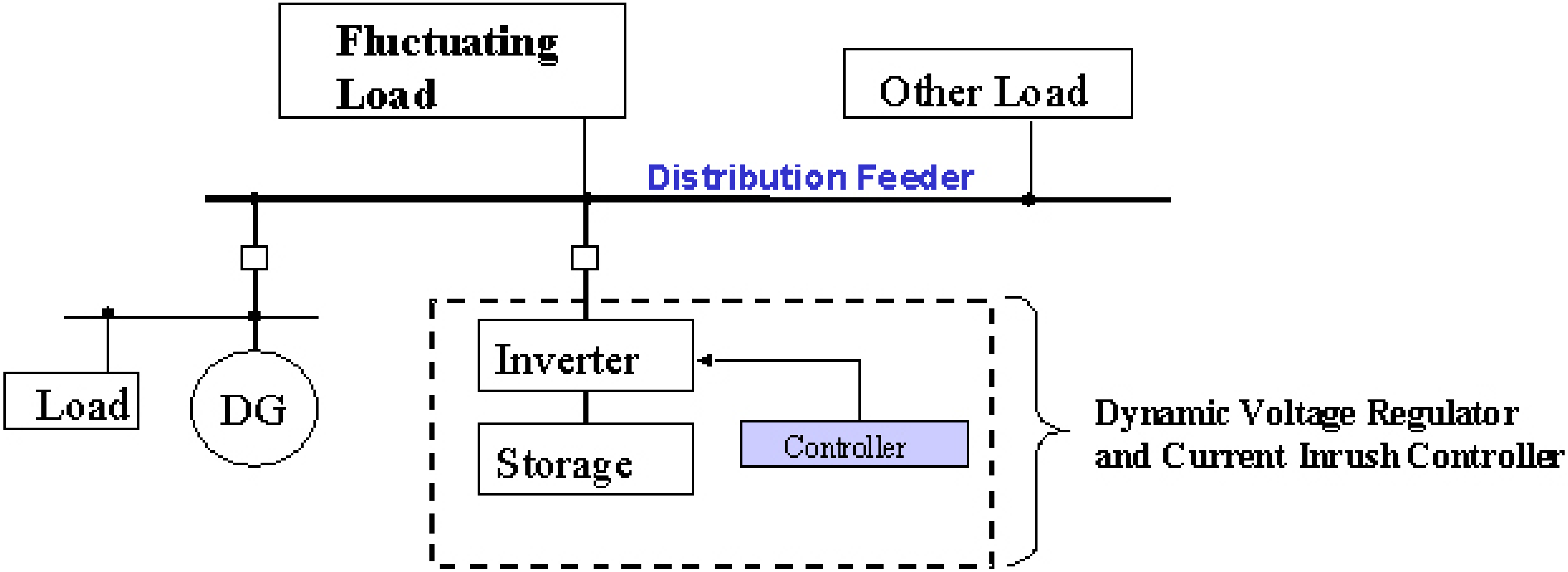
IV. Example Cases and Future Technology Applications

Instructor – Thomas Key and Haresh Kamath, EPRI PEAC

- **Electric Trains, Photovoltaics, Wind, and Hybrid Applications**
- **System Comparison Factors**
- **Advanced Topics**
- **Other Example Cases from Class Inputs**

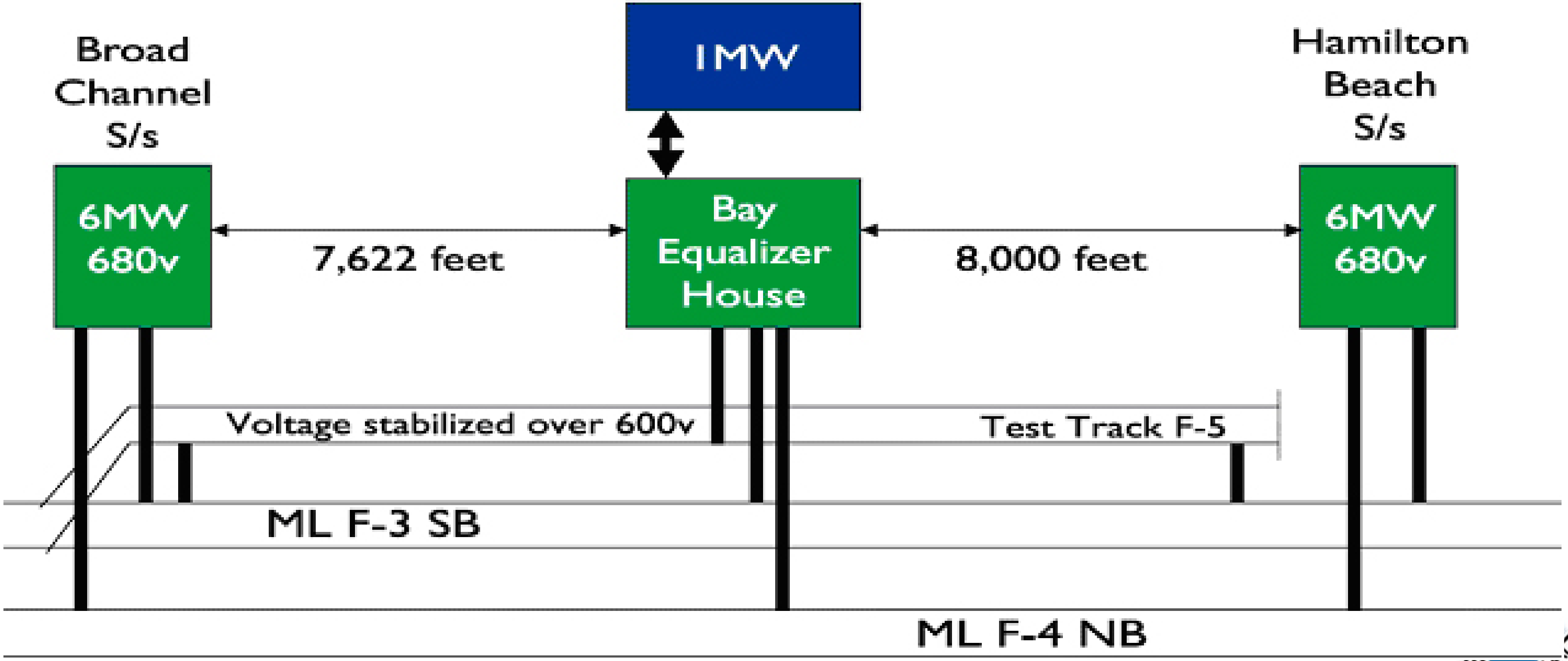
Energy Storage Application for Electric Train
Block Diagram And Electrical Schematic



