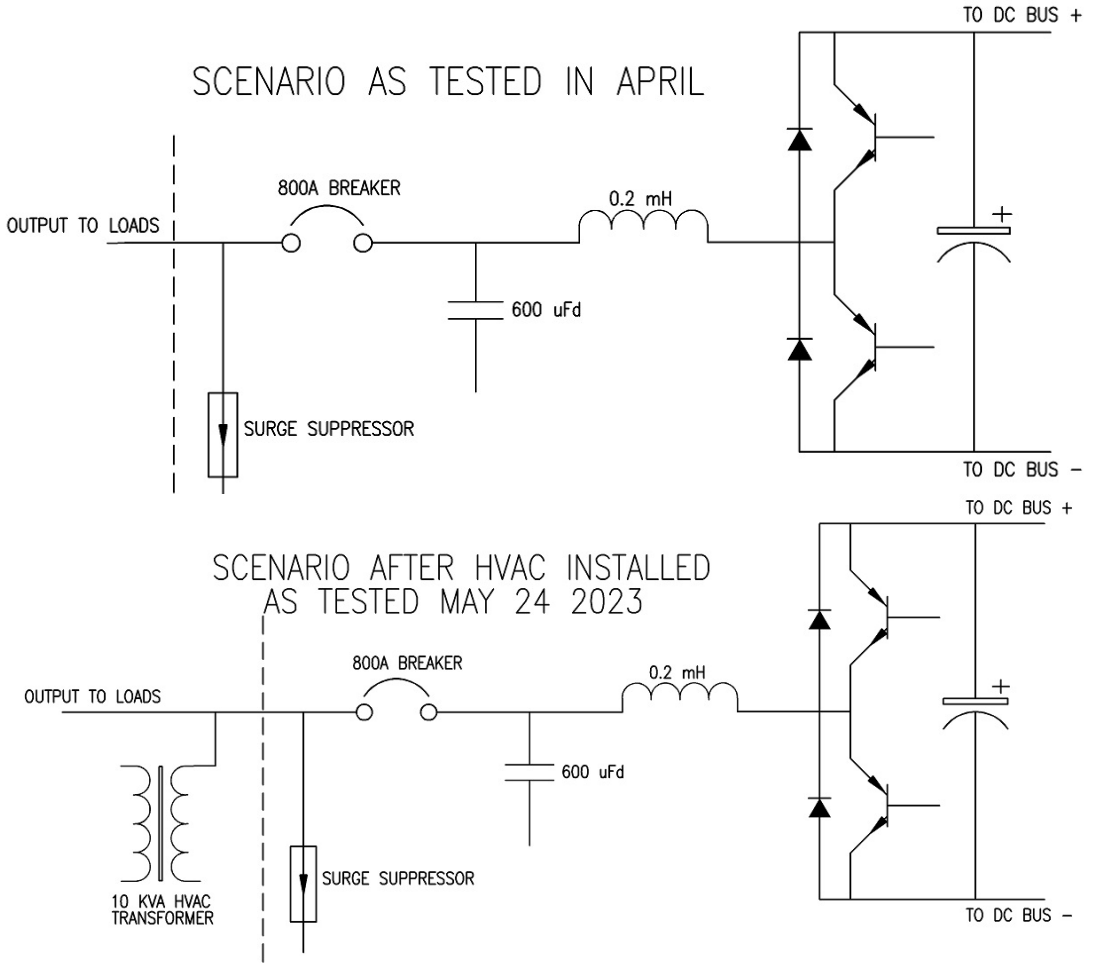
- The modules were mistakenly shipped expecting to be connected to an isolation transformer as shown on the top right.
- The inverters were missing the additional capacitors and inductors necessary to operation with a direct connection to the loads.
- On the lower right you can see the complete inverter as tested successfully in July.



AVEC Grid Bridge Project - Denouement

What caused the May 24 2023 Event?

- Due to lack of time, we attempted to test while FREQCON was still doing black start and Grid Forming Development work. This was difficult, although we ended up with a good working knowledge of the FREQCON technology.
- This development and testing work was difficult due to high levels of harmonics. But there were no extreme events
- HVAC equipment was installed during May, including 10 kVA 480V transformers to supply HVAC equipment in each module.
- The surge occurred after an inverter fault that shut down the IGBT bridges. This left residual voltage on the filter capacitors that started discharging through the newly connected 10 kVA transformers.
- The transformers received DC current for the next 80 mSec, fully saturating the transformer iron.
- 80 mSec later, the breaker was opened, releasing a flyback voltage from the HVAC transformers and blowing the surge suppressors and fuses.
- With the fully completed inverters, this cannot happen because of additional installed 150 mFd capacitors.



AVEC Grid Bridge Project

Total Estimated cost:	$1,550,000
DOE Cost share for soft costs:	$ 700,000
Partner Cost:	$ 850,000

Our testing partner: Alaska Center for Energy and Power in Fairbanks Alaska

Thank You

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This work is funded by the DOE OE Stationary Energy Storage program directed by Dr. Imre Gyuk.