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Analytics for utility-operated lithium ion energy storage

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Disclaimer

- Work was performed while working at Ergon Energy
- Not related to current employment
- Work performed during 2015/16, during commissioning and rollout
- Monitoring and analytics work has since evolved

Acknowledgments

- Ergon Energy for permission to use photographs and graphs
- Former colleagues/managers
  - Steve Richardson
  - Michelle Taylor
  - Jason Hall
- Spatial data
  - qldspatial.qld.gov.au
  - Ergon Energy
  - Geoscience Australia

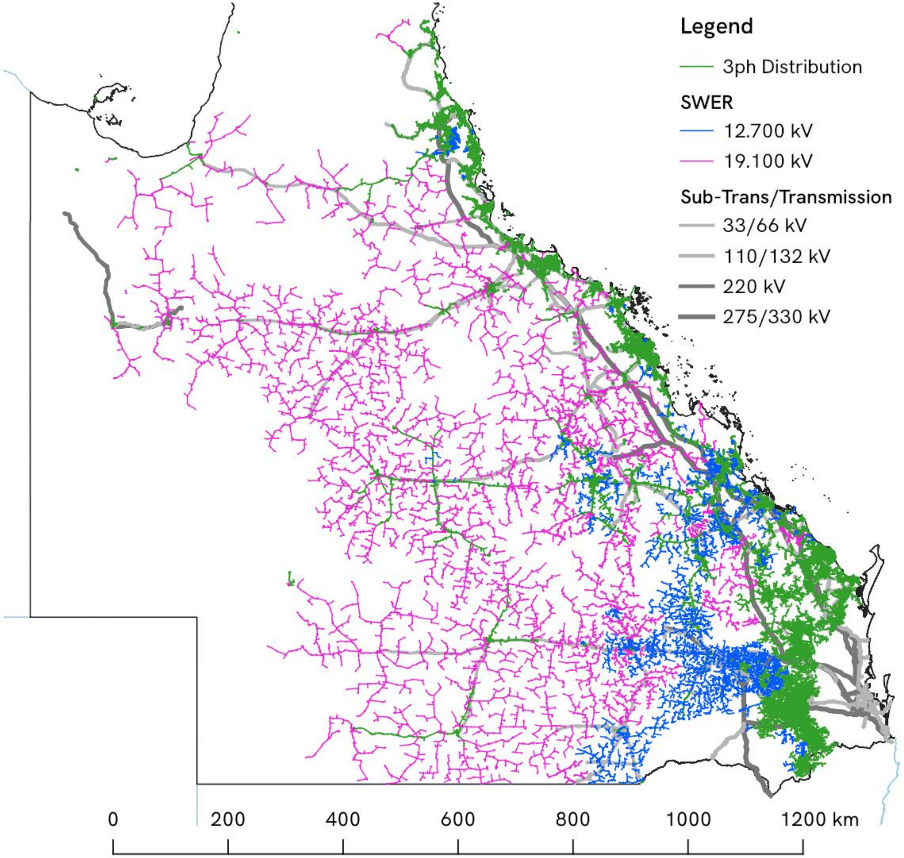
Michelle, Jason and Steve at the 2016 Australian Engineering Excellence Awards

Overview

- Regional electricity supply in Queensland & SWER
- The Grid Utility Support System (GUSS)
- Lithium ion battery terminology & technology
- Remote data collection and sensor fusion
- Performance monitoring
- Examples of monitoring & fault identification
- Future opportunities

Regional supply in Queensland

- Ergon
  - 728 000 customers
  - 118 000 km of distribution
  - 1 836 500 km^2
  - 5.2 customers/km
- Single Wire Earth Return
  - 25 000 customers
  - 62 500 km of lines
  - 500 400 km^2
  - 0.4 customer/km

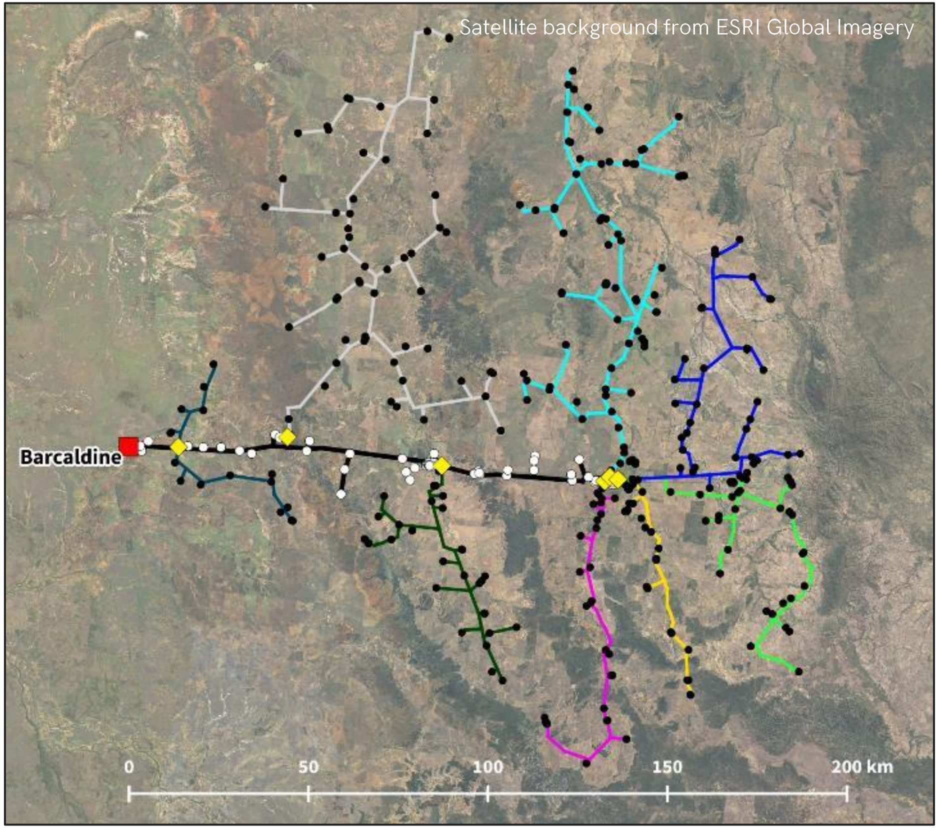


Single Wire Earth Return (SWER) networks

- Single conductor
- 12.7 kV and 19.1 kV
- Long spans
- Highly resistive
  - Steel conductor
  - R/X is 5 to 10
- Point of Load transformers
- Voltage regulation issue
  - Increasing load
  - More sensitive loads