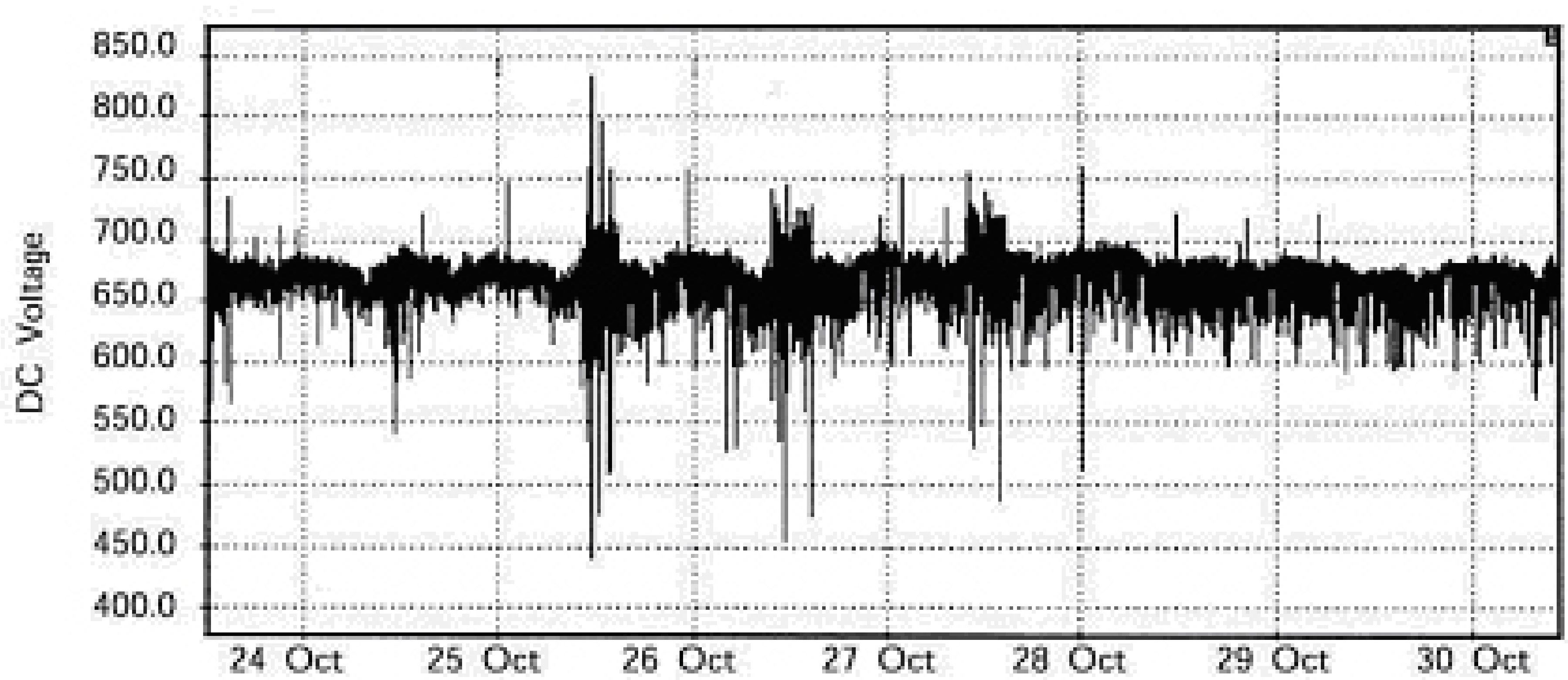
Application for Enhance Service to Fluctuating Loads

- **Application** – Provide local starting inrush current and absorb excess energy while mitigating bus voltage sags and swells
- **Power Level** – Depends on the size of the fluctuating load, .5-5 MVA (both real and reactive power required for ac load)
- **Energy Capacity – .**2 to 20 kWh
- **Duration** – Less than 30 seconds
- **Response Time** – 100 to 200 Milliseconds
- **Duty Cycle** – Variable depending on type of fluctuating loads and supply, may be continuous duty as automatic welding equipment.
- **Roundtrip Efficiency** – >90% (assumes less than 10% duty cycle)**Standby Losses -** < 3%
- **Plant Footprint** – .1 MW/m^2
- **Environmental Issues –** EMI, EMF, Aesthetics

