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FLISR in the Presence of DERs
ADMS Test Bed Use Case

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Power Systems Engineering Center
August 25, 2022

DOE ADMS and DERMS Core Development

Transform utility electric distribution management systems to enable the integration and management of all assets and functions across the utility enterprise regardless of vendor or technology.

Today		Future
Closed, proprietary, vendor specific	→	Open architecture, standards-based data exchange

Four program areas:

Platform:	Develop an open-source platform; evaluate advanced applications.
Test bed:	Build a vendor-neutral test bed to evaluate existing and future advanced distribution management system (ADMS) functionalities in a realistic setting.
Applications:	Develop an initial suite of ADMS applications.
Advanced control:	Develop new integrated optimization and control solutions.

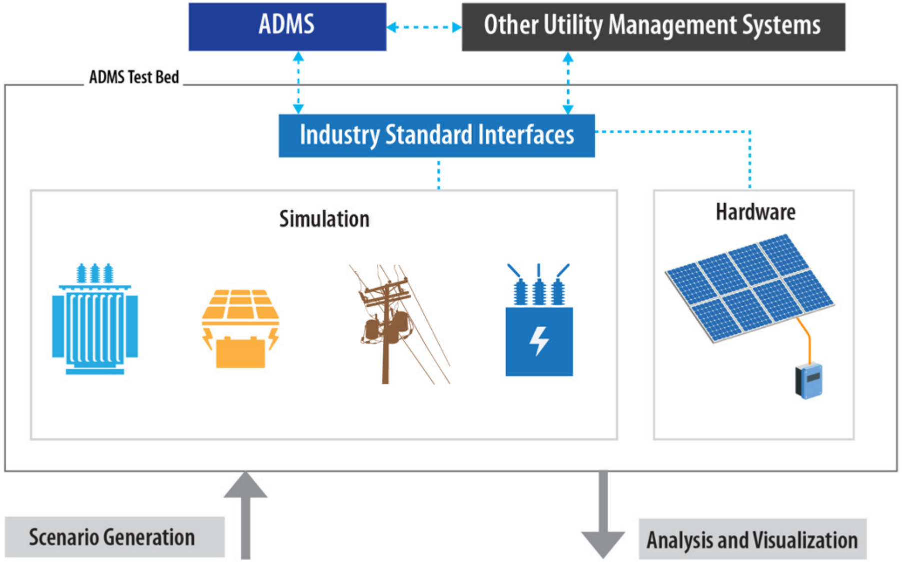
ADMS Test Bed

Goal: Accelerate industry adoption of ADMS to:

- Improve normal operations with high levels of distributed energy resources (DERs).
- Improve resilience and reliability.

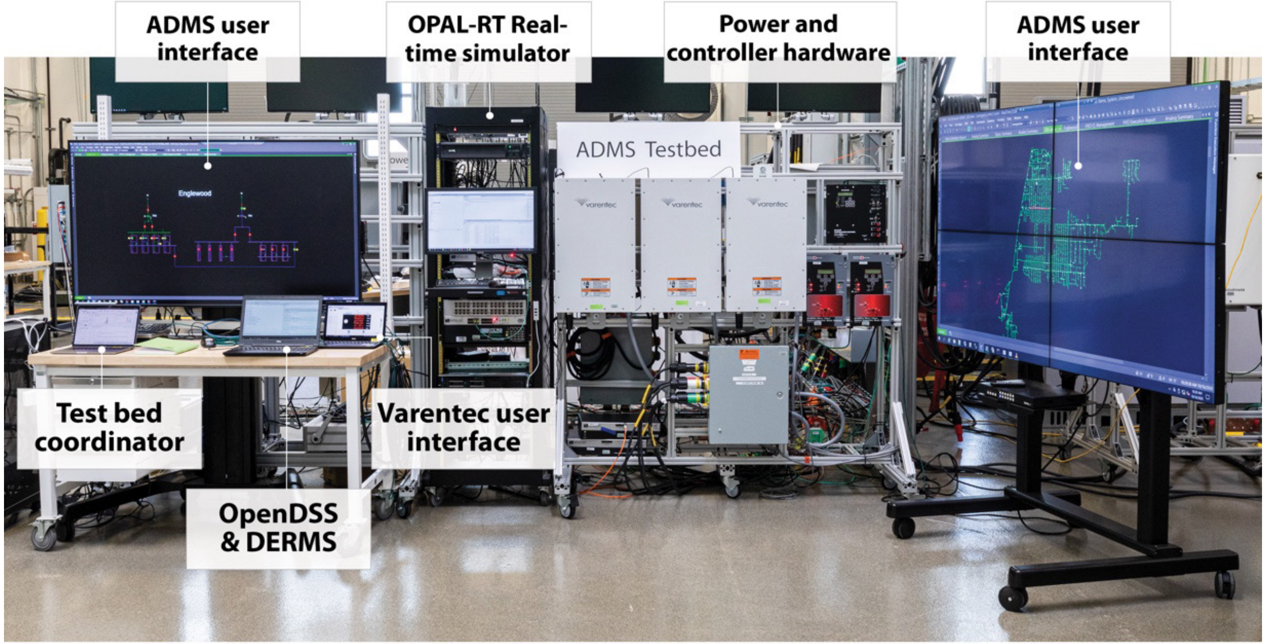
Approach: Partner with utilities and vendors to evaluate specific use cases and applications to:

- Set up a realistic laboratory environment.
- Simulate real distribution systems.
- Integrate distribution system hardware.
- Use industry-standard communications.
- Create advanced visualization capability.



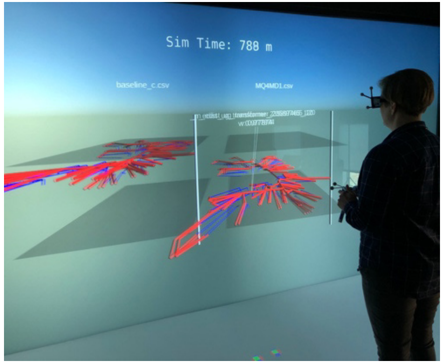
https://www.nrel.gov/grid/advanced-distribution-management.html

ADMS Test Bed



Photos by NREL

2D real-time visualization



3D visualization

ADMS Test Bed Use Cases

- Peak load management with ADMS and DERMS
  - Holy Cross Energy/Survalent
- ADMS network model quality impact on VVO
  - Xcel Energy/Schneider Electric
- AMI-based, data-centric grid operations
  - SDG&E + GridAPPS-D
- **FLISR in the presence of DERs**
  - **Central Georgia EMC/Survalent → August 2022**
- Federated DERMS for high PV system
  - Southern Company/Oracle + GridAPPS-D → February 2023
- DER controls strategies for T&D grid services
  - Xcel Energy + GridAPPS-D → September 2022
- Modeling and co-optimizing grid operations and facility operations with interoperable ADMS, VPP, microgrids, and grid-edge DERs
  - Shell + Spirae → October 2023
- Integration of advance grid monitoring and analytics with ADMS FLISR application
  - IEC + EGM → December 2023

ADMS test bed capabilities used by:

- Non-wires alternatives
- ECO-IDEA
- GO-SOLAR
- SolarExpert
- FAST-DERMS
  - SDG&E, Oracle, EPRI + GridAPPS-D → April 2023
- Resilient Operation of Networked Microgrids (RONM)
  - SDG&E, Cobb EMC → Nov 2022
- REORG
  - Holy Cross Energy, Minsait ACS → Mar 2024
- PV Integration using a Virtual Airgap (PIVA)
  GridBright, SDG&E → Sep 2023

FLISR in the Presence of DERs

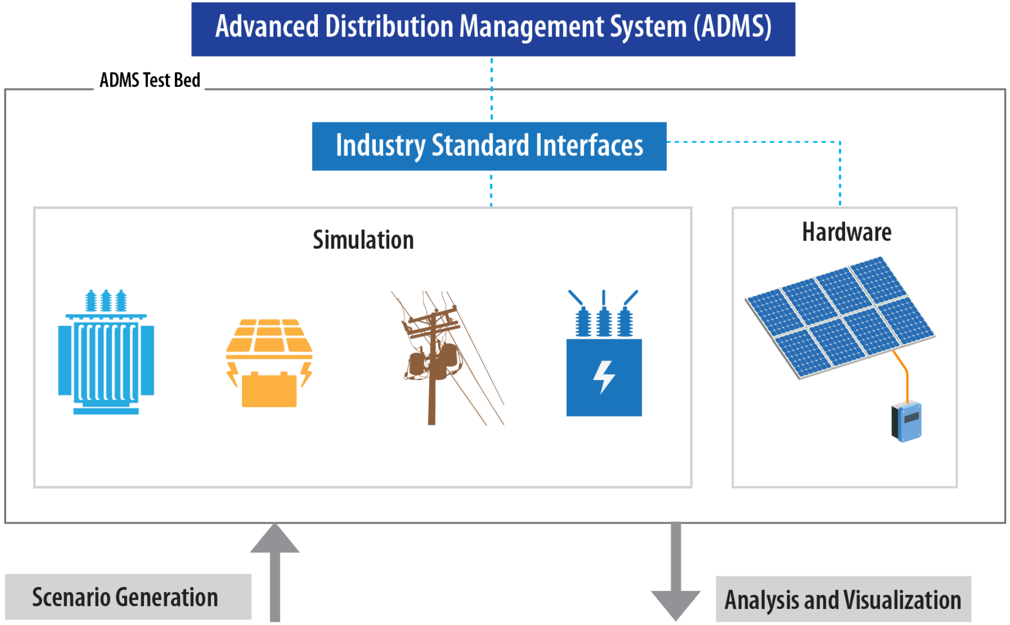
Objective: Evaluate the performance of a commercially available ADMS fault location, isolation, and service restoration (FLISR) application in the presence of DERs.

Partners:

– Utility: Central Georgia EMC
– ADMS: Survalent.

Evaluate the impact of:

– DER locations
– Fault locations
– DER trip settings.



Central Georgia EMC Overview

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Central Georgia EMC
A Touchstone Energy® Cooperative

- 59,000 customers
- 5,100 miles of lines
- 20 substations, 73 feeders, 32,206 dist. transformers
- Peak load: 316 MW

Mission:

Central Georgia EMC's purpose is to provide customer-owners the most reliable electric service at the lowest practicable cost.