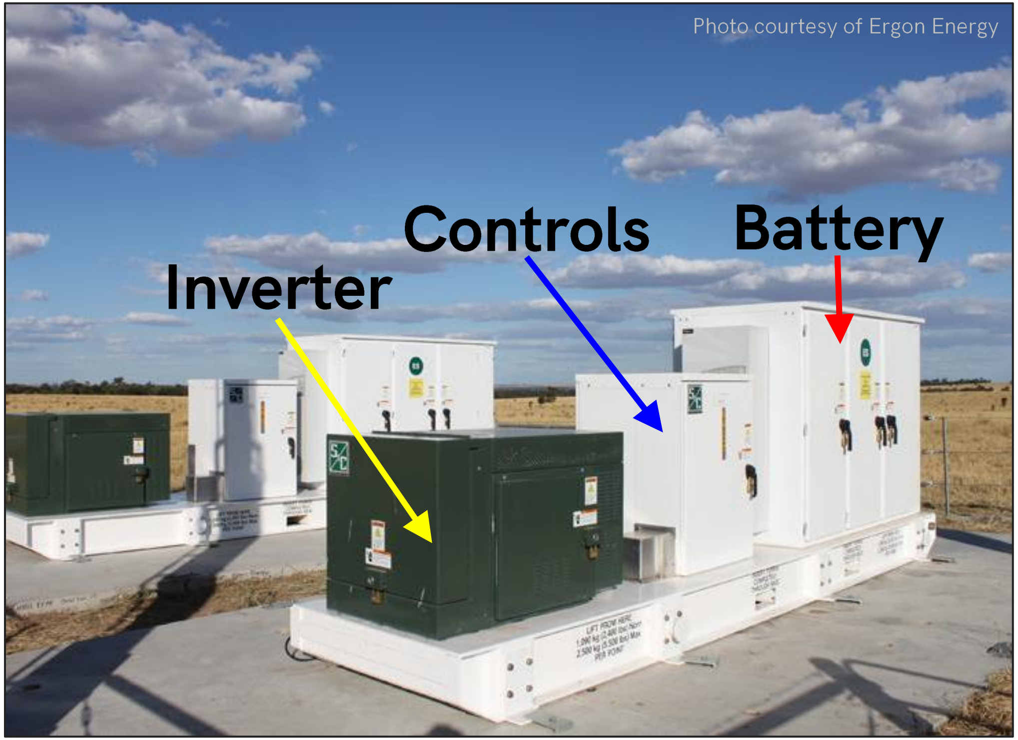
Example of multiple SWERs on one feeder

- "Alpha" Feeder
  - 1890 circuit km
  - 29 000 km^2
  - ~900 connections
  - 2.3 MVA peak
- 8× SWER Systems



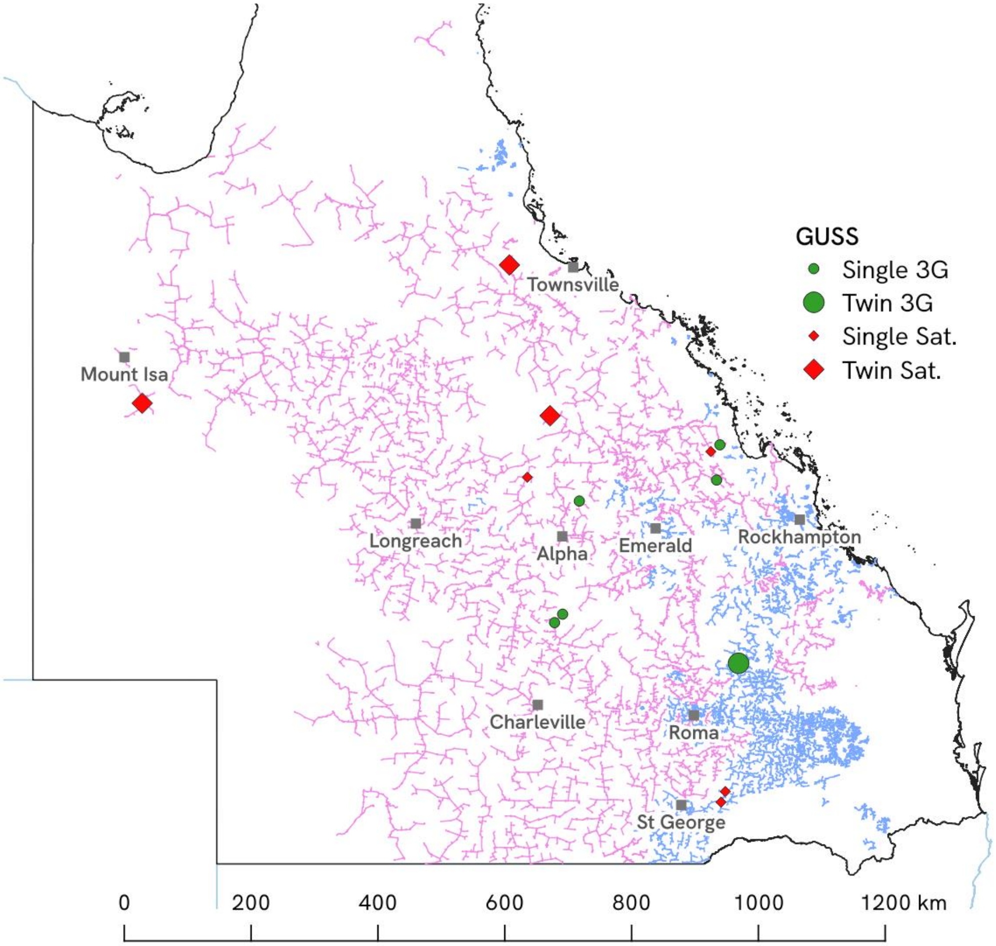
Introducing GUSS (Grid Utility Support System)

- **25 kVA** inverter
- Four quadrant (±P/±Q)
- **100 kWh** of storage
- Skid-mounted
- Remote control and alarming
  - On-board data collection
  - INMARSAT/3G modem
- Production design
  - **Not a trial**



Installation locations

- Thirteen sites
  - Nine 25 kVA "single"
  - Four 50 kVA "twin"
- 12.7 kV and 19.1 kV
- Mixed communications
  - 3G used where available
  - Inmarsat BGAN for remote areas
  - Satellite backs up 3G
- **Isolation and distance**



Commissioning philosophy

- New pre-commissioning approach used
  - Maryborough workshops
- Treated as if deployed
  - Remote access tools used
  - Proved communication & data processing systems
- Find and fix faults faster
- Minimised on-site time
  - **Fatigue management**

