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Ultracapacitor Grid Energy Storage for VSM

National Grid WG Meeting 3
July 12th, 2018

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Agenda

- **Introduction Maxwell**
- **Ultracapacitor Technology and Highlights**
- **Ultracapacitor Grid Energy Storage Solutions**
- **VSM Sizing based on NG‘s discussions**
- **Summary**

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Introduction Maxwell

Introduction Maxwell Technologies

Business Highlights

Overview

- Founded 1965; IPO 1983 (NASDAQ: MXWL)
- Energy storage & power delivery solutions
- Headquarters: San Diego, CA
- Locations: U.S.A., Switzerland, China, South Korea
- Employees: 456

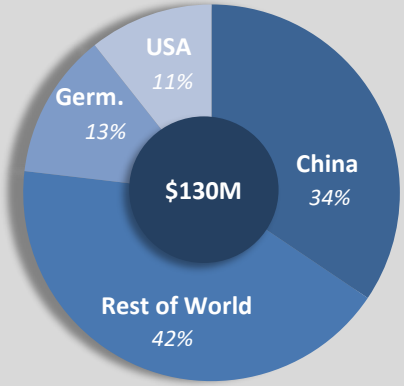
Products & Markets

High Voltage	Energy Storage	Dry Battery Electrode
Circuit Breakers • Metering • Converters	Automotive • Grid • Rail • Industrial	Lithium-Ion Battery

Financial Highlights

- 2017 Revenue: $130M
- 2017 Adjusted EBITDA: ($9.6M)
- FYE 2017 Cash Balance: $50M

Geographic Revenue Breakdown



*Revenue from external customers in ROW does not individually comprise of more than 12% of total
*See Appendix for GAAP to non-GAAP reconciliation of EBITDA

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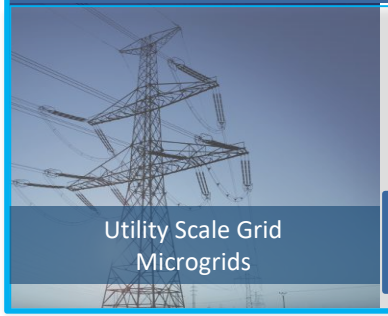
Grid Energy Storage



Utility Scale Grid
Microgrids

- **Enabling grid stability and resiliency**
- **Leading projects with major utilities and OEMs**

- Largescale storage
- Focused on safety
- Highly integrated solution

Wind

Electric Pitch Control
Battery Retrofit System

- **Global Leader in Electric Wind Pitch Control**
- **Operating in over 61,000 Turbines**

- Long life
- Low weight
- Minimal mainatinance

Automotive

Start Stop, eActive Suspension
Autonomous Driving

- **E-Active Suspension Ramp**
- **Significant Autonomous Driving Opportunities**
- **New design win with Geely-Volvo**

- Reliability
- Performance
- Qualification

Bus, Rail, Truck

Onboard Rail
Wayside Rail

- **Operating in over 40K hybrid busses**
- **Multiple and growing rail wins for braking energy recuperation and electric propulsion**
- **Major truck OEMs / fleets installing Engine Start Module for reliable engine starting**

- Robustness
- Cycleability
- Homologation

~65M Cells Field-Deployed Over the Last Two Decades in Core Markets

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Ultracapacitor Technology and Highlights

Ultracapacitor Technology and Highlights

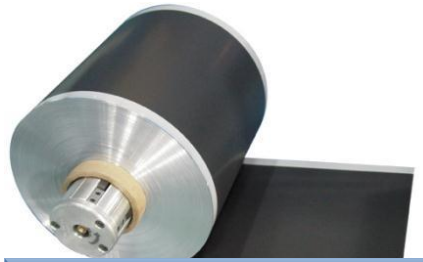
How it's made…..