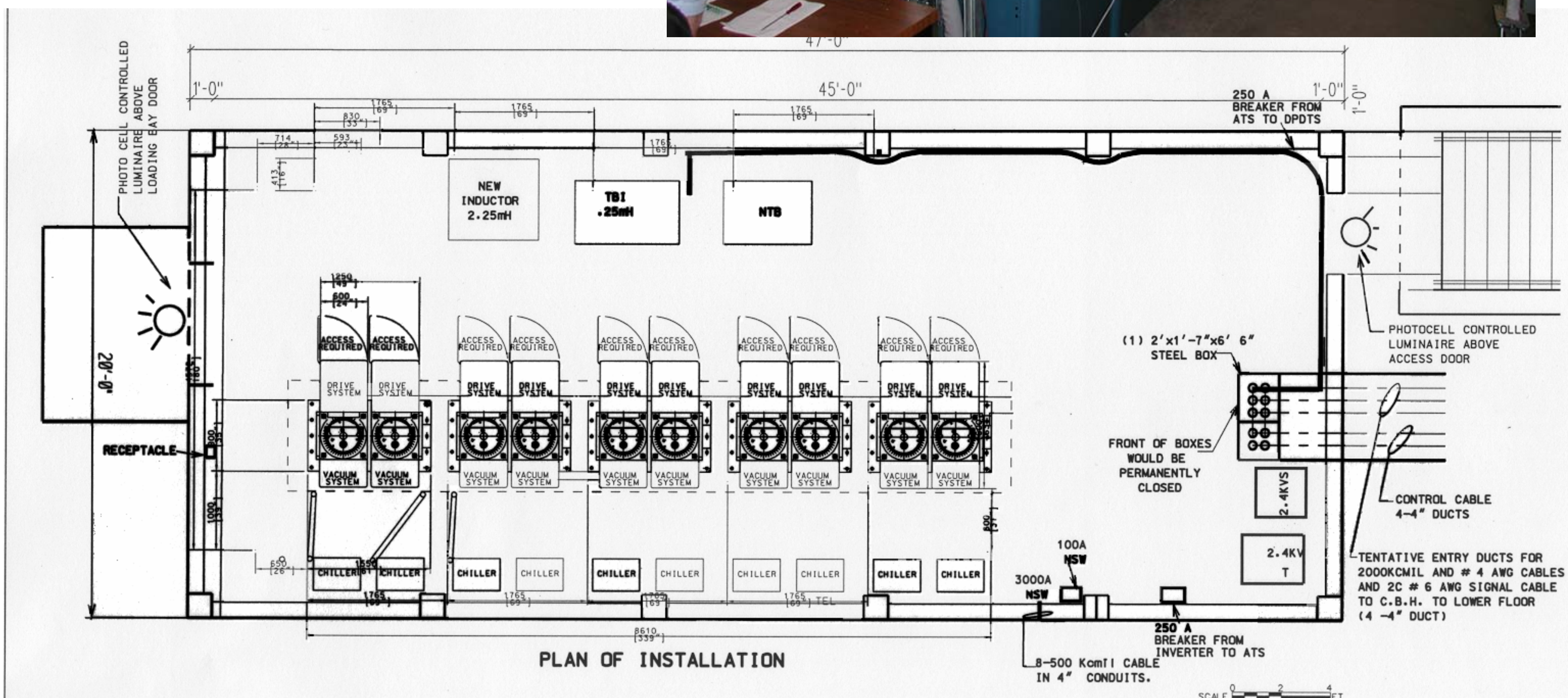
Two 6-MW Substations (NYPA) and 1MW Storage (NYCT) Serve Subway Station



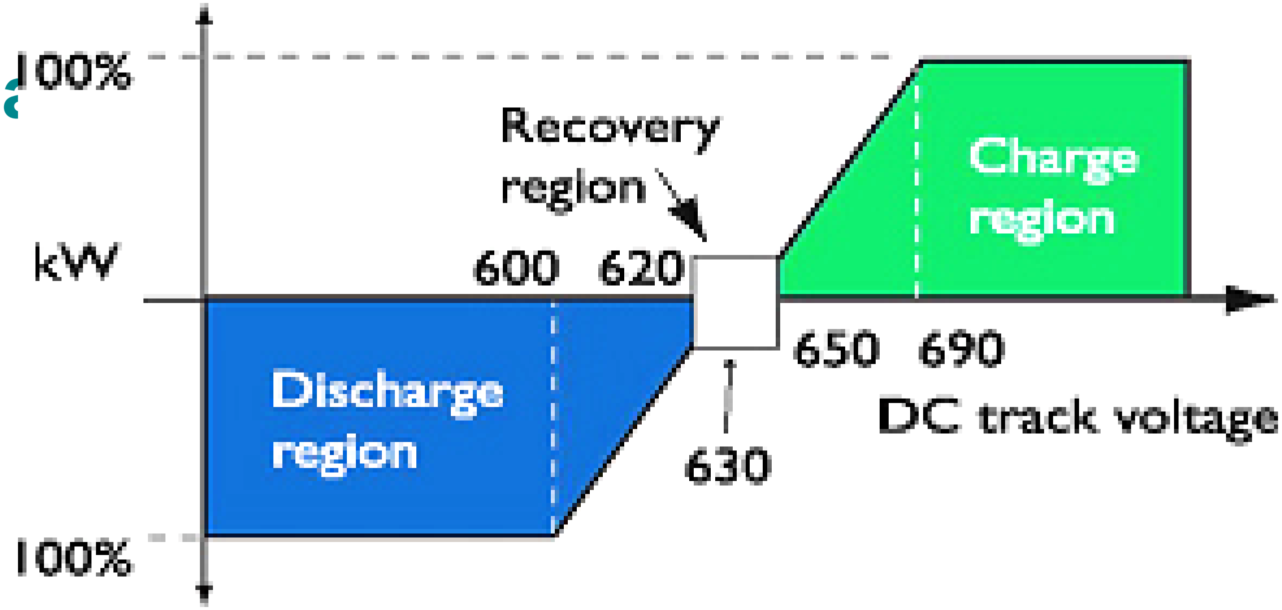
Typical Voltage Profile At The Far Rockaway Test Track In October 2001