Twin GUSS installation

Photo courtesy of Ergon Energy

Building a battery system

Cell

Module

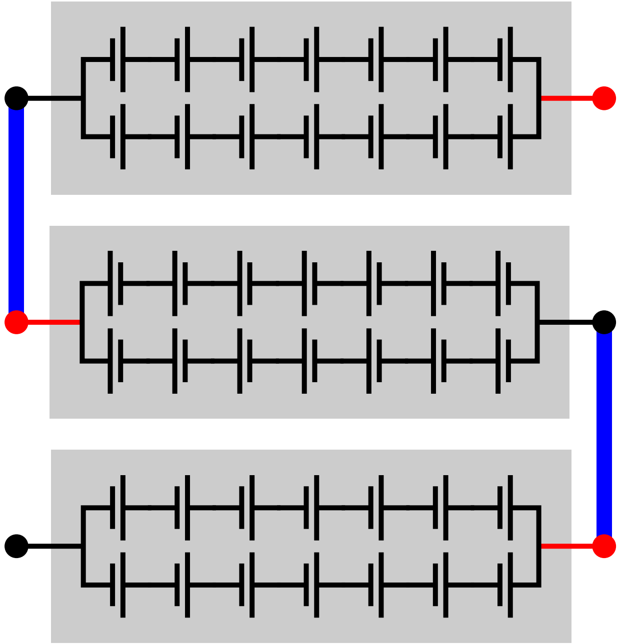
String

Photos courtesy of Ergon Energy

System

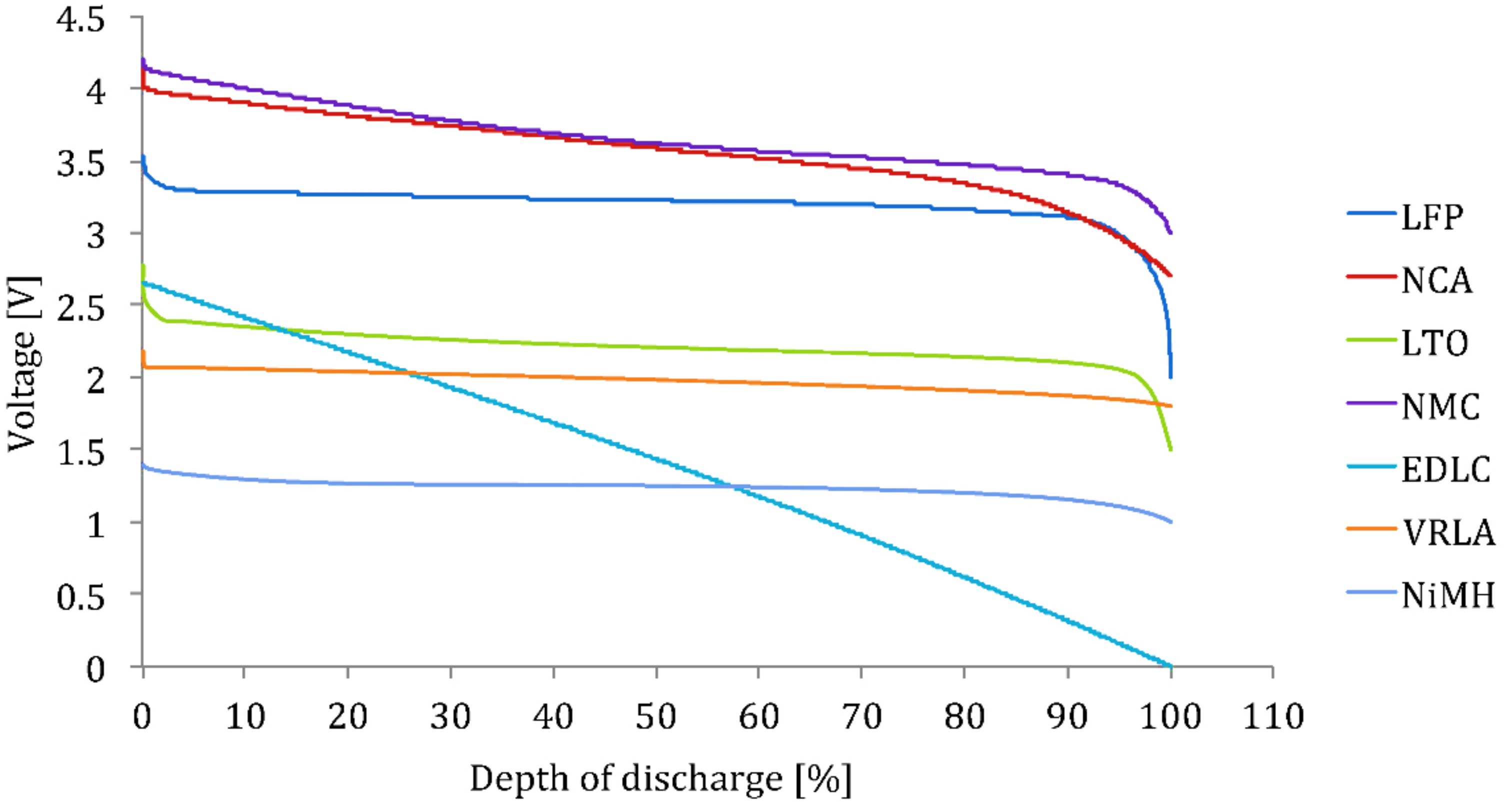
The need for balance

- **Safety critical function**
- Cell voltages must be similar
- Worst-case limits battery capacity
- Automatic balancing by discharging
- Intelligent monitoring
  - SMU monitors all cells in module
  - BMS monitors all modules
- Series/parallel combo of 784 cells
- Total voltage of 706 V



Energies **2012**, *5*(8), 2952-2988
doi:10.3390/en5082952

Lithium-ion behaviour



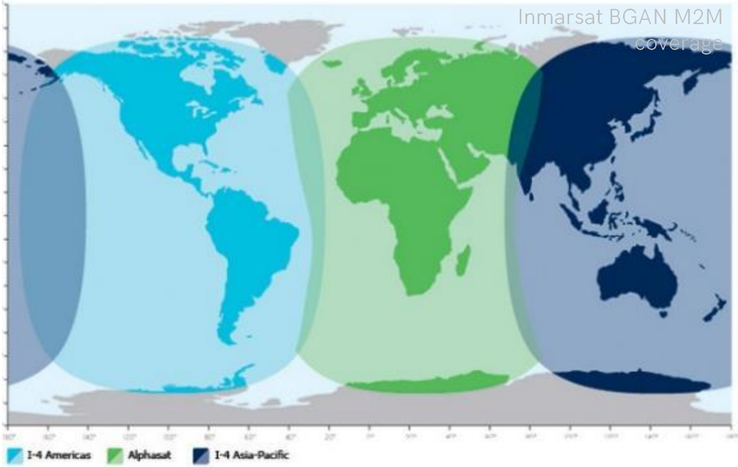
Reasons for monitoring

- Monitor string balance
- Provide advanced warning
- Collect engineering data along with operating data
- Fine tuning of advanced control algorithms
- Assess effect on network
- Verify technical specification is met


Photo courtesy of Ergon Energy

Technical constraints

- Satellite data is expensive
- Need to be selective
- Couldn't alter BMS or PCS
  - **Safety critical systems**
- Pre-process of data before transmission to reduce size
- File transfer protocols
  - Effect of latency
  - Compression
  - Cyber-security



Sensor fusion

- Intelligent devices
  - Energy meter
  - Power Conversion System
  - Battery Monitoring System
- Grid monitoring
  - Isolation transformer monitors
  - Series step regulators
  - Automatic circuit reclosers
  - Power quality meters
- Combine data for greater insights



Photos courtesy of Ergon Energy


Cooper Industries

Data sources and transfer method

- Report By Exception (RBE)
  - Alarms and events
  - PCS analog measurements
  - *DNP 3.0 SCADA*
- Daily batch transfer
  - String data
  - Module data
  - Cell data
  - *SCP file transfer*
- Daily Metering batch
  - Energy meter data