COCONUT SHELLS

- Source of Activated Carbon

ACTIVATED CARBON

- Mixed with "Binder"



MAXWELL ELECTRODE

- Fabricated into Proprietary Electrode

MAXWELL ULTRACAPACITOR

- Assembled into Ultracapacitors

Grind & Activate → Dry Process → High Volume Production

Ultracapacitor Technology and Highlights

Ultracapacitors Differentiators

- **High Power, Fast Charge & Discharge**
- **Power provision from sub-seconds to minutes**
- **Long lifetime 1,000,000 cycles (15 years) ***
- **Scalable from W to MW**
- Wide operating temperature (- 40°C to 65°C)
- No chemical but electrostatic process
- Low to zero maintenance

Technology Highlights:

- Deep discharge ability
- Supplied at zero charge for safe transport, storage and installation
- Can use in series and parallel to any desired specification
- No thermal runaway

*Results may vary, additional terms and conditions include limited warranty, apply at the time of purchase. See the data sheet and warranty details for applicable operating end user requirements.

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Ultracapacitor Grid Energy Storage Solutions

Ultracapacitor Grid Energy Storage Solutions

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Ultracapacitor - Cell Pack for Stationary Grid Market

BMOD0141 P064 B04

- Digital communication for integration with system controller
- **Integrated active cell balancing, temperature and voltage monitoring** within advanced ultracapacitor management system (CMS)
- Maxwell High Voltage Interlock Loop (M-HVIL™) enables **advanced safety functionality** - redundant alarm system
- Full range of depth of discharge capability
- Wide operating temperature: **-40 to +65ºC**
- Cycle life of over **1,000,000**, typical project lifetime of **15 years***

ELECTRICAL	
Rated (Min.) Capacitance, BOL	141 F
Rated (Max.) ESR_{DC}, BOL, 5 sec	8.3 mΩ
Module Rated Operating Voltage	64.0 V
Stored Energy	80 Wh
Absolute Maximum Current	2000 A
Maximum Series String Voltage Rating	1500 V
Number of Cells within Module	24
Maximum Module in Series Supported	20

MONITORING / CELL VOLTAGE MANAGEMENT	
Internal Temperature Sensor	NTC Thermistor x2
Temperature Interface	CAN
Cell Voltage Monitoring	Smart
Connector (Mating)	RJ45
Cell Management System	Maxwell CMS 3.1

COMMUNICATIONS	
Data Communications Interface (included)	CAN
Optional Data Communications Interface (DC-11)	MODBUS

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Ultracapacitor Grid Energy Storage Solutions

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Ultracapacitor – System for large scale Stationary Grid Market

Ultracapacitor Module
BMOD0071 P130 B04

Cabinet Controller/Gateway
DC-11

Example 19" rack configuration (1.3MW)

Example 20" Containerized Solution

ELECTRICAL	
Rated (Min.) Capacitance, BOL	71 F
Rated (Max.) ESR_{DC}, BOL, 5 sec	16.8 mΩ
Module Rated Operating Voltage	129.6 V
Stored Energy	165 Wh
Absolute Maximum Current	2000 A
Maximum Series String Voltage Rating	2000 V
Number of Cells within Module	48
Maximum Module in Series Supported	10

Standardized for use in cargo containers

- Rated to 2,000V basic & 1,350V reinforced insulation
- Utility Grade
- Cabinet Controller to enable integration of many UCAP modules into large control systems
- External Field bus interface,
- ProfiNet IRT Fiber Optic (DC-10),
- Modbus (DC-11)
- Advanced prognostic, diagnostic management with redundant safety
- Meets power requirements with out oversizing for power delivery or cycling performance

MW to 100's MW
Utility Scale Storage Solutions

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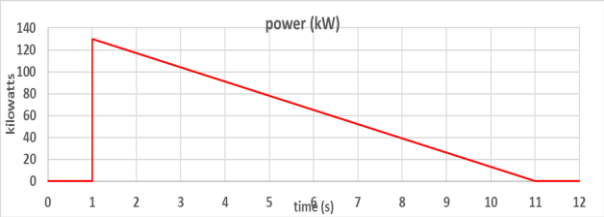
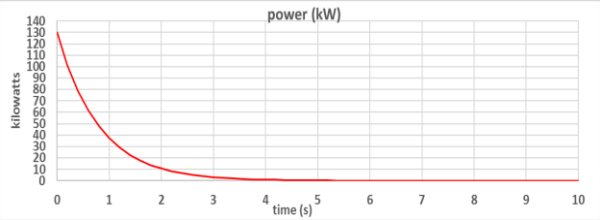
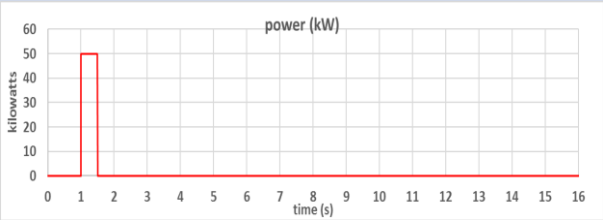
VSM Sizing based on NG's discussions