1-MW Flywheel Installation

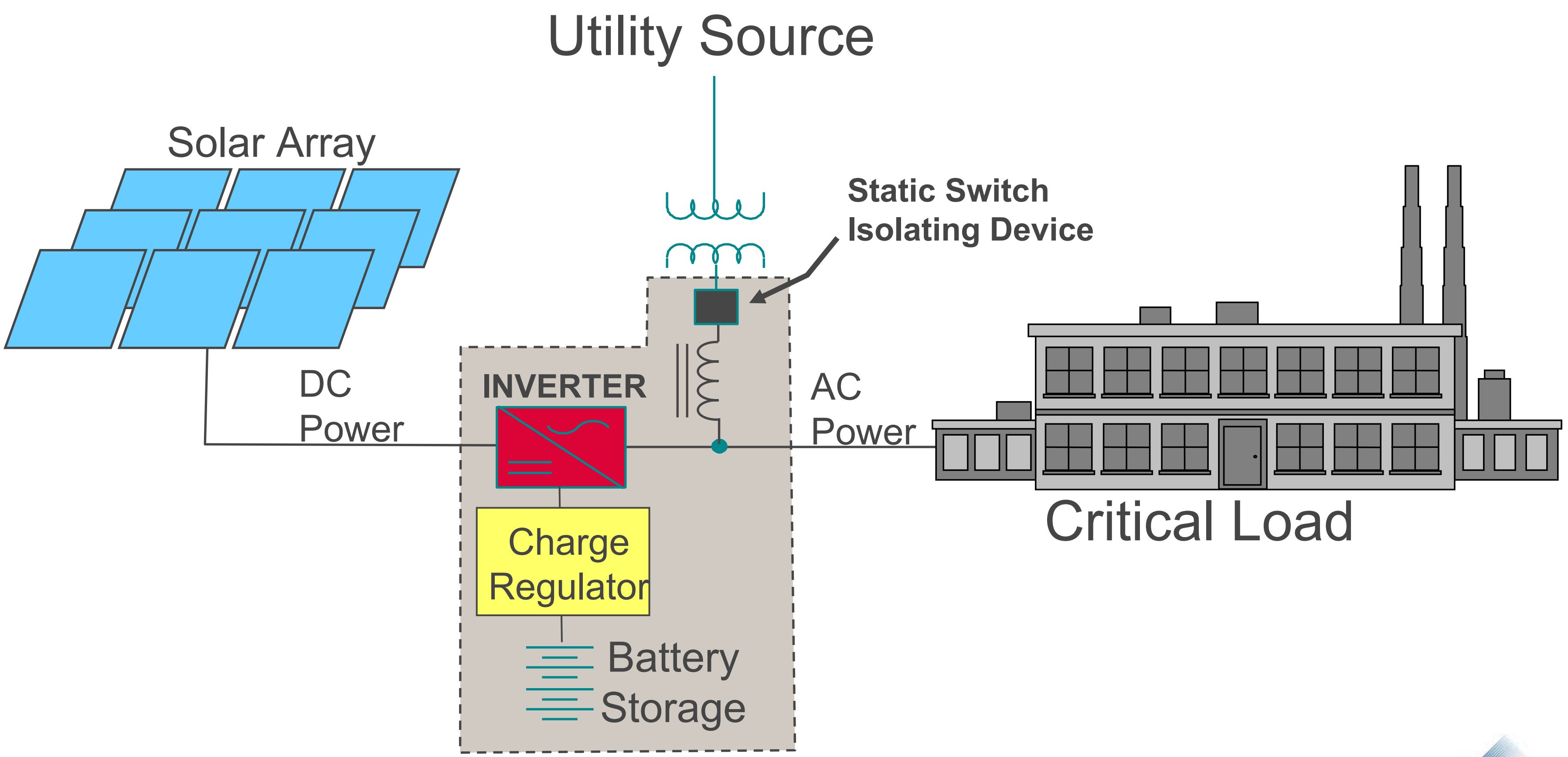


Benefits Rea

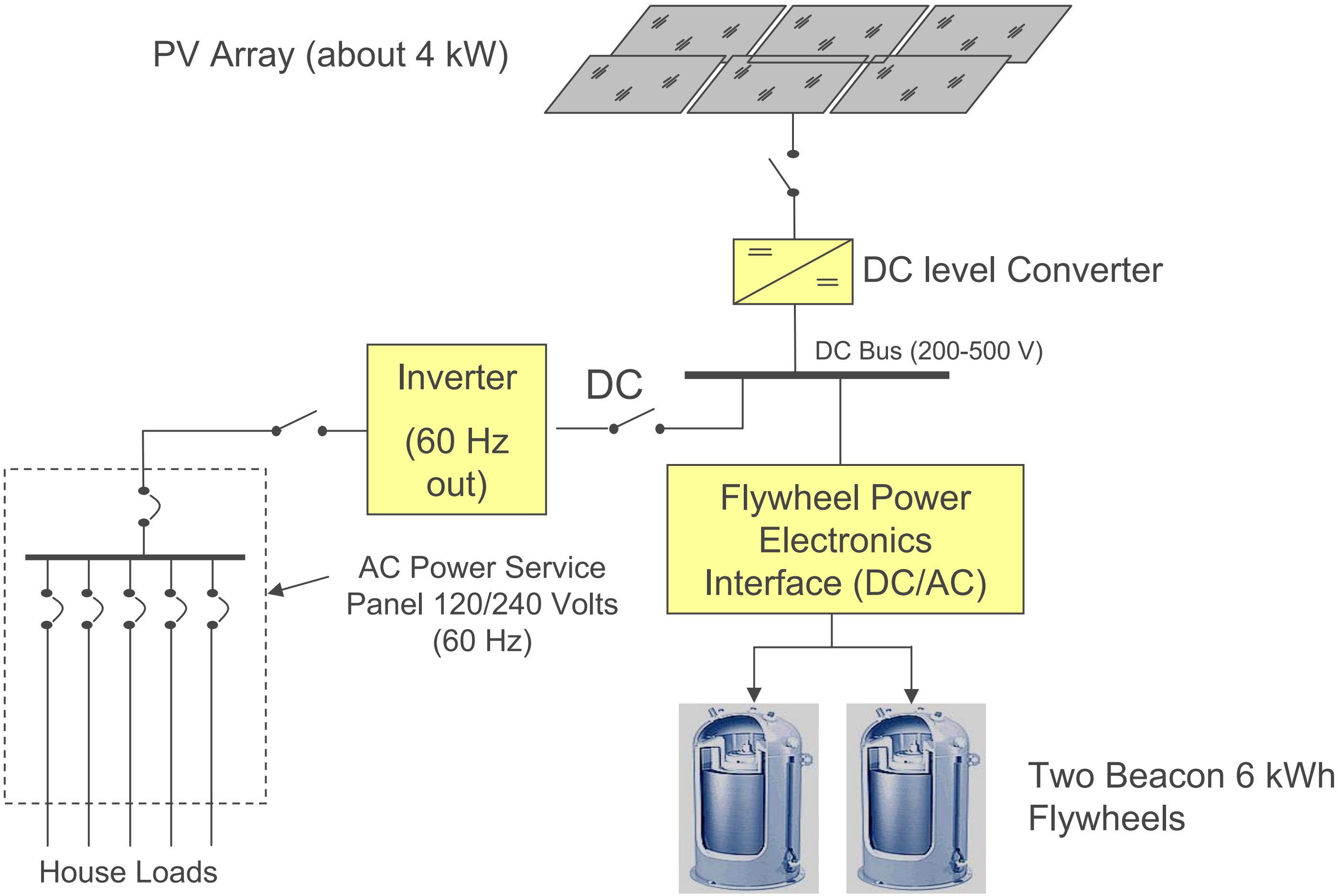


1. Third-rail voltage regulation improvement allows operation of new more efficient AC trains.
2. Cost savings for reduction in demand charges are 10-15% of total electric bill.
3. Energy savings from recaptured regenerative braking, not coincident with train starts, is 7-25%.