	A	B	C	D	E	F	G	H	I	J	K
1	DATETIME	SERIALNO	MODULE_T	MODULE_V	CELLV_01	CELLV_02	CELLV_03	CELLV_04	CELLV_05	CELLV_06	CELLV_07
2	2016-09-02 00:01:00		23	25990	3713	3710	3707	3715	3719	3719	371
3	2016-09-02 00:01:00		23	25970	3702	3702	3702	3703	3719	3718	371
4	2016-09-02 00:01:00		23	25990	3712	3709	3707	3695	3718	3719	371
5	2016-09-02 00:01:00		23	26000	3709	3716	3710	3712	3719	3719	372
6	2016-09-02 00:01:00		23	25990	3706	3707	3706	3711	3719	3719	371
7	2016-09-02 00:01:00		23	25990	3712	3704	3710	3712	3719	3719	371
8	2016-09-02 00:01:00		23	25990	3710	3708	3710	3710	3719	3719	371
9	2016-09-02 00:01:00		23	25990	3709	3711	3710	3712	3719	3719	371
10	2016-09-02 00:01:00		24	25990	3710	3713	3709	3710	3719	3714	371
11	2016-09-02 00:01:00		23	25990	3707	3709	3714	3712	3717	3717	371
										3718	371
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										3715	371
										3718	371

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	DATE	HOUR	Vmin	Vmin_SmuId	Vmax	Vmax_ SmuId	Tmin_ Module	Tmin_ Module_ SmuId	Tmax_ Module	Tmax_ Module_ SmuId	SMU_sum _VCell[]	SMU_sum _VCell[]	SMU_sum _VCell[]	SMU_sum _VCell[]
2	12-17-2015	00:08:11	3719	195	3792	169	30	1	32	8	26500	26510	26500	26500
3	12-17-2015	00:09:09	3720	195	3793	168	30	1	32	8	26500	26520	26500	26500
4	12-17-2015	00:10:06	3721	194	3793	168	30	1	32	26	26510	26520	26510	26510
5	12-17-2015	00:11:04	3723	195	3794	168	30	1	31	2	26520	26530	26510	26510
6	12-17-2015	00:12:01	3724	194	3795	169	30	1	31	2	26520	26530	26520	26520
7	12-17-2015	00:12:59	3726	195	3796	168	30	1	31	2	26530	26540	26530	26530
8	12-17-2015	00:13:56	3727	194	3797	169	30	4	31	1	26530	26550	26530	26530
9	12-17-2015	00:14:54	3728	192	3798	169	30	4	32	28	26540	26550	26540	26540
10	12-17-2015	00:15:51	3730	193	3798	169	30	6	32	26	26550	26560	26540	26550
11	12-17-2015	00:16:49	3730	193	3799	168	30	6	32	26	26550	26560	26550	26550
12	12-17-2015	00:17:46	3732	193	3801	169	30	18	32	8	26550	26570	26560	26550
13	12-17-2015	00:18:44	3734	192	3801	169	30	18	32	8	26560	26580	26560	26560
14	12-17-2015	00:19:41	3735	193	3802	169	30	18	32	3	26570	26580	26570	26570
15	12-17-2015	00:20:39	3736	193	3803	168	30	18	32	3	26570	26590	26570	26570
16	12-17-2015	00:21:36	3738	192	3804	169	30	18	32	3	26580	26590	26580	26580
17	12-17-2015	00:22:34	3739	193	3804	169	30	18	32	2	26580	26600	26580	26590
18	12-17-2015	00:23:31	3739	193	3805	168	30	18	32	2	26590	26610	26590	26590
19	12-17-2015	00:24:29	3741	193	3806	168	30	18	32	2	26590	26610	26600	26600
20	12-17-2015	00:25:26	3742	193	3807	146	30	18	32	2	26600	26620	26600	26600
21	12-17-2015	00:26:24	3744	197	3808	151	30	18	32	2	26610	26620	26610	26610
22	12-17-2015	00:27:21	3745	196	3809	173	30	18	32	2	26610	26620	26610	26610
23	12-17-2015	00:28:19	3746	196	3810	173	30	18	32	2	26620	26640	26620	26620
24	12-17-2015	00:29:16	3748	196	3811	151	30	18	32	2	26620	26640	26630	26630
25	12-17-2015	00:30:14	3749	197	3812	150	30	18	32	2	26630	26640	26630	26630
26	12-17-2015	00:31:11	3750	197	3813	151	30	18	32	2	26630	26650	26630	26630
27	12-17-2015	00:32:09	3751	196	3813	172	30	18	32	2	26640	26660	26640	26640
28	12-17-2015	00:33:06	3751	196	3814	151	30	18	32	2	26650	26660	26650	26650
29	12-17-2015	00:34:04	3752	196	3815	150	30	18	32	2	26650	26670	26650	26650

Automated workflow

- Automated daily download of data into shared database
  - Download each GUSS sequentially
    - Satellite bandwidth is shared
  - Feed data into corporate repository
- Process the data and generate graphs
  - Series of charts with different focus
  - Provide a summary website
  - Reduces server workload
- Weekly and monthly processing
  - Examine long term trends
  - Data archiving

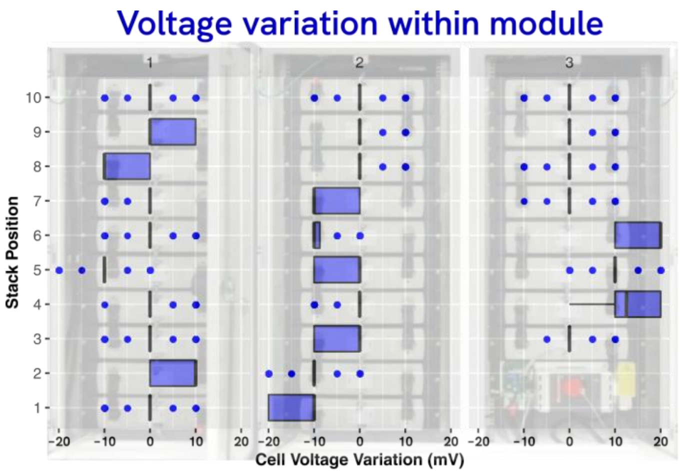
Battery monitoring

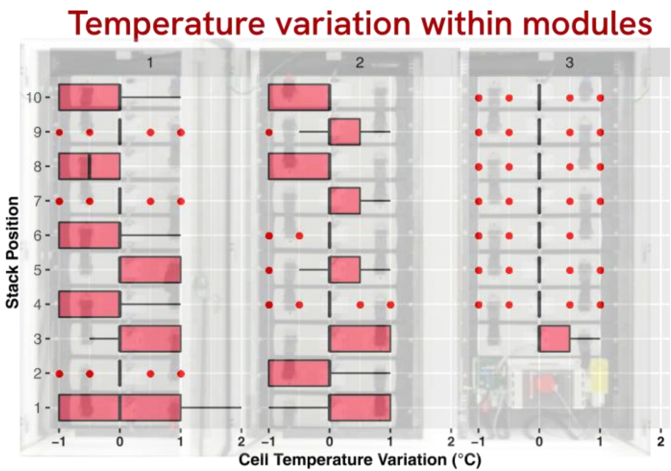
- System-level monitoring (2 str)
  - DC bus & max/min cell voltages
  - Estimated State of Charge
  - Battery string currents
  - Maximum/minimum cell temps
- Module-level monitoring (56)
  - Voltage/temp variation
  - Average voltages & temperatures
- Cell-level monitoring (784)
  - Voltage variation
- Statistical processing needed to identify outliers