VSM –Support: Sizing based on Ultracapacitors

Sizing Scenarios "Inertia Response"

Profile A „Triangel“	Profile B „Exponential decay“	Profile C „Pulse“
Power: 130 kW Duration: 10 seconds	Power: 130 kW Duration: 0.8 seconds (TC)	Power: 50 kW Duration: 0.5 seconds
~ few cycles per year	~ one cycle per minute	~ one cycle per minute
		

Operation Voltage Range

U_DC LinkMax: ~510 VDC

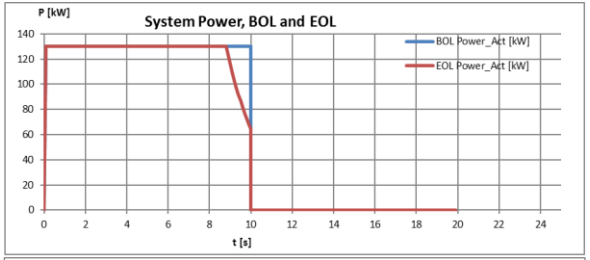
U_DC LinkMin: ~240 VDC

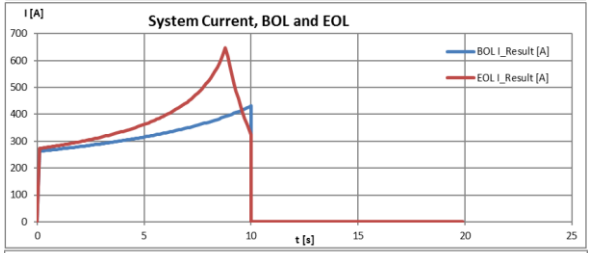
Source: „FFCI Expert Working Group Enstore VSM- 002.pdf"

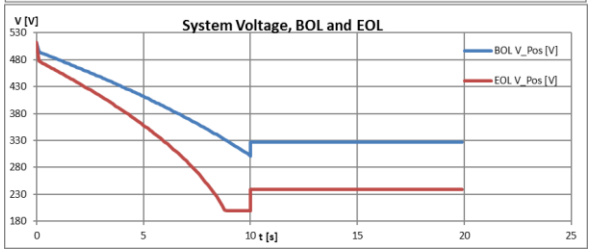
VSM –Support: Sizing based on Ultracapacitors

Sizing and runtimes based on Grid Cell Pack
130kW Constant Power

Type	Grid Cell pack based storage Parameters			
State Of Life	BOL		EOL	
Minimum Initial Capacitance	141.00	F	112.80	F
Number of unit in serie	8.00		8.00	
Number of stack in parallel	1.00		1.00	
Quantity of unit for a system	8.00		8.00	
Max Absolute system voltage	547.20	V	547.20	V
Rated Voltage	518.40	V	518.40	V
System Rated Capacitance	17.63	F	14.10	F
Usable Energy	0.66	kWh	0.53	kWh
Stored Energy	0.54	kWh	0.44	kWh
	2.37	kJ	1.89	kJ
Peak Power	1.11	MW	0.56	MW
Device max ESR DC	60.00	mOhm	120.00	mOhm
System max ESR DC	60.40	mOhm	120.40	mOhm







System Summary 130kW System:

Total number of Modules: 8 modules (in series)

Note:

- To achieve desired voltage 8 modules in series are required!
- This configuration meets the shown parameters.
- Scalability to higher voltage and higher power possible.