PV Assisted UPS



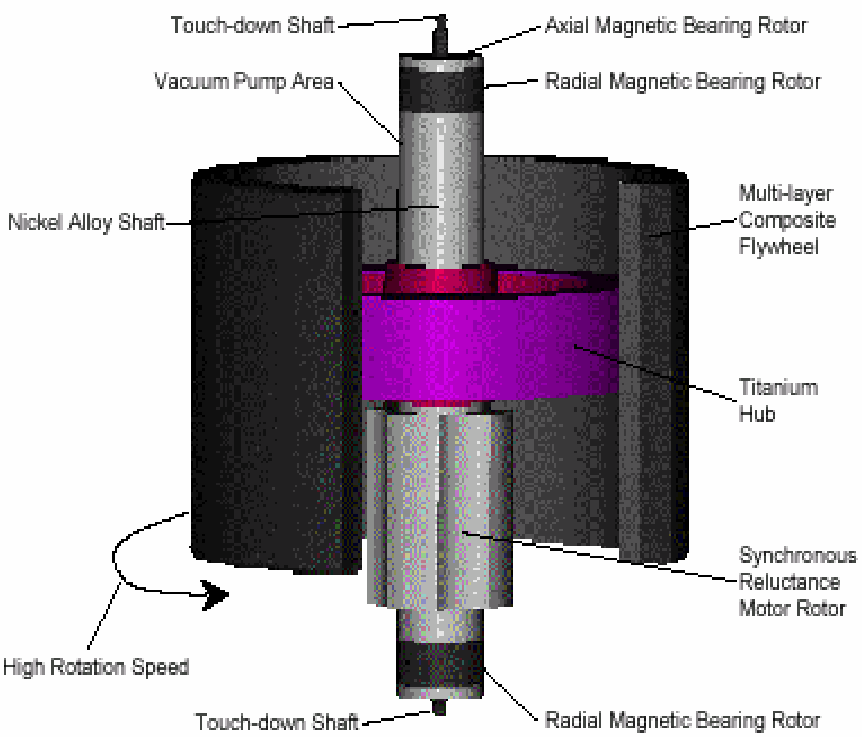
Flywheel Storage Field Test With PV (Off-grid Version)