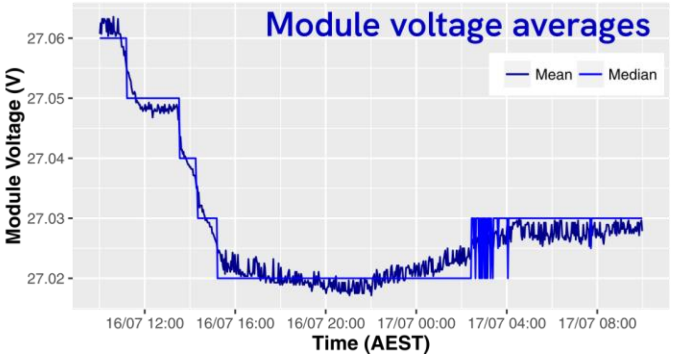
Performance assessment

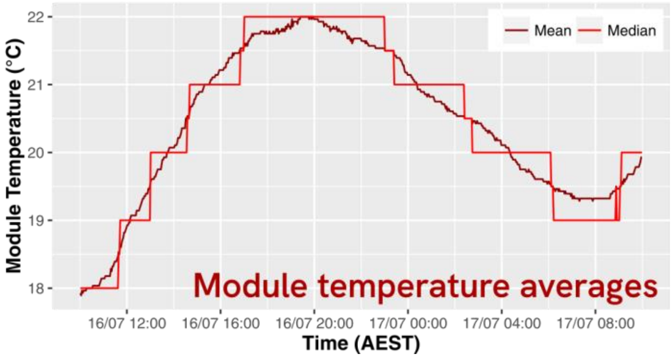
- Look at the “fleet” individually and as a whole
  - Watch for abnormalities
- Too much data to look at in numerical form
  - Visualisation is key
  - Catch potential faults early
  - Too early for machine learning; no training data available
- Use data from multiple sources
  - No one source has all the required information
- Visualise data in a variety of ways