BMOD0141 P064 B04

Begin of Life (BOL): 100% Cap / 100% ESR **End of Life (EOL):** 80% Cap / 200% ESR

VSM –Support: Sizing based on Ultracapacitors

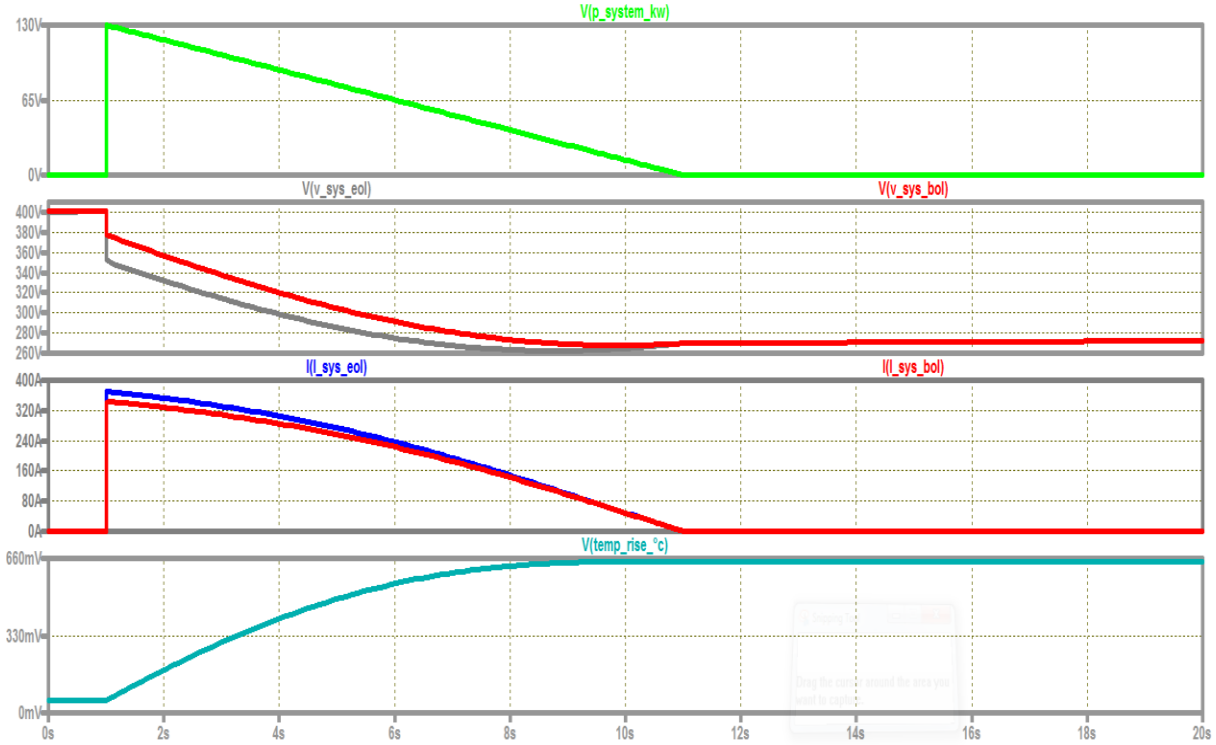
Simulation results of Profile A : “Triangel”

Power

Voltage

Current

Temperature increase



- Initial Voltage: 400V
  (75% of rated Ucap system voltage)
  power response in both directions
- Temperature rise is < 1 degrees Celsius for a single pulse.
- This would allow many consecutive cycles including recharging back to start voltage.

Lifetime:
If held at const. ambient temp of 40° C life time is estimated to be 15 Years*

*Results may vary, additional terms and conditions include limited warranty, apply at the time of purchase. See the data sheet and warranty details for applicable operating end user requirements.