Survalent Overview

Survalent.

Survalent provides advanced distribution management systems to electric, renewable energy, water/wastewater, oil & gas, and transit utilities across the globe. The SurvalentONE ADMS platform is a fully integrated supervisory control and data acquisition (SCADA), outage management system (OMS), and distribution management system (DMS) solution that runs on a single, easy-to-use graphical interface. The solutions are designed for the needs of utilities, making them easy to deploy, manage, scale, and use. Built from the ground up on a platform that is scalable, secure, and open, SurvalentONE ADMS efficiently integrates, manages, and processes data from a broad array of sources.

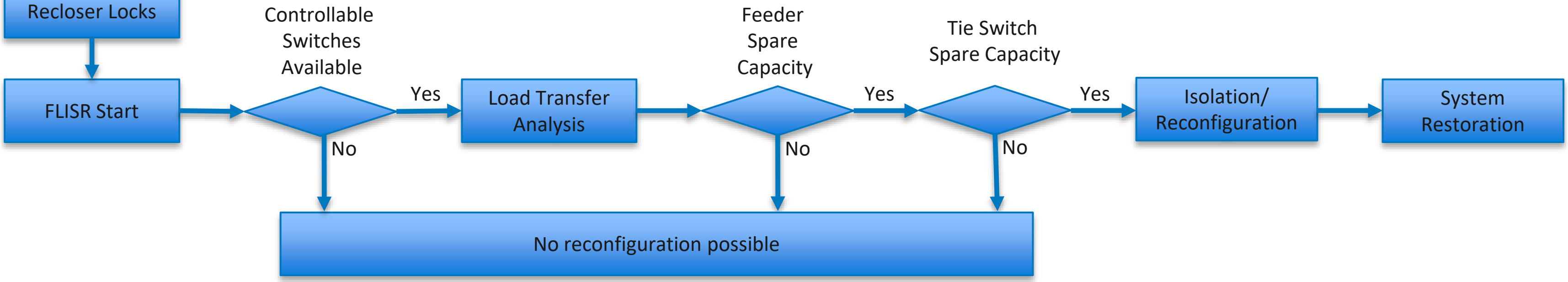
Fault Location, Isolation, and System Restoration

- FLISR is an advanced application that assists distribution electric utility operators during a fault or disturbance to:
  - Automatically locate the impacted area.
  - Isolate the portion of the feeder by operating upstream and downstream controllable switches to reduce the number of affected customers.
  - Transfer portion(s) of the feeder load to adjacent feeders that have the capacity to support the load and reestablish service to a portion of the affected customers in a matter of seconds.

Photo by NREL

Photo by NREL

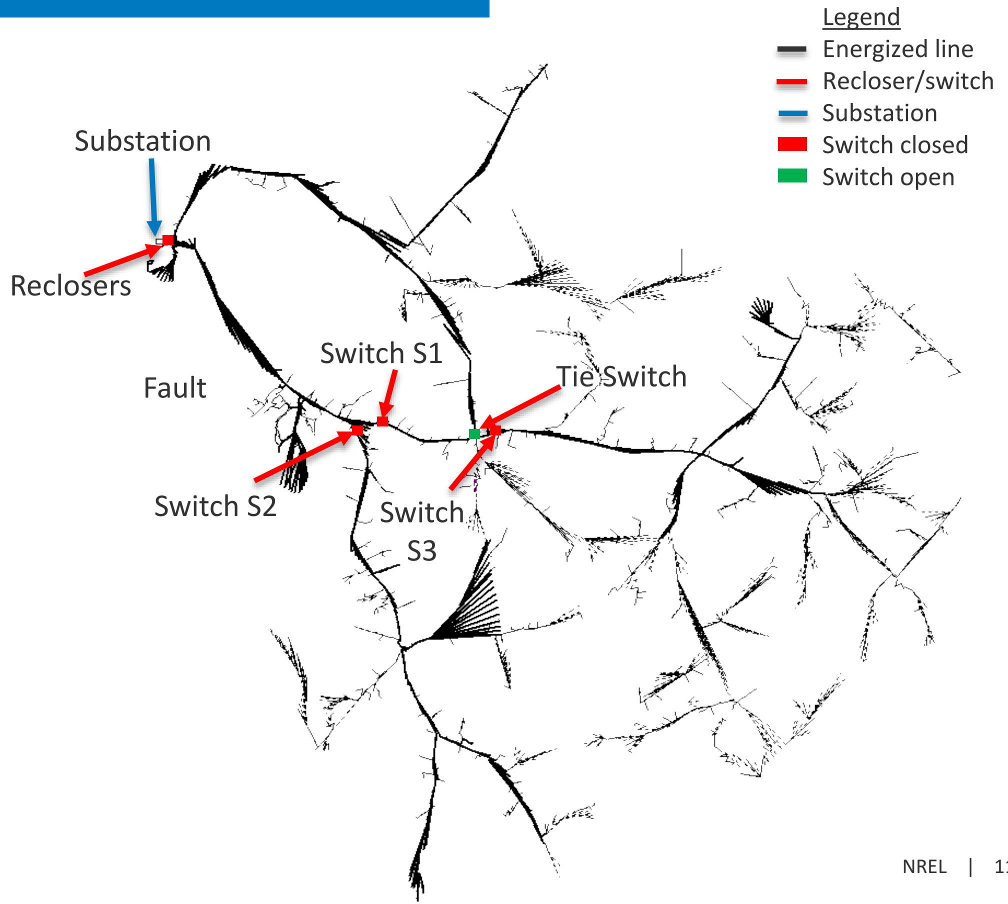
FLISR Flowchart



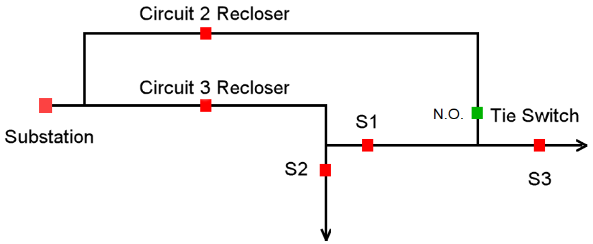
Simplified, not showing all possible iterations

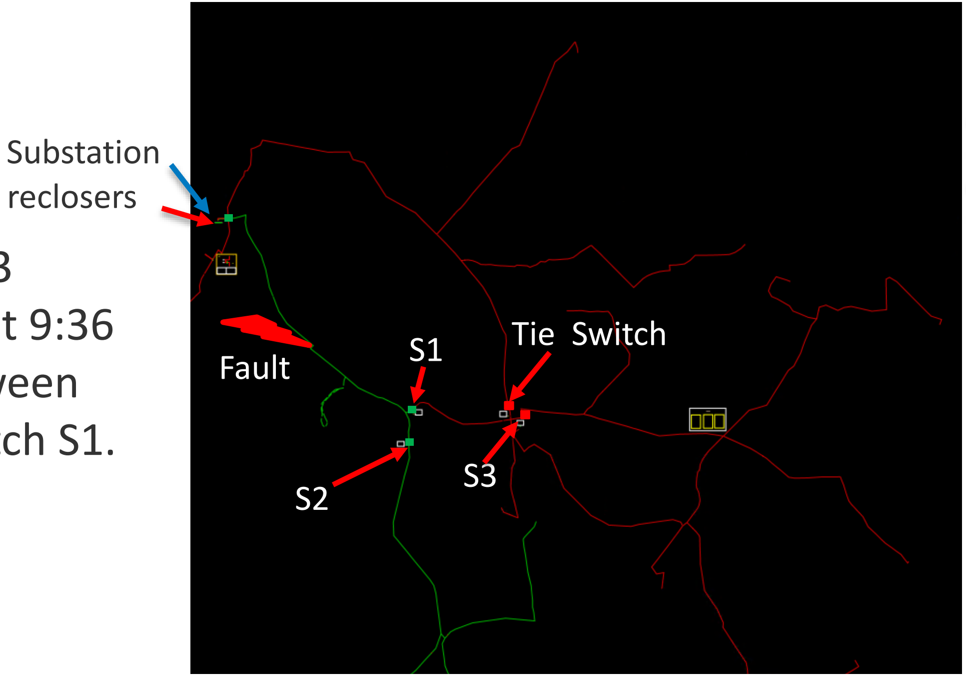
Use Case Overview

- Rural feeders with tie switch
- Central Georgia EMC is evaluating battery energy storage systems (BESS)
  - For improved resilience:
    - Grid-forming (GFM).
  - Two potential locations.
- Substation details:
  - 9.2 MW total active power
  - 1,018 loads:
    - 10% small commercial.
  - 4,045 nodes
  - 2,760 lines
  - ADMS controllable devices:
    - Substation reclosers
    - Tie switch
    - Switch S1
    - Switch S2
    - Switch S3.



Historical FLISR Evaluation





Legend

- De-energized line
- Energized line
- Recloser/switch
- Substation
- Switch closed
- Switch open