Module-level voltage and temperature

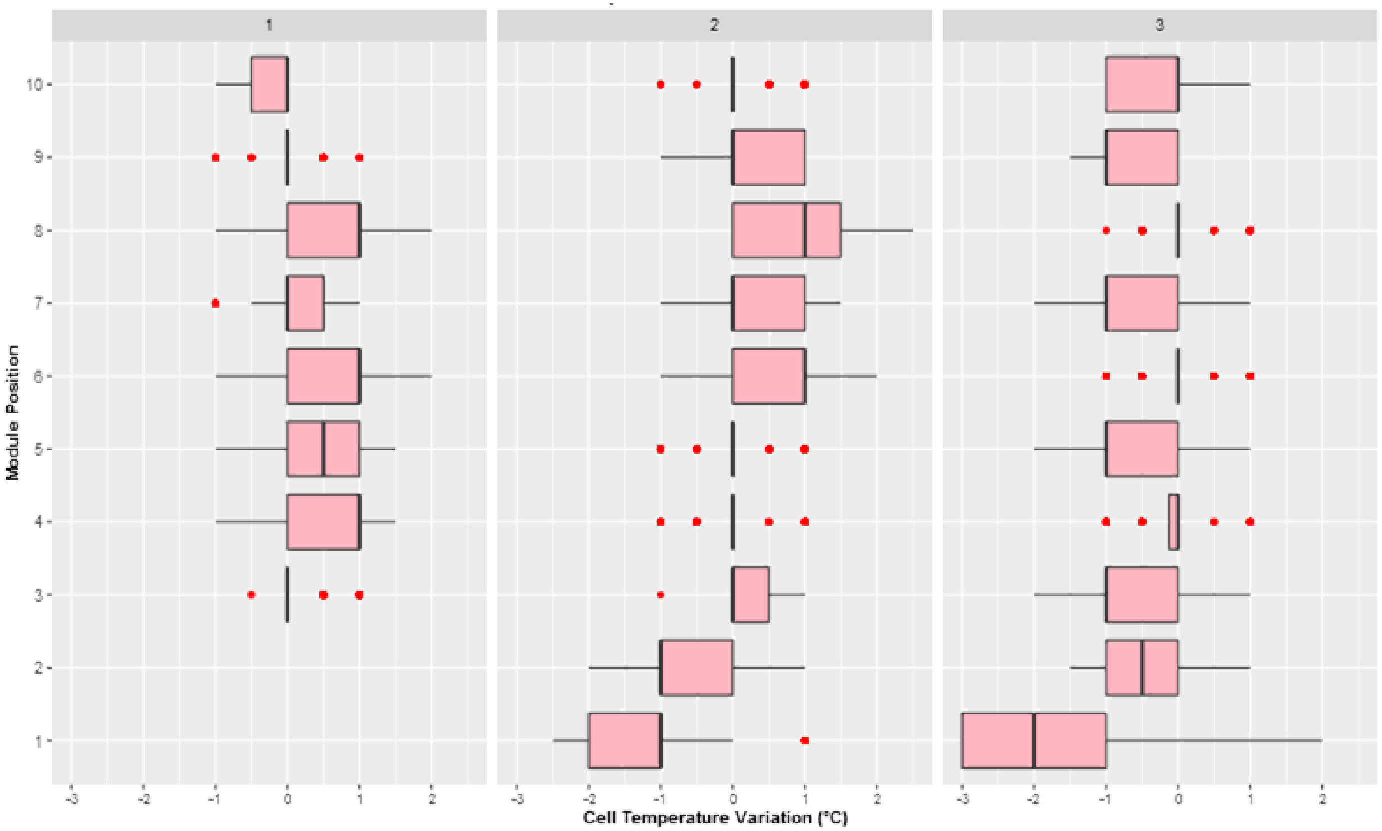




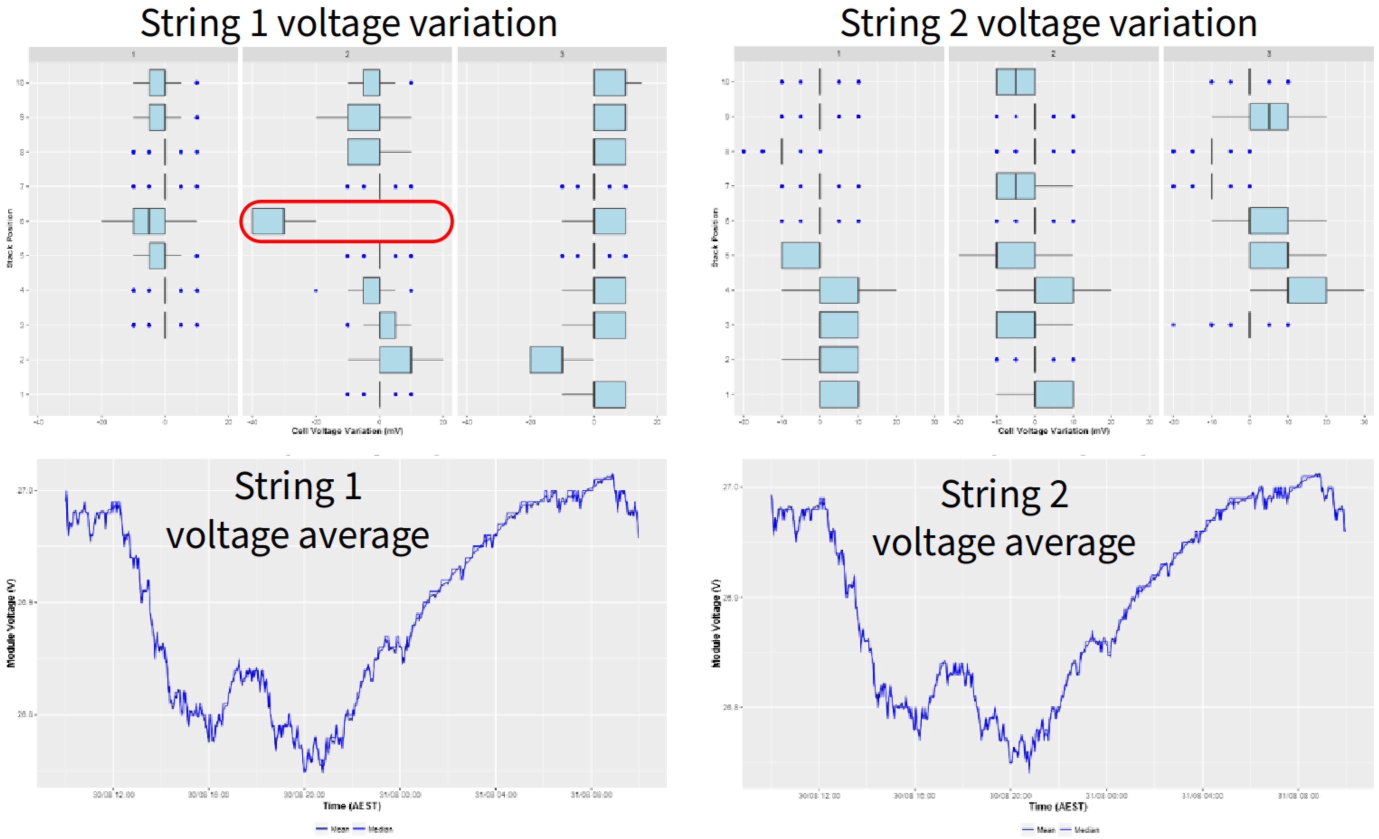




Temperature variation within string

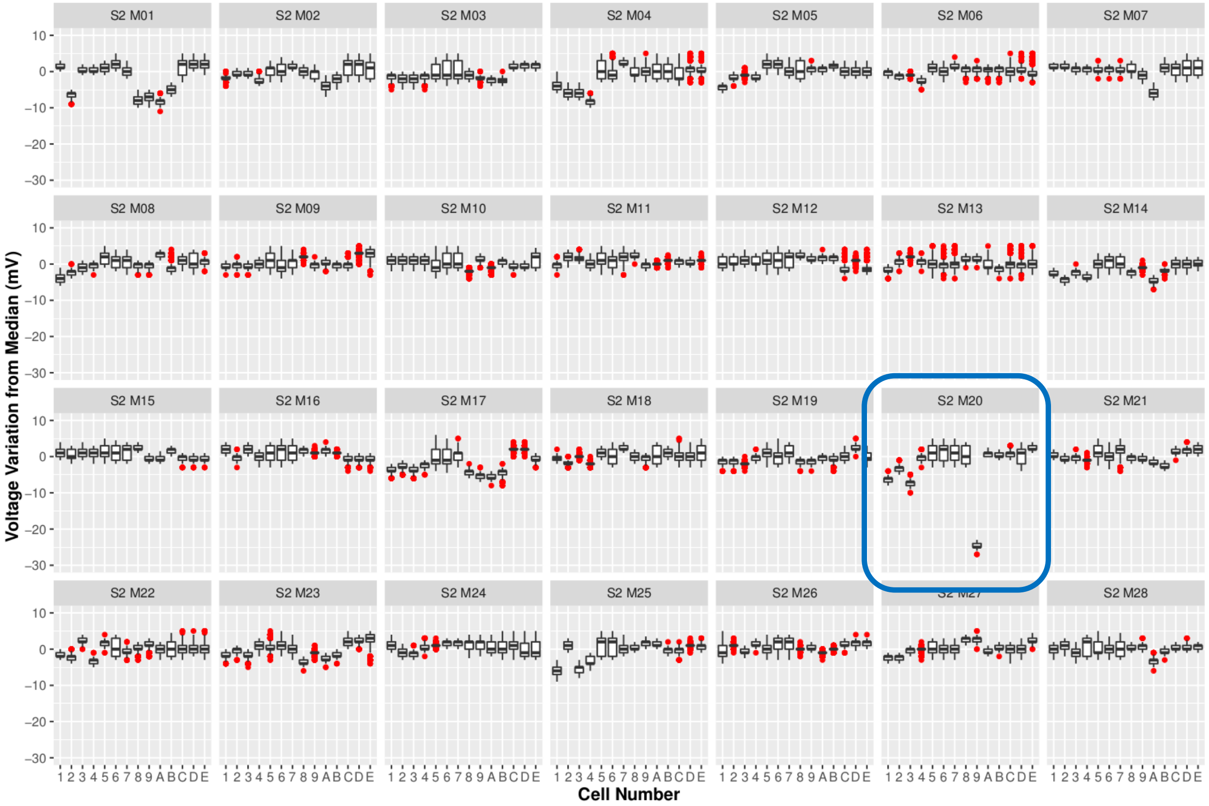


String 1 module with low voltage



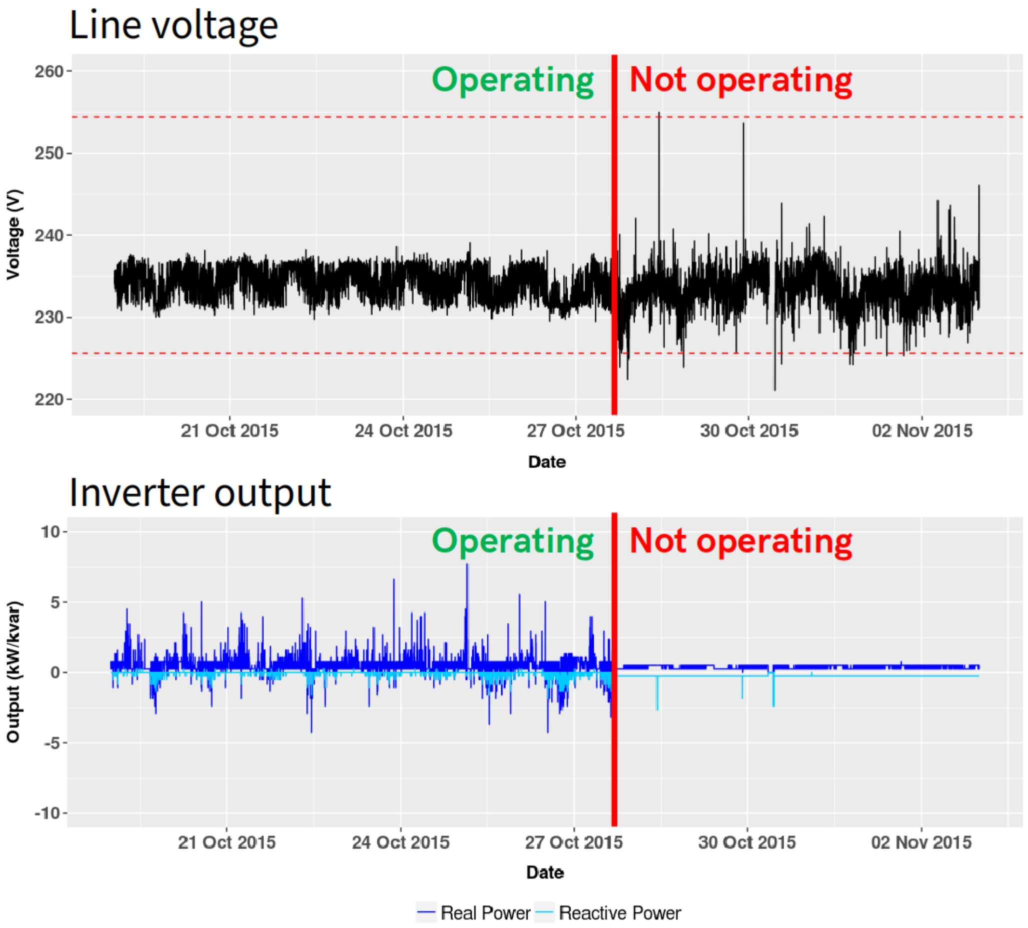
Visualising cell voltage variation

- Potential module fault in String 2
- Module 20 Cell 9
- Outliers can be masked by large variation
- Absolute value expected to vary with daily cycling



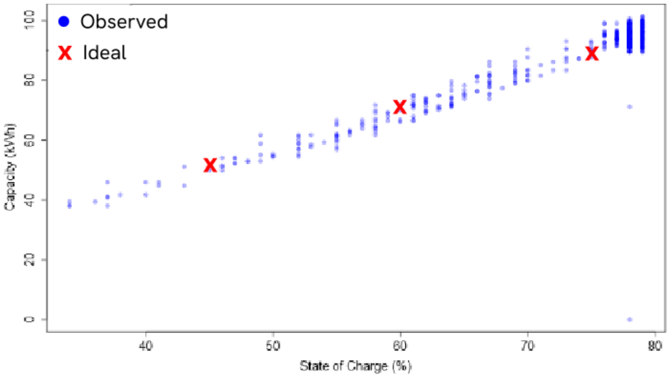
Customer voltages

- Fast transient response
- Real & reactive power output from GUSS
- Better for customers' electronic devices
- Regulating as expected