VSM –Support: Sizing based on Ultracapacitors

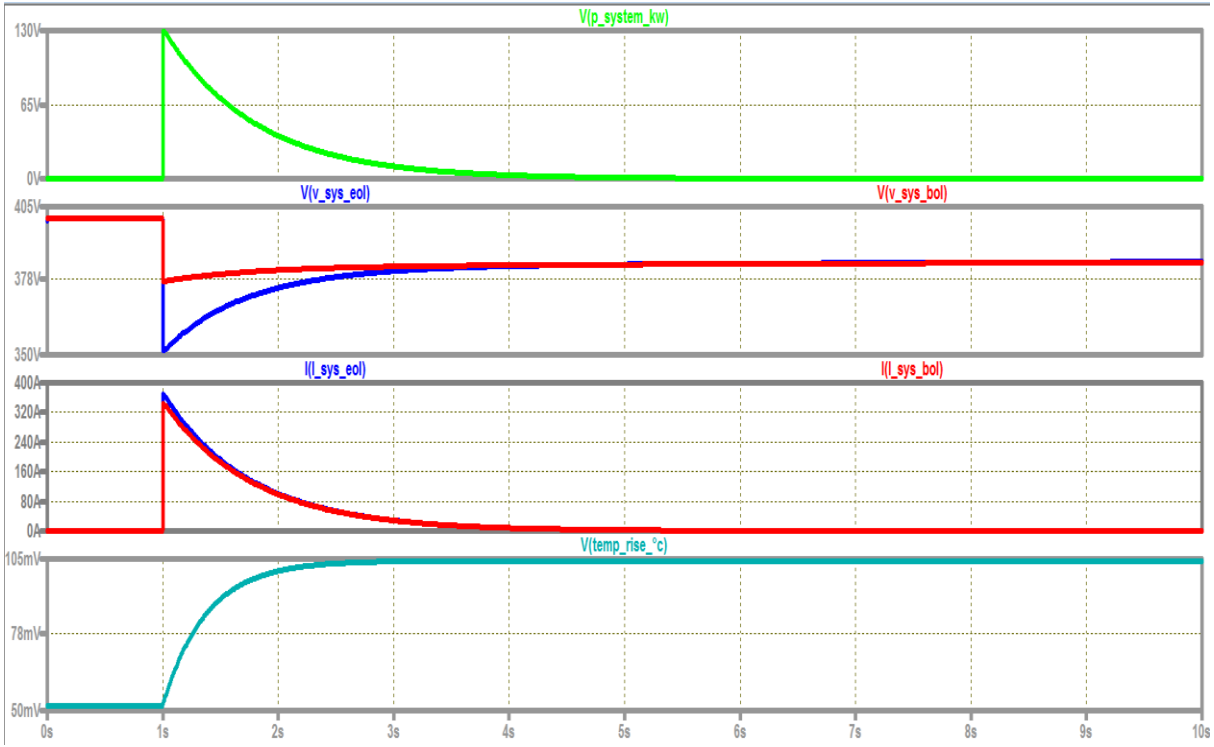
Simulation results of Profile B : „Exponential decay“

Power

Voltage

Current

Temperature increase



- Initial Voltage: 400V
  (75% of rated Ucap system voltage)
  power response in both directions
- Rms current: 24A rms
  1-minute repetition / with recharge
  Temperature rise < 3° C wrt ambient
- Rms current continuous cycling
  1- 10 sec. repetition / with recharge
  (8640 cycles/day) = 72A rms Temperature rise ~ 22° C wrt Ambient

Lifetime: (I_{RMS} 24A)
If held at const. ambient temp of 40° C life time is estimated to be 15 Years*

Lifetime: (I_{RMS} 72A)
If held at const. ambient temp of 30° C life time is estimated to be 10 Years*

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VSM –Support: Sizing based on Ultracapacitors