	KVA	KW	KVAR
CKT 2	688	687	28
CKT 3	5473	5429	646
CKT 4	2028	2028	20
TOTAL	8188	8143	694
SYSTEM	123935	120998	-10943

Feeder head measurement before the fault

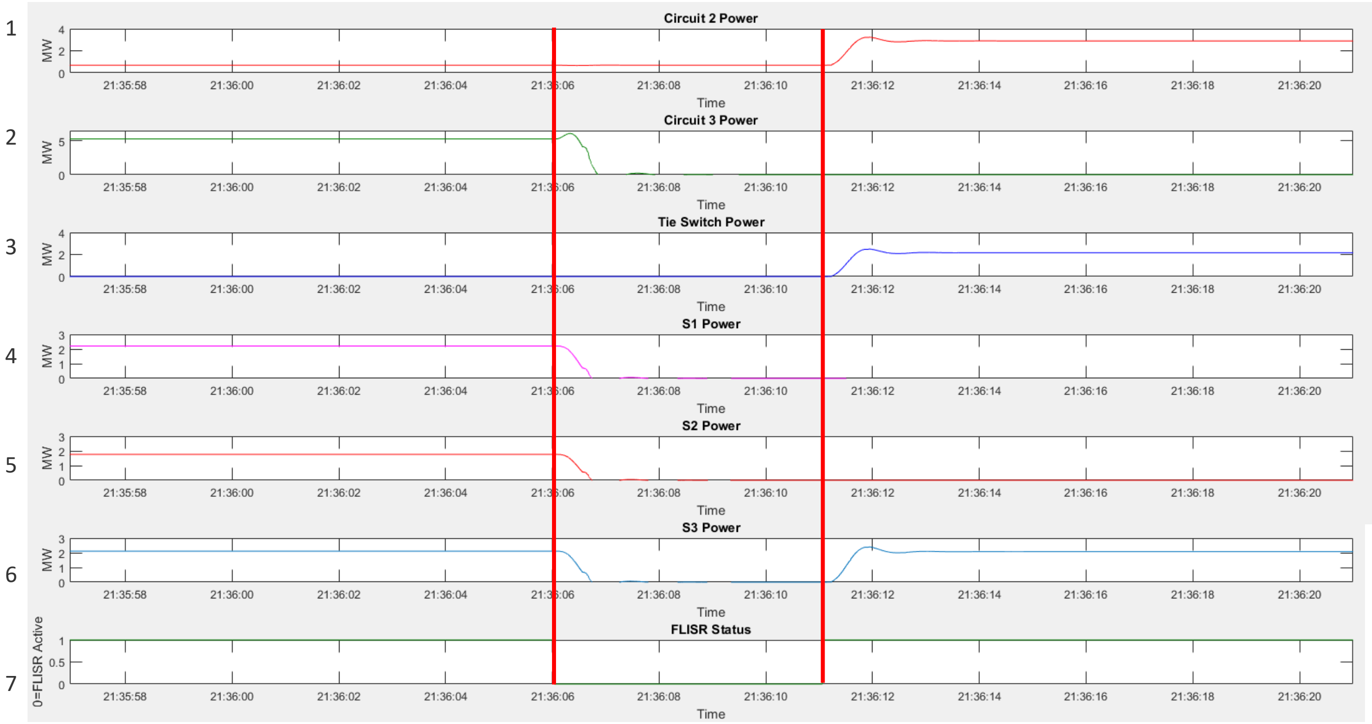
A three-phase fault in Circuit 3 occurred on August 9, 2020, at 9:36 p.m. near the substation between the Circuit 3 recloser and Switch S1.

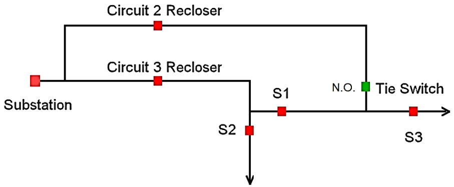
FLISR switching instructions:

- Open Circuit 3 recloser.
- Open Switch S1 and Switch S2.
- Close the tie switch (reenergizes part of the feeder).

S1 and S2 are left open for the operator to manually close after necessary repairs.

Baseline Power Measurements (No BESS)





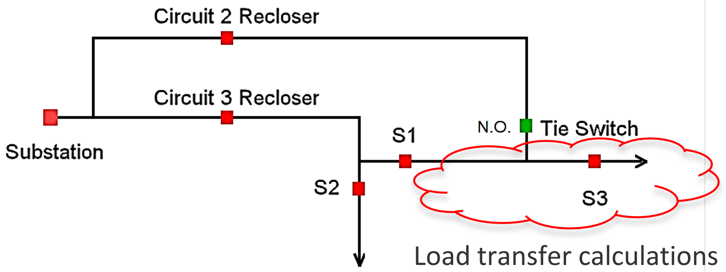
t=21:36:06: Fault occurs, de-energizing Circuit 3

t=21:36:11: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3

Baseline Load Transfer Operation

- Table 1 shows the ADMS FLISR snapshot load transfer analysis portion behind Switch S1.
  - Based on calculated kVA scaled by feeder injection and measured values.

Table 1. Load Transfer Calculations		
	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	725.88	kVA
Circuit 2 spare capacity	12,774.12	kVA
Load behind Switch S1	2,253.23	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA



Load transfer calculations section

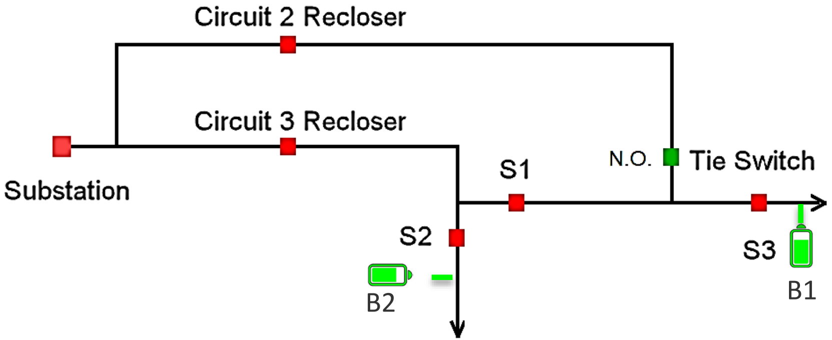
Table 2. Load Transfer Simulation Measurements		
	Total	Units
Circuit 2 measured power before the fault	0.685	MW
Circuit 2 measured power after the fault	2.896	MW
Circuit 3 measured power before the fault	5.272	MW
Tie switch measured power after the fault	2.168	MW

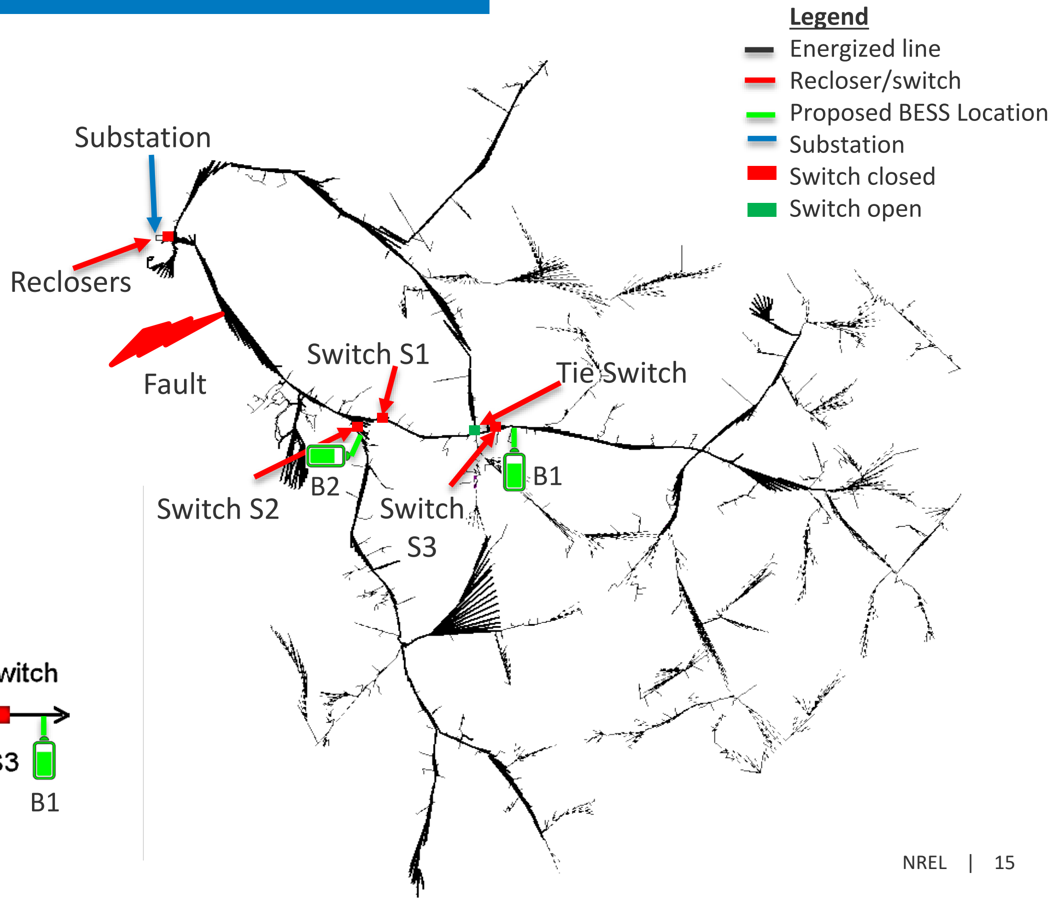
- Table 2 shows the simulation load transfer measurements.

Evaluation Points

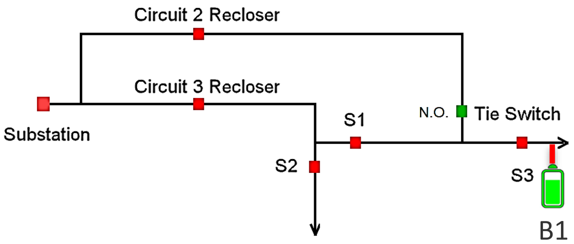
Consider two BESS locations:

- Impact on feeders downstream of BESS
- Impact on load transfer (backup feeder and tie switch)
- FLISR opportunities.





BESS Partial Load Support—First Location

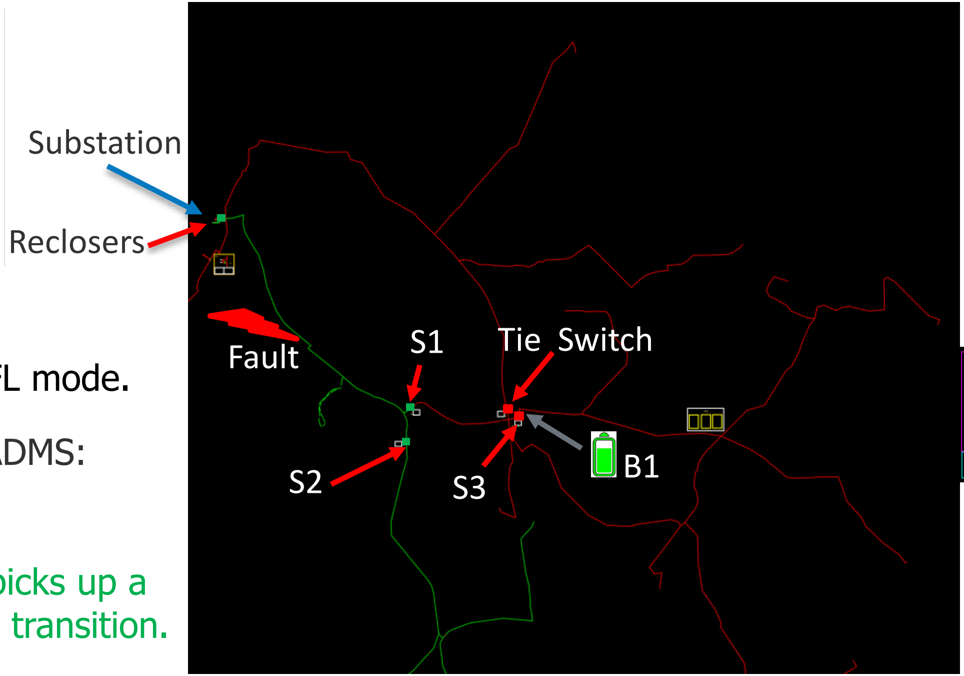


B1 information:

- 3.0-MVA system
- Injecting 25% (~750 kW) in GFL mode.