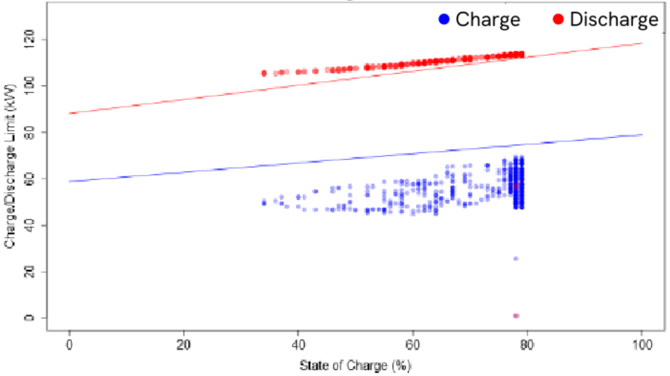


Weekly and monthly review

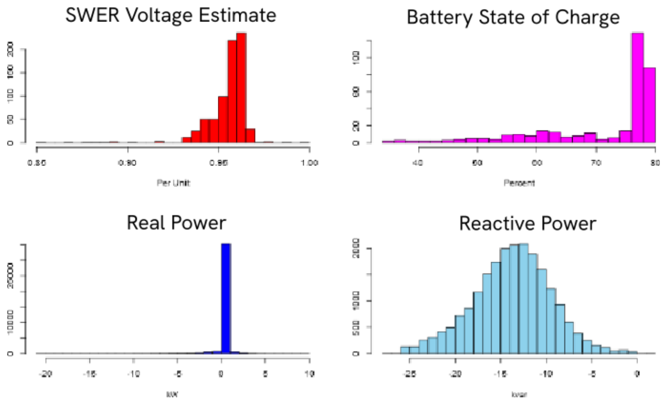
Battery capacity



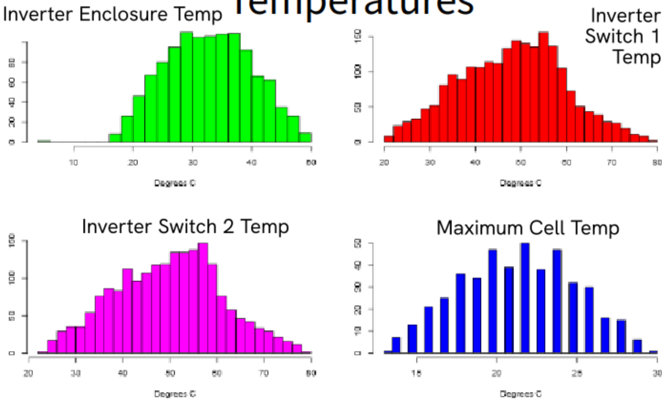
Battery limits



Network performance

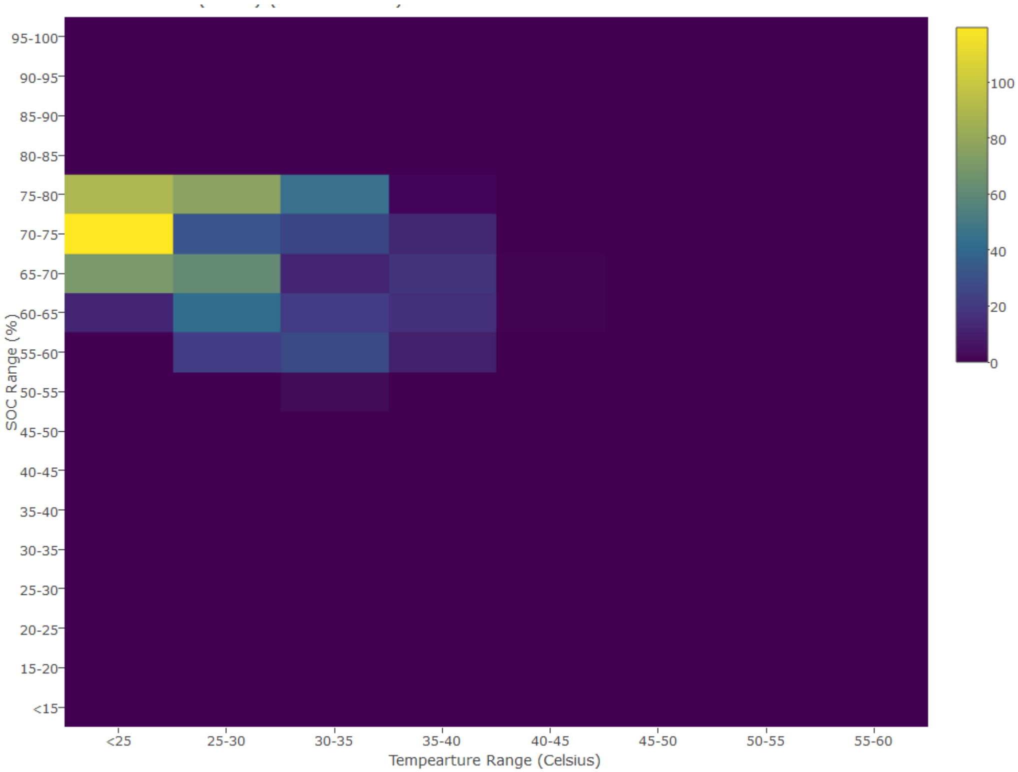


Temperatures



Modelling of battery performance over time

- Building a library of operation over a range of conditions
- No two sites are the same
- Cell-level and module-level logging creates a deep dataset
- Applicable to three-phase and isolated use too



Optimising control system parameters

- Power system models give initial estimate
- Designed for autonomous and directed operation
- Control systems do interact
- Observed response can be used to tune power models
- Power electronics reduce wear on switched equipment

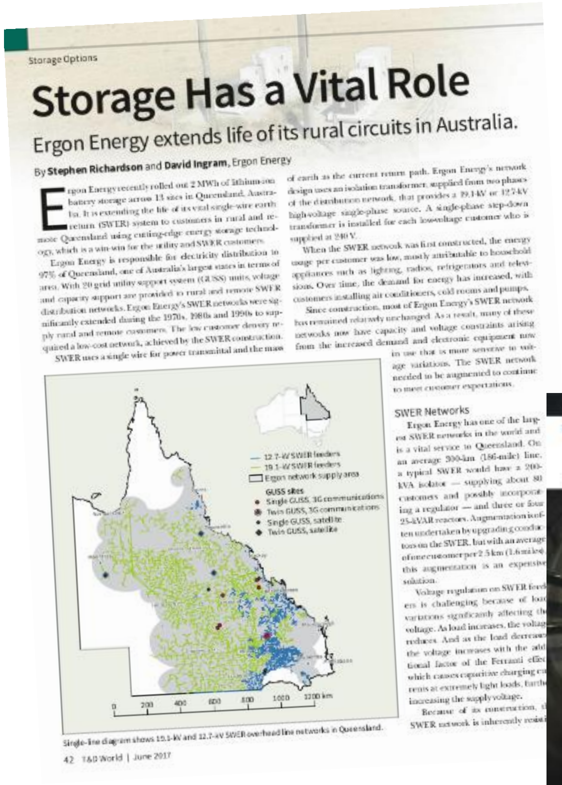
Data-constrained environments

- "Design for data"
  - Make key items available
  - Open protocols
  - Enable automation
- Utility applications
  - Automatic circuit reclosers
  - Step voltage regulators
  - Energy & power quality meters
- End-user applications
  - Irrigation
  - Load control
- Satellite
  - Medium bandwidth
  - Very high latency
  - Expensive
- Internet of Things
  - Low bandwidth
  - Medium to high latency
  - Power is limited
- Cyber Security
  - Access permissions
  - Data portals

Conclusions

- Power electronics can solve capacity & voltage problems
- Incorporate performance monitoring at design stage
- Consider constraints of selected communications network
- Use of communications reduces risk of deployment
  - Better situational awareness improves decision making
  - Early indication of problems gives opportunity to plan for repair
- Remote data collection gives great insight into behaviour

For further detail



Storage Options

Storage Has a Vital Role

Ergon Energy extends life of its rural circuits in Australia.

By **Stephen Richardson** and **David Ingram**, Ergon Energy

Ergon Energy recently rolled out 2 MWh of lithium-ion battery storage across 13 sites in Queensland, Australia. It is extending the life of its vital single-wire earth return (SWER) system to customers in rural and remote Queensland using cutting-edge energy storage technology, which is a win-win for the utility and SWER customers.

Ergon Energy is responsible for electricity distribution in 97% of Queensland, one of Australia's largest states in terms of area. With 20 grid utility support system (GUSS) units, voltage and capacity support are provided to rural and remote SWER distribution networks. Ergon Energy's SWER networks were significantly extended during the 1970s, 1980s and 1990s to supply rural and remote customers. The low customer density required a low-cost network, achieved by the SWER construction.

SWER uses a single wire for power transmittal and the mass of earth as the current return path. Ergon Energy's network design uses an isolation transformer, supplied from two phases of the distribution network, that provides a 19.1-kV or 12.7-kV high-voltage single-phase source. A single-phase step-down transformer is installed for each low-voltage customer who is supplied at 240 V.

When the SWER network was first constructed, the energy usage per customer was low, mostly attributable to household appliances such as lighting, radios, refrigerators and televisions. Over time, the demand for energy has increased, with customers installing air conditioners, cold rooms and pumps.

Since construction, most of Ergon Energy's SWER network has remained relatively unchanged. As a result, many of these networks now have capacity and voltage constraints arising from the increased demand and electronic equipment now in use that is more sensitive to voltage variations. The SWER network needed to be augmented to continue to meet customer expectations.

SWER Networks

Ergon Energy has one of the largest SWER networks in the world and is a vital service to Queensland. On an average 300-km (186-mile) line, a typical SWER would have a 200-kVA isolator — supplying about 80 customers and possibly incorporating a regulator — and three or four 25-kVAR reactors. Augmentation is often undertaken by upgrading conductors on the SWER, but with an average of one customer per 2.5 km (1.6 miles), this augmentation is an expensive solution.

Voltage regulation on SWER feeders is challenging because of load variations significantly affecting the voltage. As load increases, the voltage reduces. And as the load decreases, the voltage increases with the additional factor of the Ferranti effect, which causes capacitive charging currents at extremely light loads, further increasing the supply voltage.

Because of its construction, the SWER network is inherently resisti

Single-line diagram shows 19.1-kV and 12.7-kV SWER overhead line networks in Queensland.

42 T&D World | June 2017

Design and commissioning detail:

- Transmission and Distribution World June 2017, pages 42-48
  www.tdworld.com/distribution/storage-has-vital-role

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