Battery-Less UPS

EPRI Project Opportunity

Laboratory and Field Testing of Flywheel-Based UPS Technologies

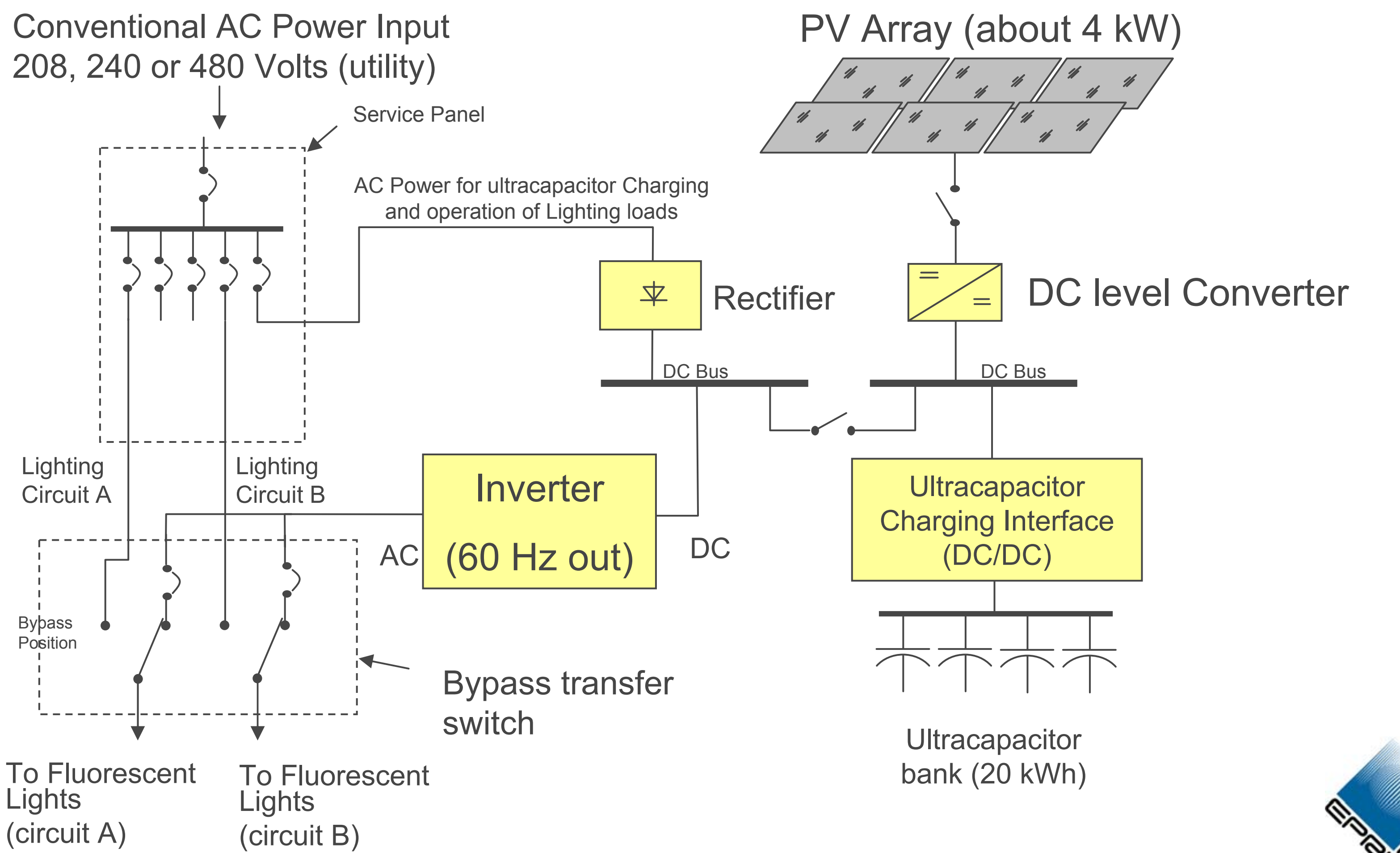


Replacement of traditional batteries with flywheel energy storage systems is becoming more and more common.

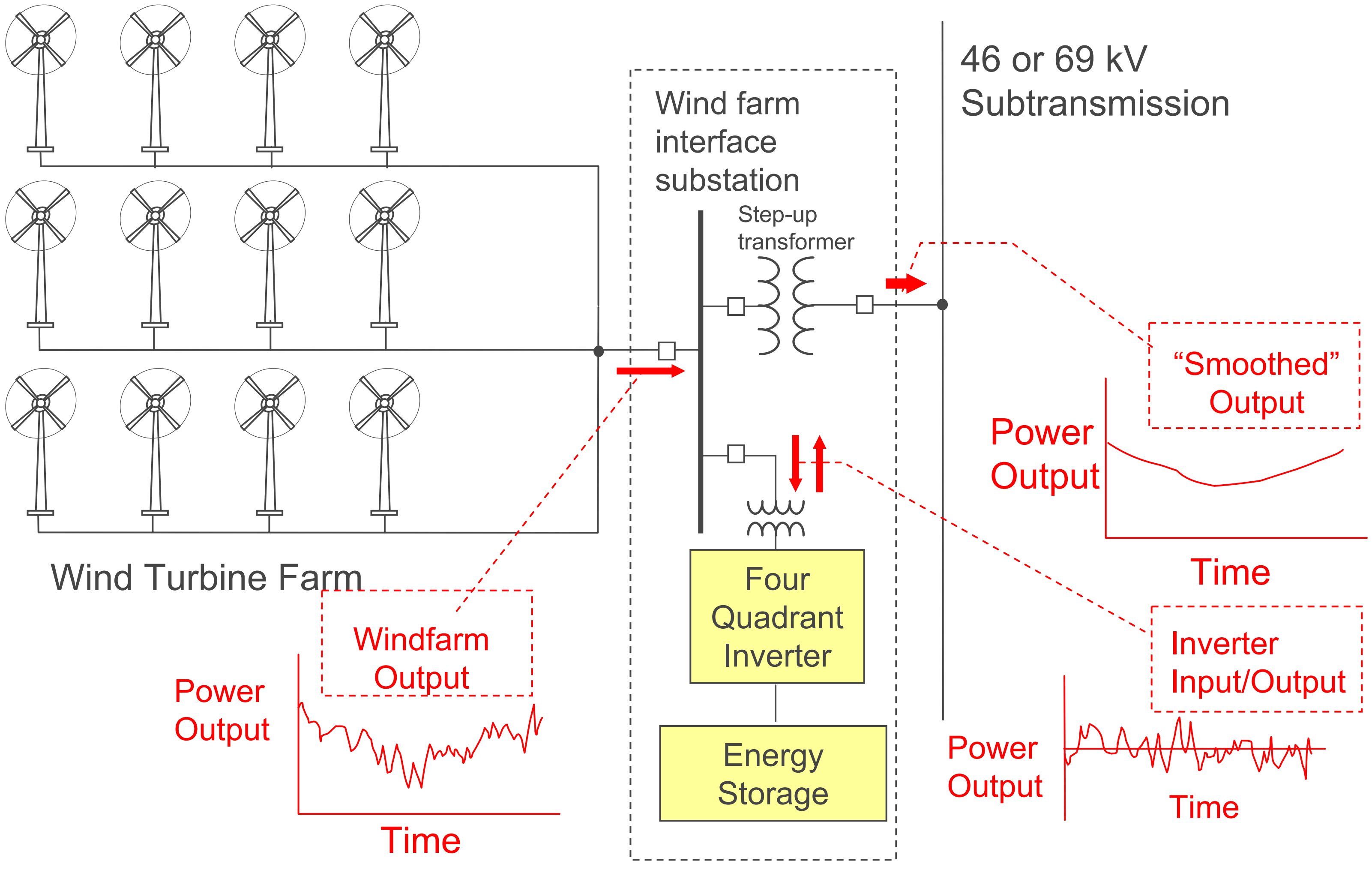
- Batteries have a finite number of charge and discharge cycles. A three-year battery is good for approximately 200 full discharges, and a five-year battery is good for approximately 400 full discharges.

Advancement in battery technology has been slow to come, whereas other energy-storage technologies have flourished and are becoming cost-competitive with battery-based energy-storage technologies without the necessary disadvantages. One key issue that will promote non-battery-based technology is the characteristic of typical voltage sags and momentary interruptions. Because most of these disturbances are short duration (<1 second), battery-based technologies are inherently inefficient to deal with these disturbances. In addition, because most mission-critical applications in the commercial sector are protected by stand-by generators—which can be started in most cases under 10 seconds—any energy-storage technology that can inexpensively provide 10 seconds of ride-through with a higher reliability than batteries can be an attractive choice as