FLISR switching instructions from the ADMS:

- Open Circuit 3 recloser.
- Open Switch S1 and Switch S2.
- B1 changes mode to GFM and picks up a portion of the feeder during the transition.
- Close tie switch.
- B1 changes to GFL mode.



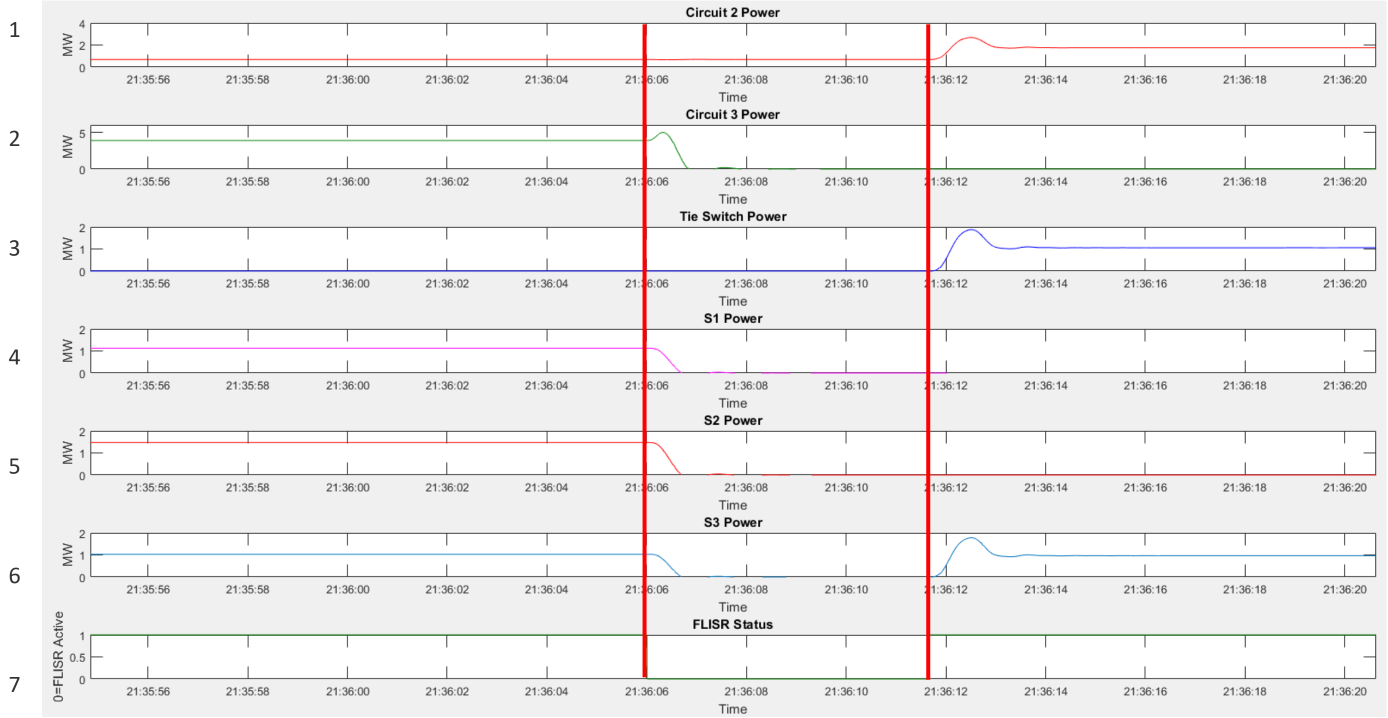
Legend
- De-energized line
- Energized line
- Recloser/switch
- Substation
- Switch closed
- Switch open
- Proposed BESS location

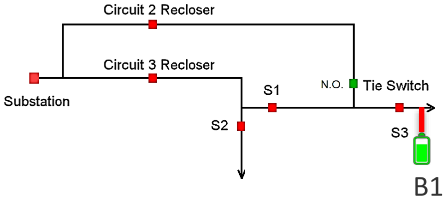
	KVA	KW	KVAR
CKT 2	688	687	28
CKT 3	4811	4765	647
CKT 4	2028	2028	20
TOTAL	7527	7479	695
SYSTEM	123273	120334	-10941

Feeder head measurement before the fault

Impact: Avoids loss of power downstream of Switch S3 by enabling the BESS to operate automatically by changing the mode to GFM and picking up the load during the transition and then reconnecting S3 when the tie is closed after ~5 seconds.

Power Measurements With B1 (GFM BESS)



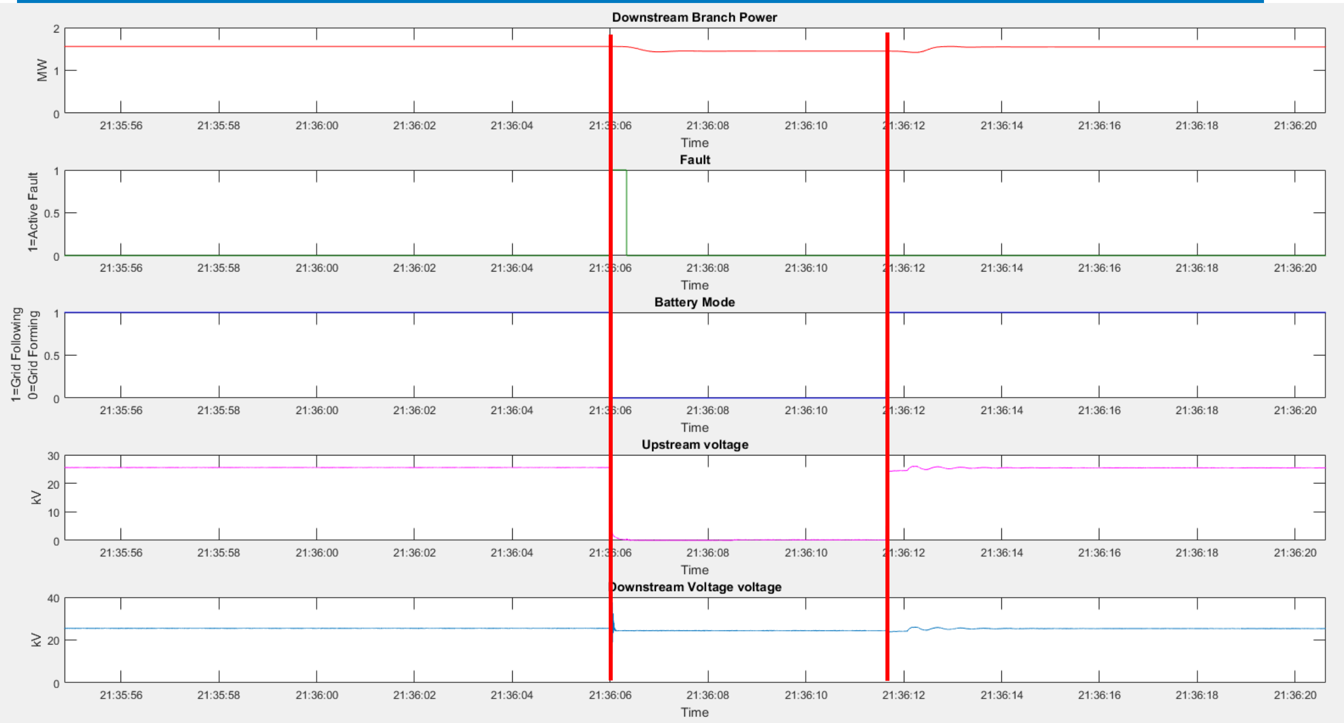


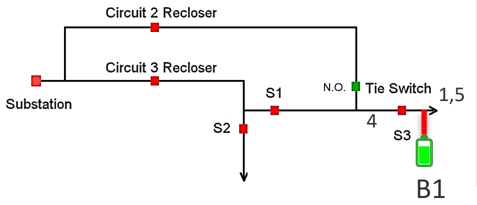
t=21:36:06: Fault occurs, de-energizing Circuit 3

t=21:36:11.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3

Single BESS Measurements

1 2 3 4 5





t=21:36:06: Fault occurs, de-energizing Circuit 3; BESS 1 switches to GFM mode to pick up load during the transition

t=21:36:11.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; BESS changes back to GFL mode

Load Transfer Operation With B1

- Table 3 shows the ADMS FLISR snapshot load transfer analysis in the presence of a single BESS for partial load support.
- Table 4 shows the simulation load transfer measurements.
- B1 operation assists by:
  - Reducing the load transfer compared to the baseline by ~1 MW
  - Avoiding the cold-start load pick-up of Circuit 2.

Table 3. Load Transfer Calculations

	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	708.34	kVA
Circuit 2 spare capacity	12,791.66	kVA
Load behind Switch S1	1,174.79	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA

Table 4. Load Transfer Simulation Measurements

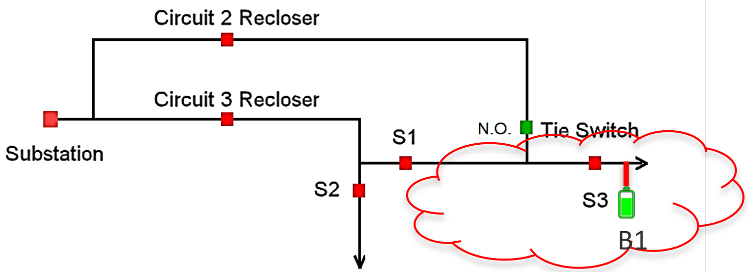
	Total	Units
Circuit 2 measured power before the fault	0.685	MW
Circuit 2 measured power after the fault	1.752	MW
Circuit 3 measured power before the fault	3.884	MW
Tie switch measured power after the fault	1.056	MW

FLISR Opportunities

- What if the feeder capacity or the tie switch capacity were reduced to less than the transfer load of ~2.2 MW?
  - No restoration is possible.
- What if FLISR could dispatch the DERs to reduce the transfer load?
  - Provides a pathway to restoration.