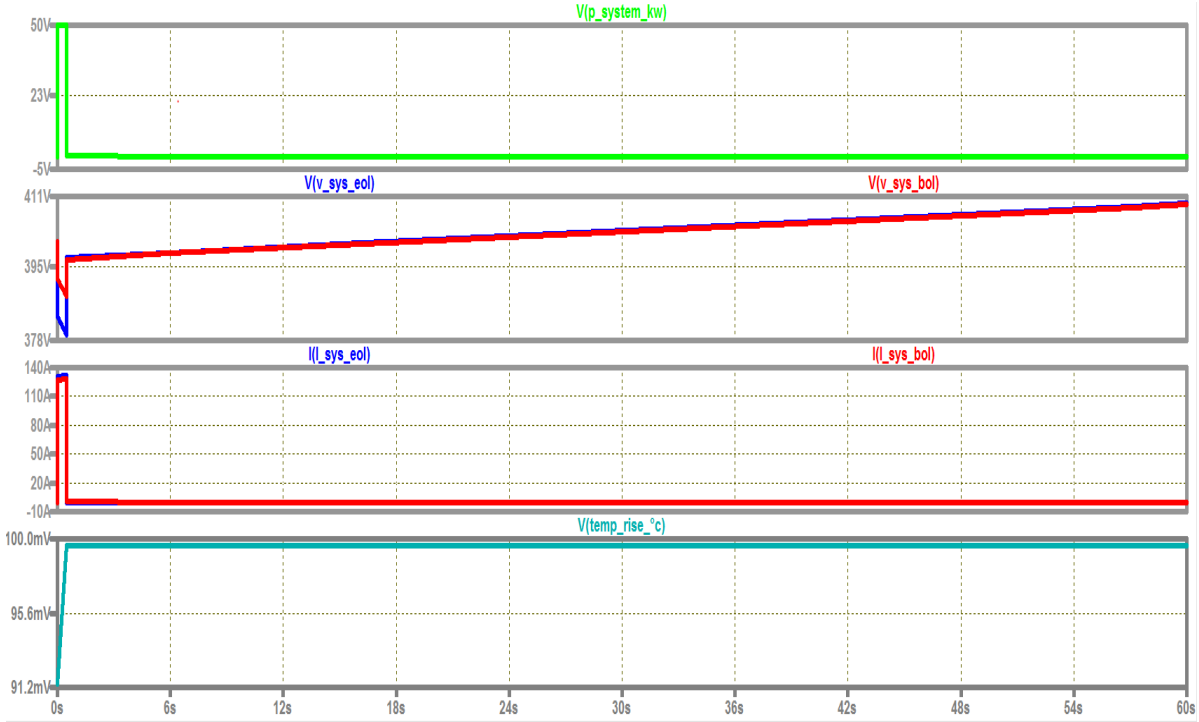
Simulation results of Profile C : “Pulse”

Power

Voltage

Current

Temperature increase



- Initial Voltage: 400V
  (75% of rated Ucap system voltage)
  power response in both directions

- **Rms current the type of pulse repetition (with recharge)**
- **12A rms**

  Temperature rise < 1° C wrt Ambient

Lifetime:
If held at const. ambient temp of 40° C life time is estimated to be 15 Years*

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Summary

Summary

Key Facts on Ultracapacitor Technology

Ultracapacitors….

…. are designed for grid scale applications (>100 MW)

…. can be operated up to multiple tens of kilo Volt

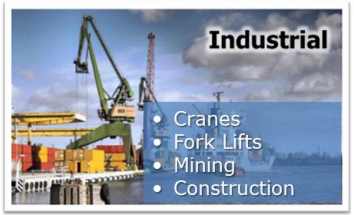
…. can be discharged to 0 Volt any time (transport, maintenance)

…. easily withstand short-circuit to ground (Safety)

…. are monitored and controlled for very safe operation

…. have most competitive footprint regarding power

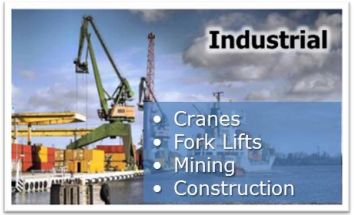
…. have most competitive pricing regarding power



Summary

A Mature Powerful Energy Source

- High Quality & Reliability meeting Performance Expectations
  (Automotive and Aviation)
- Experienced High Volume Manufacturing
- Demonstrated Success in Various Applications – Mobile and Stationary
- >80 Million Maxwell cells deployed in the Market since 15 years



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Thank You !

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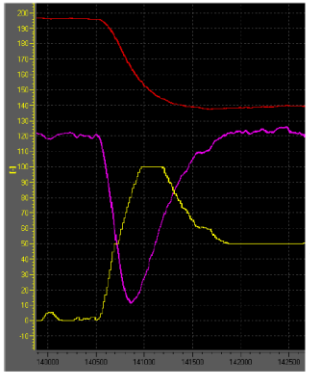
Backup

EIRGrid Microgrid

Ultracapacitor System Providing Fast Frequency Response, Battery Support



Driver: Reduced utility infrastructure investment

- Community level power stabilization
- Deferred infrastructure investment related to high penetration of renewables in Ireland
- Ultracapacitors provide fast frequency regulation and voltage stabilization
- Li-Ion batteries provide for peak shifting and operating reserve
- **Combined with advanced power electronics, UCAPS successfully providing "synthetic inertia" within ms of frequency events**
- **Proven active power response proportional to the severity of the frequency event**