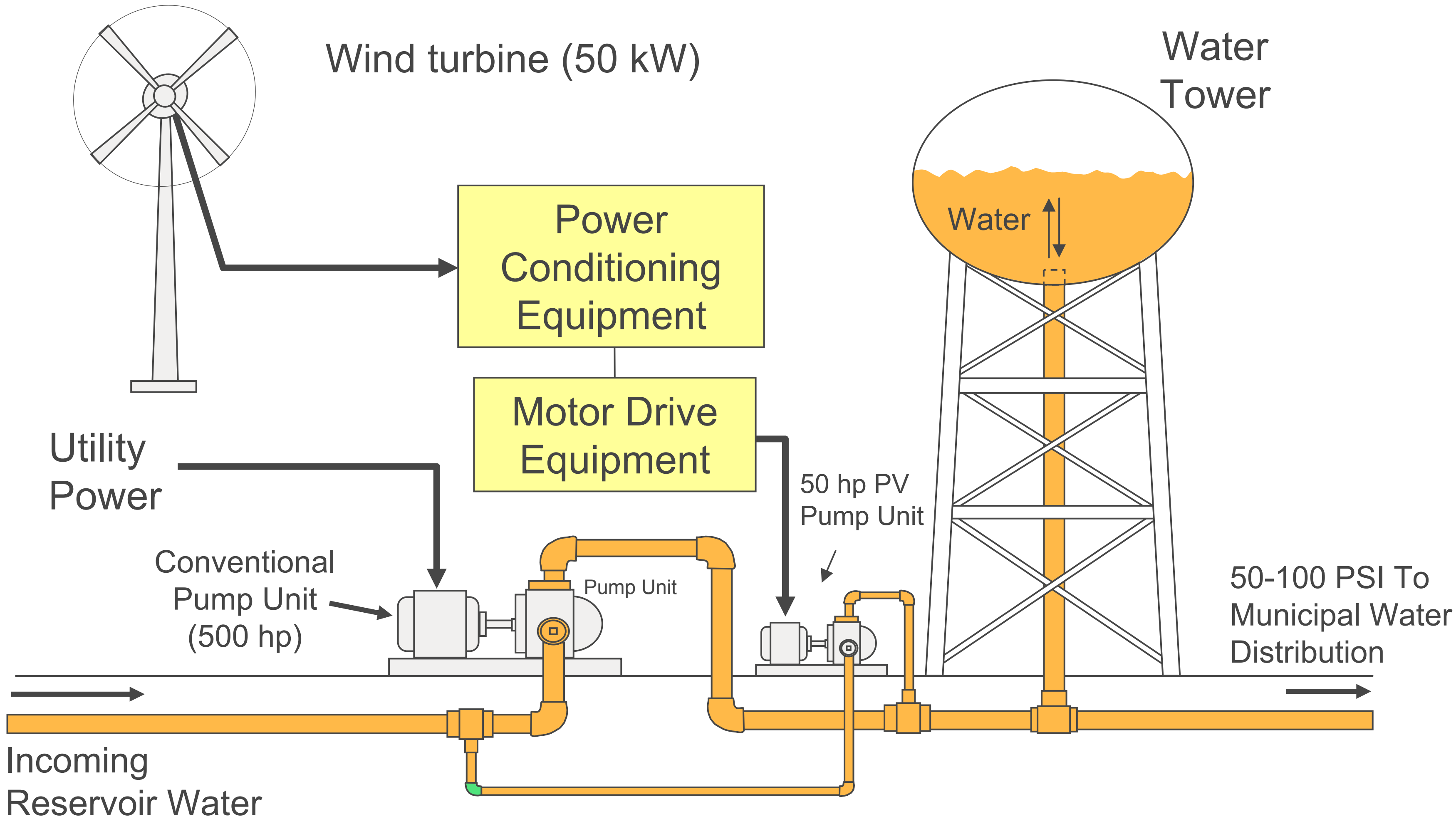
EC Capacitor Storage Field Test With PV (on-grid Version)