Table 1. Load Transfer Calculations

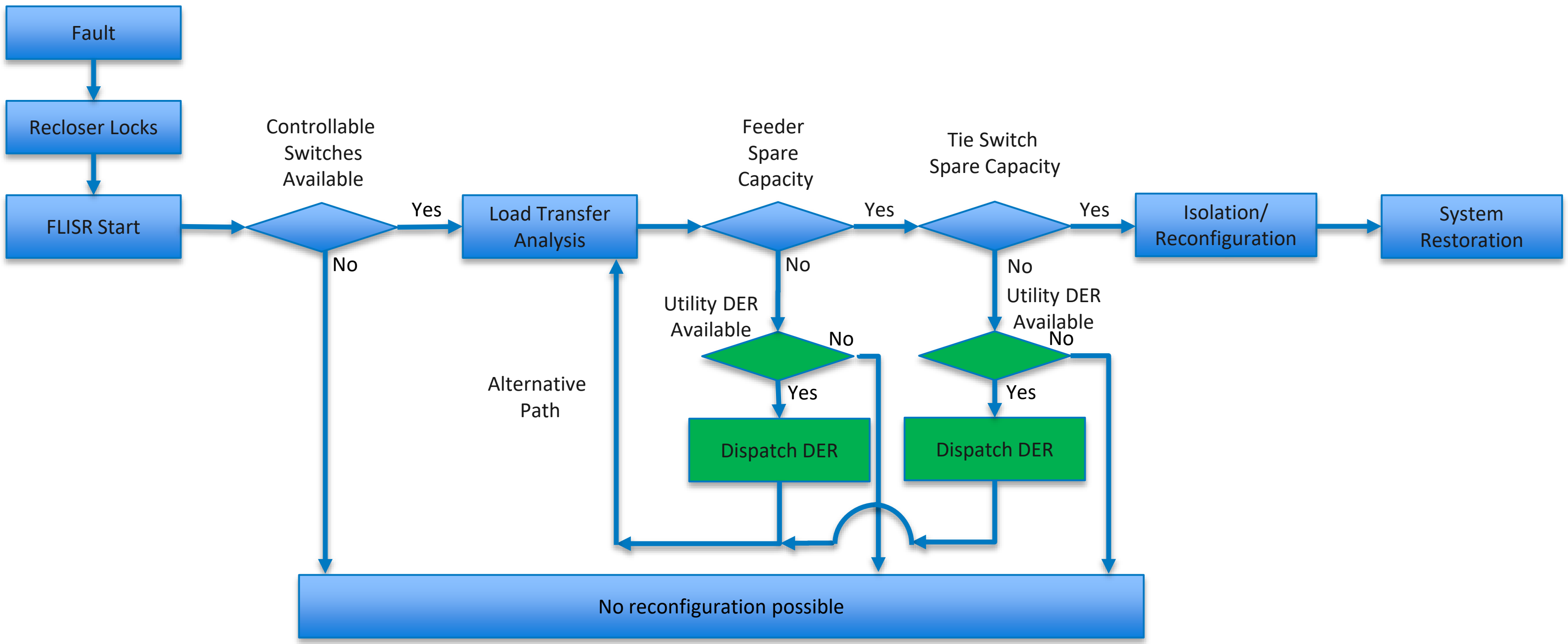
	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	725.88	kVA
Circuit 2 spare capacity	12,774.12	kVA
Load behind S1	2,253.23	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA



Load transfer calculations section

FLISR Flowchart With DER Dispatch

- What if FLISR could dispatch DERs?



Simplified, not showing all possible iterations

Load Transfer Operation With B1 Opportunity

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- Example: Reduce load transfer by increasing the B1 output to 50% (1.5 MW) before closing the tie switch.

Table 5. Load Transfer Calculations

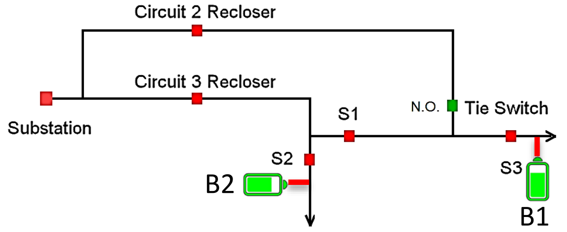
	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	710.03	kVA
Circuit 2 spare capacity	12,789.97	kVA
Load behind Switch S1	341.92	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA
BESS 50% discharge transfer load reduction (vs. baseline)	1,911.31	KVA
BESS at 25% discharge transfer load reduction (vs. baseline)	1,078.44	KVA

Table 6. Load Transfer Simulation Measurements

	Total	Units
Baseline load transfer	2.168	MW
25% BESS discharge	1.056	MW
50% BESS discharge	0.237	MW

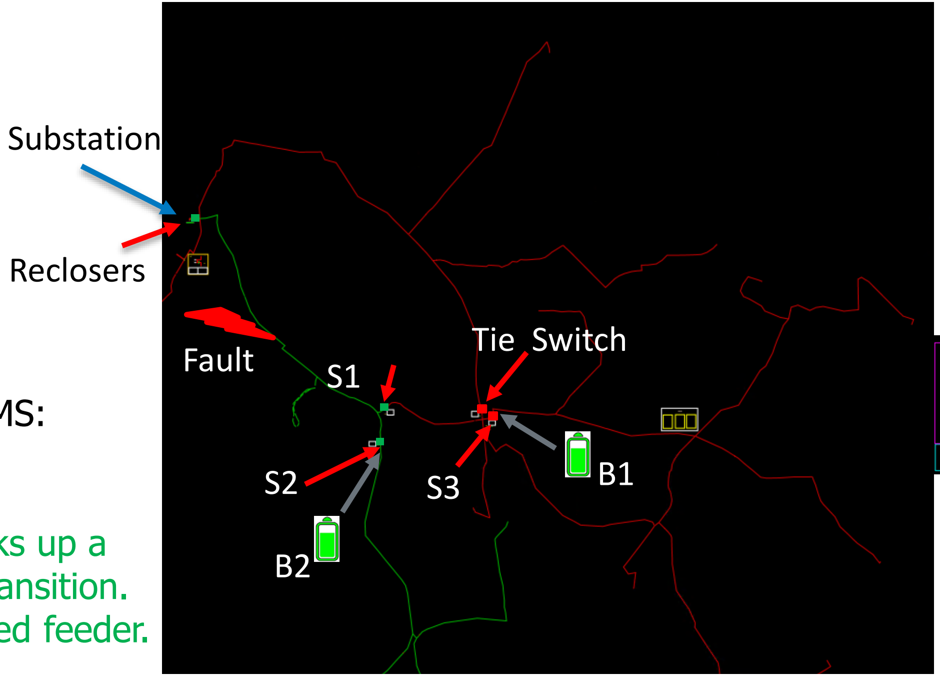
- B1 operating at 50% discharge assists by reducing the load transfer compared to the baseline by ~2 MW and lightening the demand of Circuit 2.

Two BESS Partial Load Support



BESS information:
- Two 3.0-MVA systems
- Injecting 25% (1.5 MW for both).

FLISR switching instructions from the ADMS:
- Open Circuit 3 recloser.
- Open Switch S1 and Switch S2.
- B1 changes mode to GFM and picks up a portion of the feeder during the transition.
- B2 picks up a portion of the isolated feeder.
- Close tie switch.
- B1 changes to GFL mode.
- B2 remains in GFM mode.



	KVA	KW	KVAR
CKT 2	688	687	28
CKT 3	3912	3886	646
CKT 4	2028	2028	20
TOTAL	6628	6600	695
SYSTEM	122374	119455	-10942

Feeder head measurement before the fault

Impact: Avoids loss of power downstream of S2 by enabling the BESS to operate automatically by changing the mode to GFM and picking up the load for the duration of the repairs.

Power Measurements With B1 & B2 (GFM BESS)

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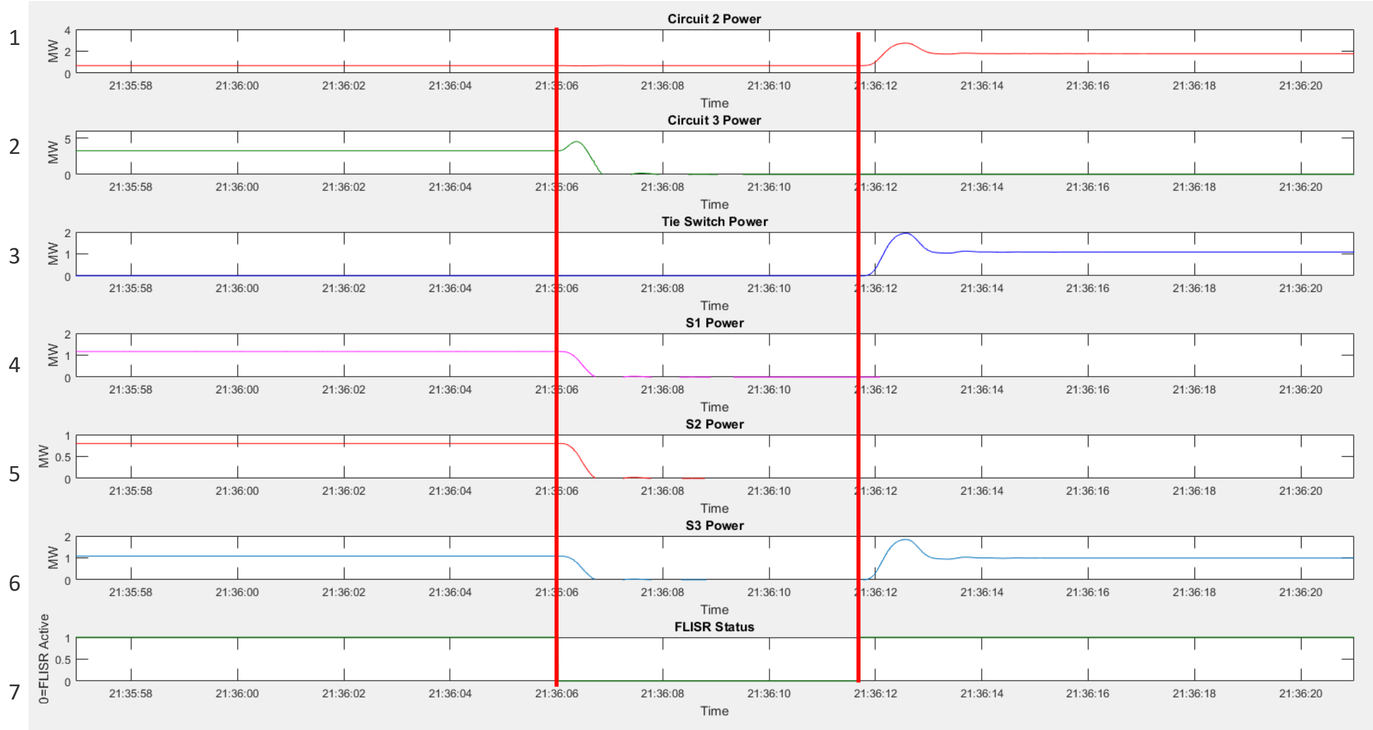
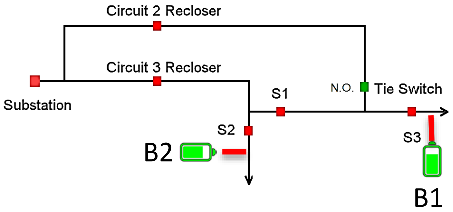
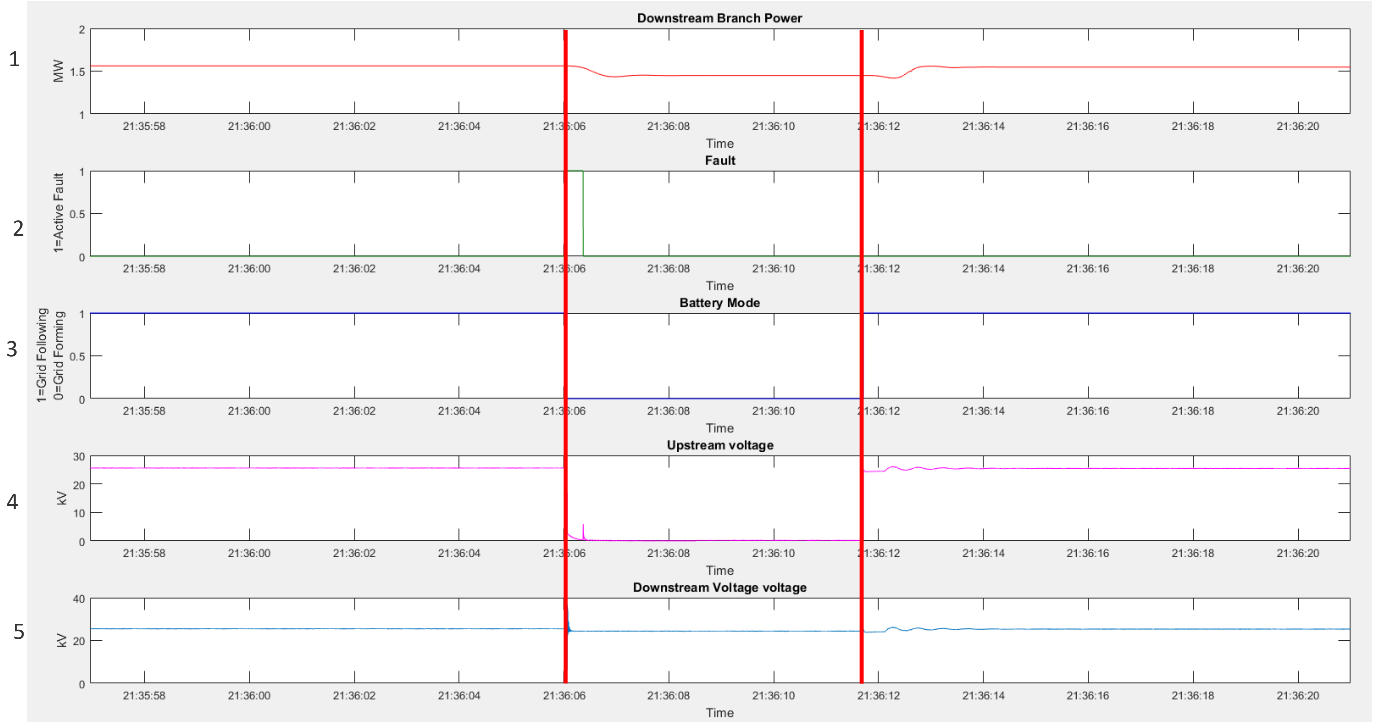


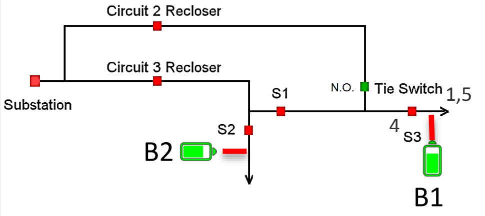


t=21:36:06: Fault occurs, de-energizing Circuit 3; both BESS switch to GFM mode to pick up load during the transition

t=21:36:11.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; BESS 1 switches to GFL

B1 Measurements





t=21:36:06: Fault occurs, de-energizing Circuit 3; B1 switches to GFM mode to pick up load during the transition

t=21:36:10.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; B1 switches to GFL mode

B2 Measurements

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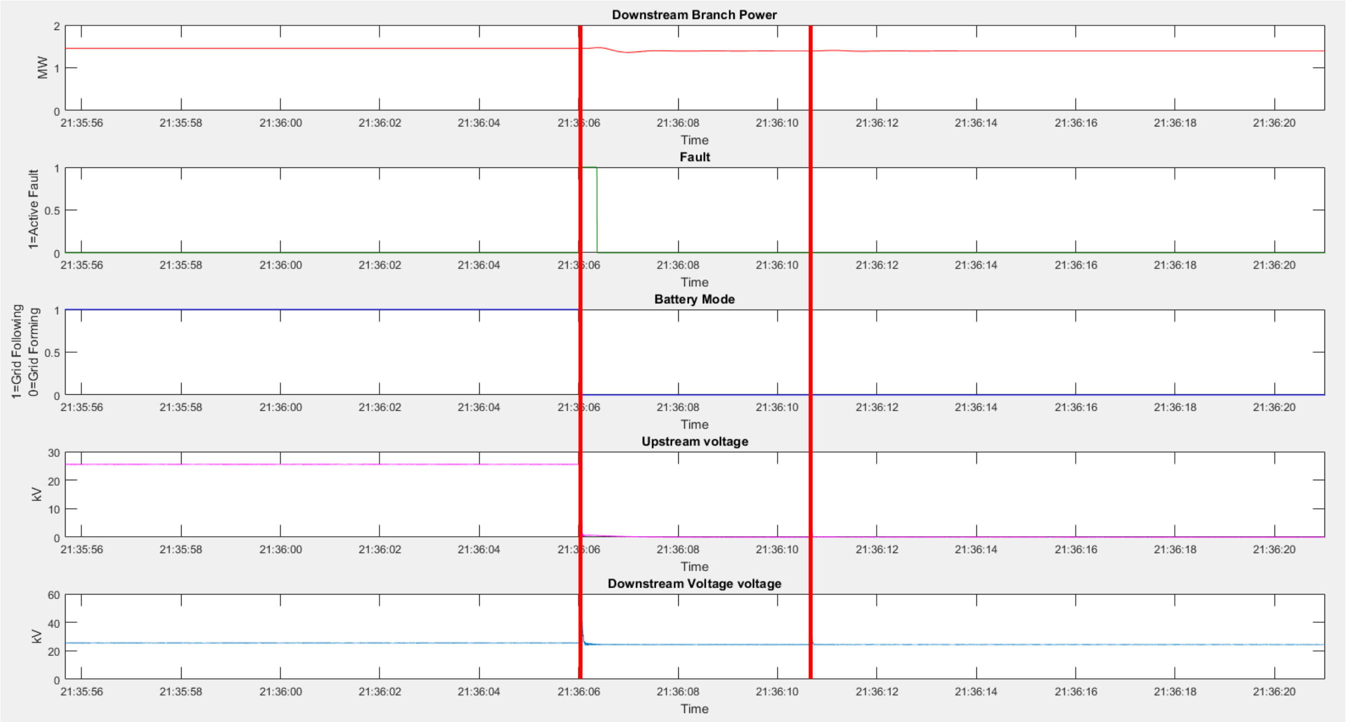
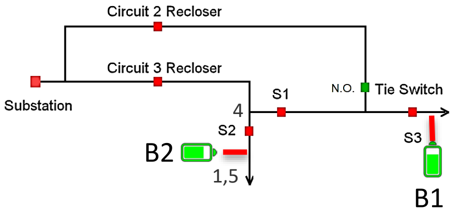
1
2
3
4
5





t=21:36:06: Fault occurs, de-energizing Circuit 3; B2 switches to GFM mode to pick up load during the extended transition

t=21:36:11.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; B2 stays in GFM mode, supporting a portion of the feeder

Load Transfer Operation With Two BESS

- Table 9 indicates the ADMS FLISR snapshot load transfer analysis in the presence of two BESS for partial load support.
- Table 10 shows the simulation load transfer measurements.
- The load transfer operation calculation impact is similar to the previous measurements of B1 because B2 is outside the load transfer calculations after Switch S1.

Table 9. Load Transfer Calculations

	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	710.03	kVA
Circuit 2 spare capacity	12,789.97	kVA
Load behind Switch S1	341.92	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA

Table 10. Load Transfer Simulation Measurements

	Total	Units
Circuit 2 measured power before the fault	0.685	MW
Circuit 2 measured power after the fault	1.779	MW
Circuit 3 measured power before the fault	3.250	MW
Tie switch measured power after the fault	1.080	MW

Conclusion

- The use case evaluated the performance of a FLISR application in a distribution feeder with GFM DERs and how FLISR could use these DERs to reduce the number of impacted customers.

- Results of this use case provide the electric utility industry with insights into DER capabilities to improve system resilience and potential improvements to FLISR applications.

Future Work

- Evaluate the FLISR algorithm performance with photovoltaics during high load conditions on a clear sunny day.

- Evaluate the impact to the restoration portion of the FLISR algorithm due to the hidden load in the case where the DERs trip after a grid disturbance.

Upcoming Events

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ADMS Test Bed Workshop

- Planned for in person at NREL, Golden, CO, Nov. 7–8, 2022

Survalent User Conference

- Atlanta, GA, Oct 19–20

Survalent.
UC | 22
2022 Global User Conference

Acknowledgements

- We would like to acknowledge Annabelle Pratt, Kumaraguru Prabakar, Soumya Tiwari, Jiyu Wang, Harsha Padullaparti, Murali Baggu, Fei Ding, and Priti Paudyal from NREL for their support and guidance.

- We would also want to express our gratitude for their assistance to Christopher Irwin from DOE, Herschel Arant from Central Georgia EMC, Young Ngo, Jose Castillo, Daniel Nechay, and Ken Dolbel from Survalent for their ongoing collaboration in the advancement of the ADMS Test Bed capabilities.

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Electricity, Advanced Grid Research & Development. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

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NREL/PR-5D00-83813

For Further Reading

- H. Padullaparti, A. Pratt, I. Mendoza, S. Tiwari, M. Baggu, C. Bilby, and Y. Ngo, "Peak Load Management in Distribution Systems Using Legacy Utility Equipment and Distributed Energy Resources," IEEE GreenTech, 2021.
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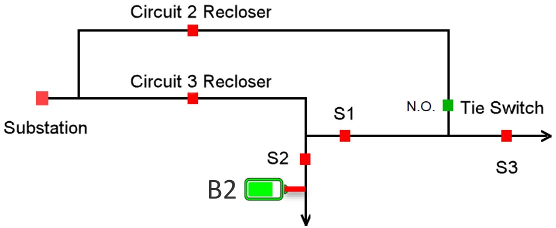
Backup slides

BESS Partial Load Support—Second Location

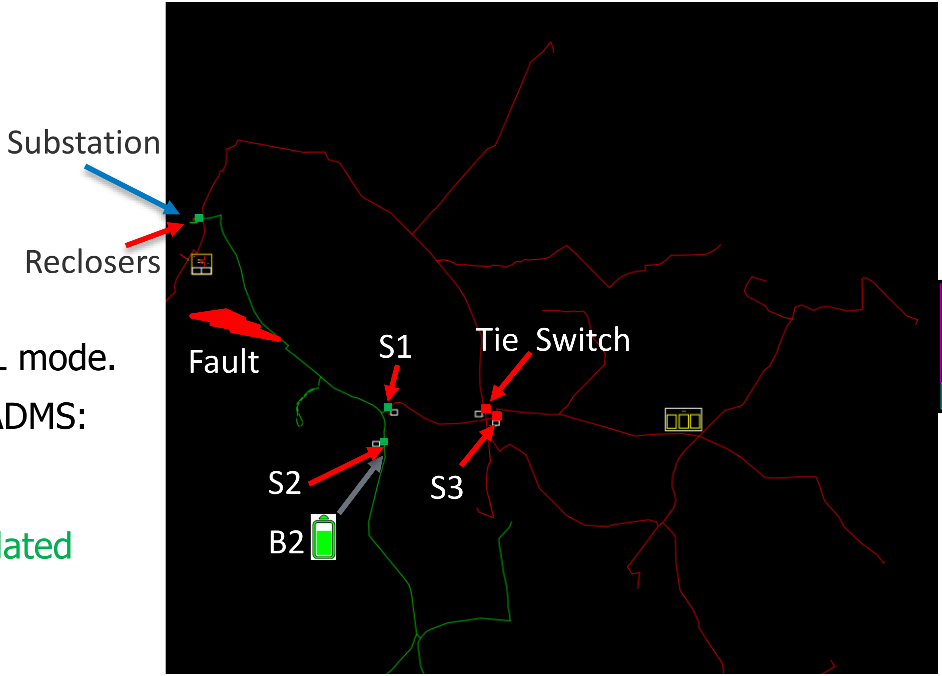


B2 information:

- 3.0-MVA system
- Injecting 25% (750 kW) in GFL mode.

FLISR switching instructions from the ADMS:

- Open Circuit 3 recloser.
- Open Switch S1 and Switch S2.
- B2 picks up a portion of the isolated feeder
- Close tie switch.



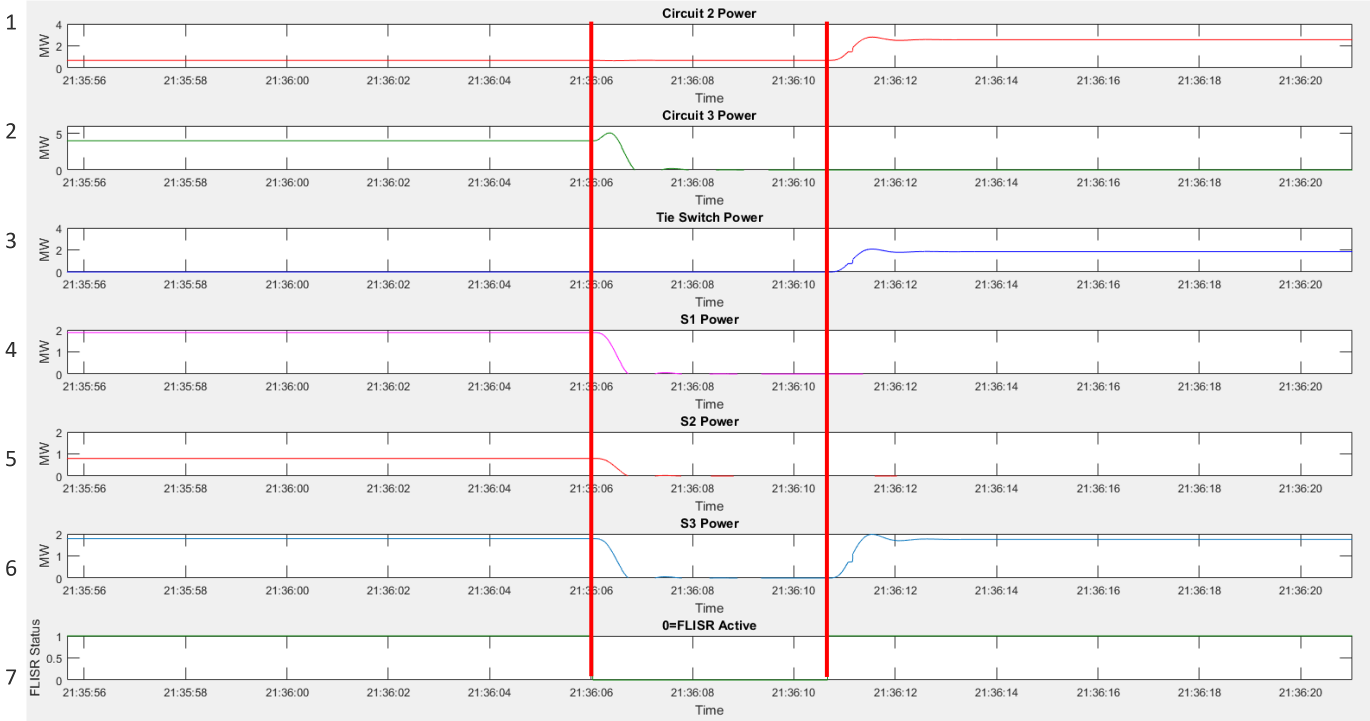
Legend
- De-energized line
- Energized line
- Recloser/switch
- Substation
- Switch closed
- Switch open
- Proposed BESS location

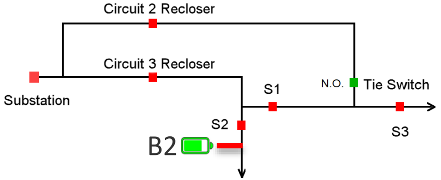
	KVA	KW	KVAR
CKT 2	691	690	28
CKT 3	4784	4735	657
CKT 4	2028	2028	20
TOTAL	7504	7453	705
SYSTEM	123250	120308	-10931

Measurement before the fault

Impact: Avoids loss of power downstream of S2 by enabling the BESS to automatically change to GFM and picking up the load for the duration of the repairs (approximately 5–90 minutes).

Power Measurements With B2 (GFM BESS)

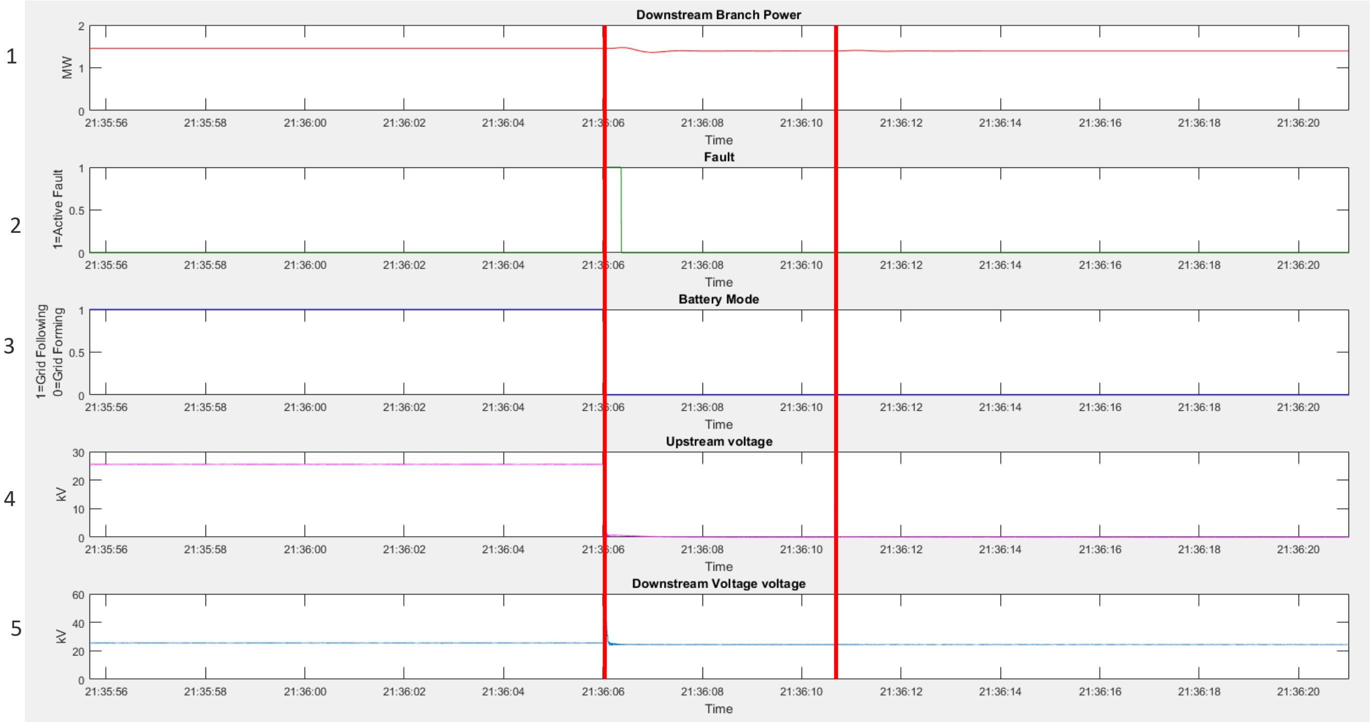


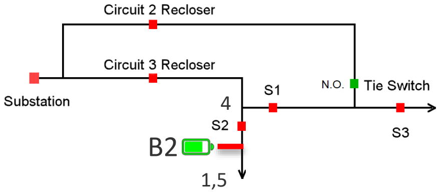


t=21:36:06: Fault occurs, de-energizing Circuit 3

t=21:36:10.6: ADMS issues the tie switch to close, reenergizing portion of Circuit 3

B2 Measurements





t=21:36:06: Fault occurs, de-energizing Circuit 3; BESS 2 switches to GFM mode to pick up load during the extended transition

t=21:36:10.6: ADMS issues the tie switch to close, reenergizing a portion of Circuit 3; B2 continues to support a portion of the feeder

Load Transfer Operation With B2

Table 7 indicates the ADMS FLISR snapshot load transfer analysis in the presence of B2 downstream of Switch S2 for extended partial load support.

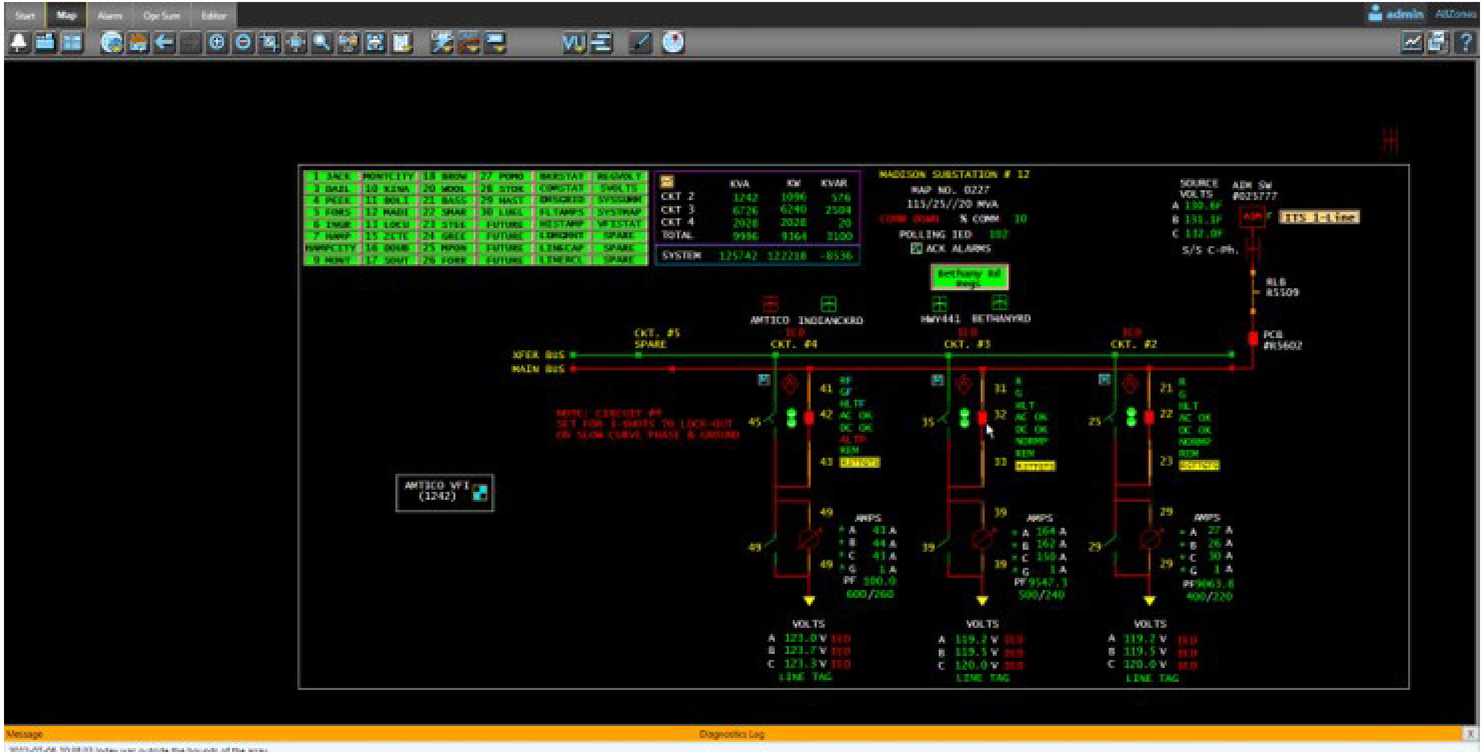
Table 7. Load Transfer Calculations		
	Total	Units
Circuit 2 total capacity	13,500	kVA
Circuit 2 current load	721.96	kVA
Circuit 2 spare capacity	12,778.04	kVA
Load behind Switch S1	1,353.62	kVA
Tie switch capacity	600	AMPS
Tie switch capacity	9,000	kVA

Table 8. Load Transfer Simulation Measurements		
	Total	Units
Circuit 2 measured power before the fault	0.685	MW
Circuit 2 measured power after the fault	2.558	MW
Circuit 3 measured power before the fault	3.964	MW
Tie Switch measured power after the fault	1.842	MW

Table 8 shows the simulation load transfer measurements.

The battery operation impact is minimal because B2 is in a isolated portion of the feeder upstream of Switch S1.

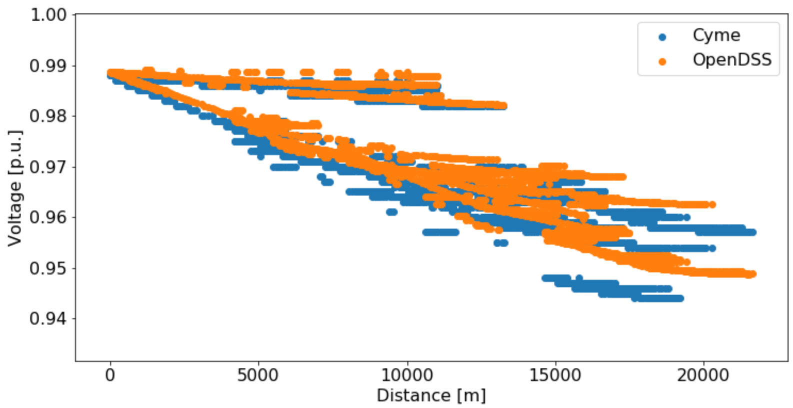
FLISR Video


MADISON SUBSTATION # 12
XFER BUS
MAIN BUS
CKT. #5
SPARE
CKT. #4
CKT. #3
CKT. #2
AMTICO
HWY441
AMTICO VFI
(1242)
AMPS
VOLTS
LINE TAG
Message
Diagnostics Log

Model Validation

- Model was exported from Windmill to OpenDSS, required some cleanup.
- Model was converted from EPRI's OpenDSS to Eaton's CYME.
  - Maximum voltage mismatch 1.2%
  - Better correlation could be achieved if CYME line code parameters are fine-tuned.

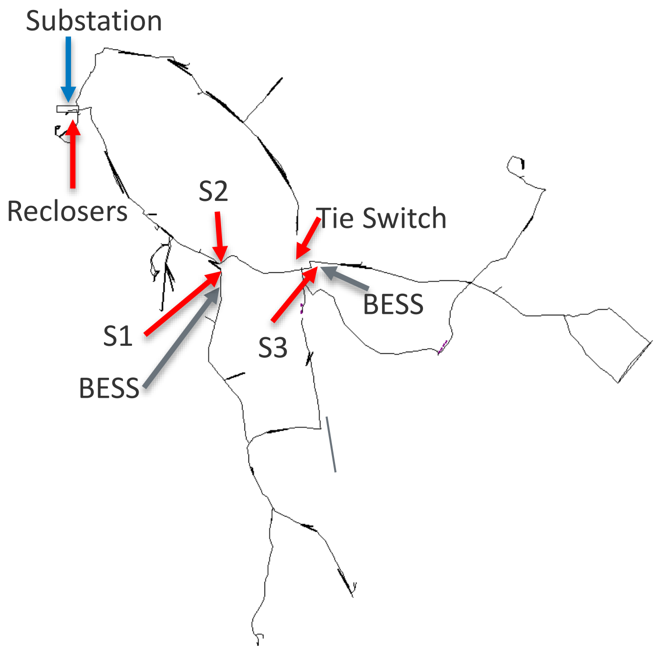
	Total KW at Feeder Head	Total KVAR at Feeder Head
OpenDSS	9231	4923
CYME	9214	4912
Mismatch	0.18%	0.23%



Voltage comparison at all lines (validated)

Model Reduction

- Leverage CYME's model reduction tool:
  - Keep lines/cables greater than 500 m.
  - Keep loads greater than 120 kW.
- 9.2 MW total active power
- 29 loads
- 200 nodes
- 171 lines.



Model Reduction Validation

- Total power generation and only lines kept in the reduced CYME model are compared.
- Maximum voltage mismatch is below 0.25%.

	Total KW at Feeder Head	Total KVAR at Feeder Head
OpenDSS	9231	4923
Reduced CYME	9200	4746
Mismatch	0.3%	3.6%