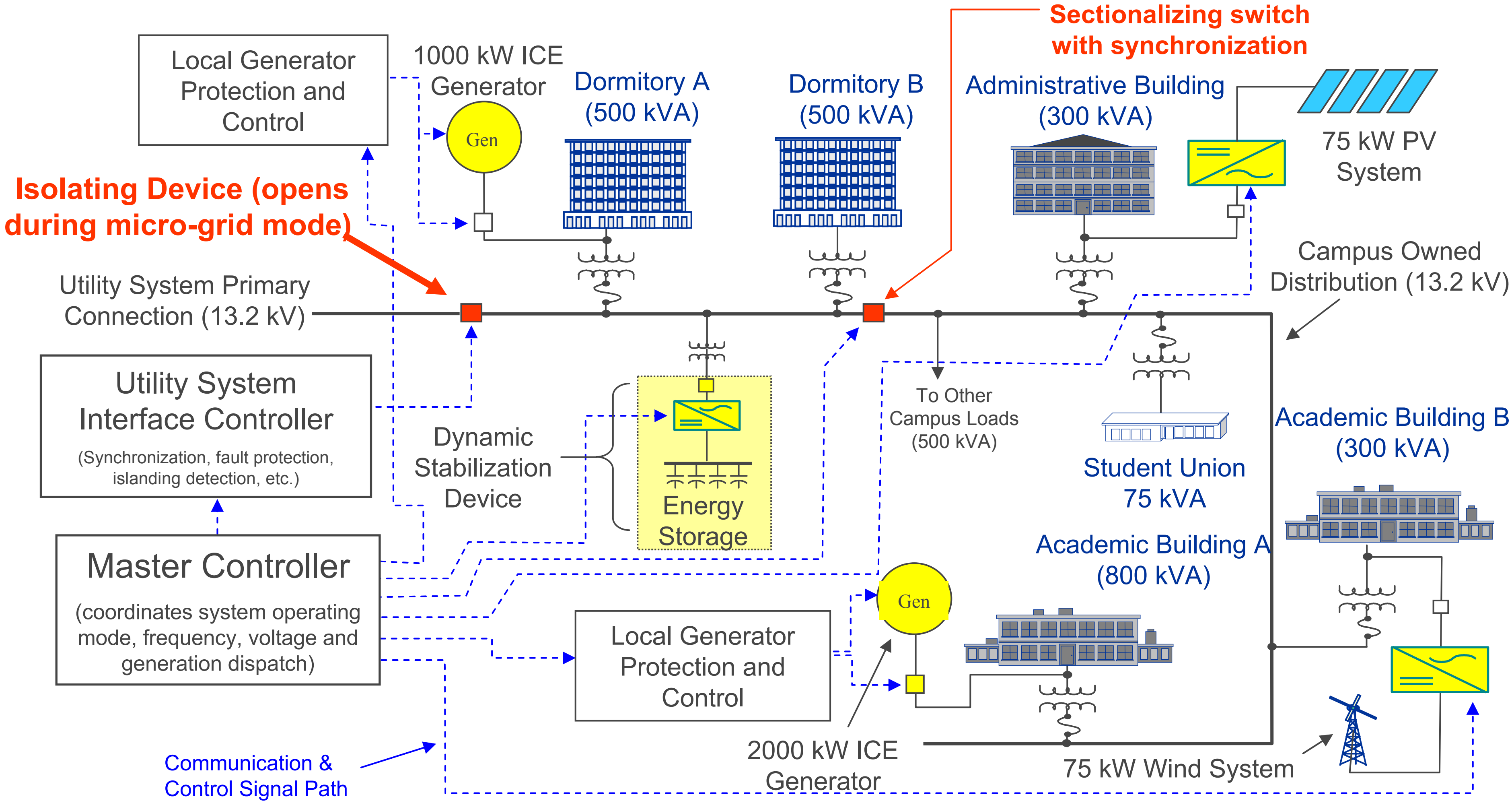
Dynamic Stabilizer Applied to Wind Farm



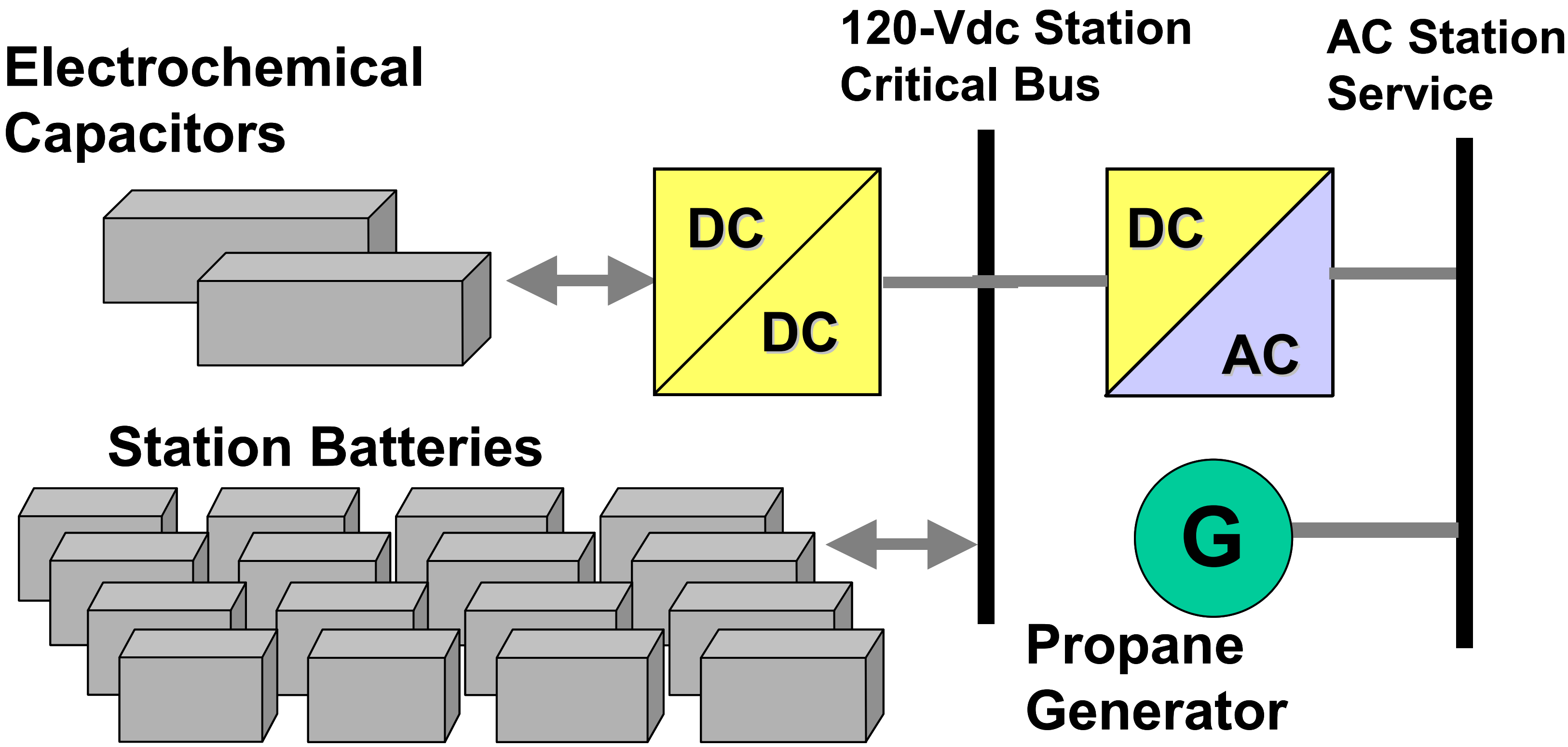
50 kW Photovoltaic Municipal Water Pumping



Microgrid Dynamic Stabilizer Application



Hybrid Energy Storage Application for a Substation Battery Support System



Specification for Substation Energy Storage System

- **Application** – High-inrush load support for a 48-kWatt-Hour station battery requirement (3 kW x 8 hours x 2)
- **Voltage Rating** – 120 Volts dc
- **Power Rating** – 36 kW (assumes 1.5 kW load x 12 for inrush)
- **Energy Storage Capacity –** 60 Wh
- **Duration** – 6 seconds
- **Response Time** – 5 milliseconds
- **Duty Cycle** – Infrequent, e.g. 10 times per month, 120 per year
- **Roundtrip Efficiency** – 70% (lower efficiency at maximum power)
- **No load Losses** – less than 2%
- **Plant Footprint** – .5 m^2
- **Environmental Issues** – same as lead-acid batteries

Hybrid Energy Storage Application for Capacitors with Engine Cranking Battery

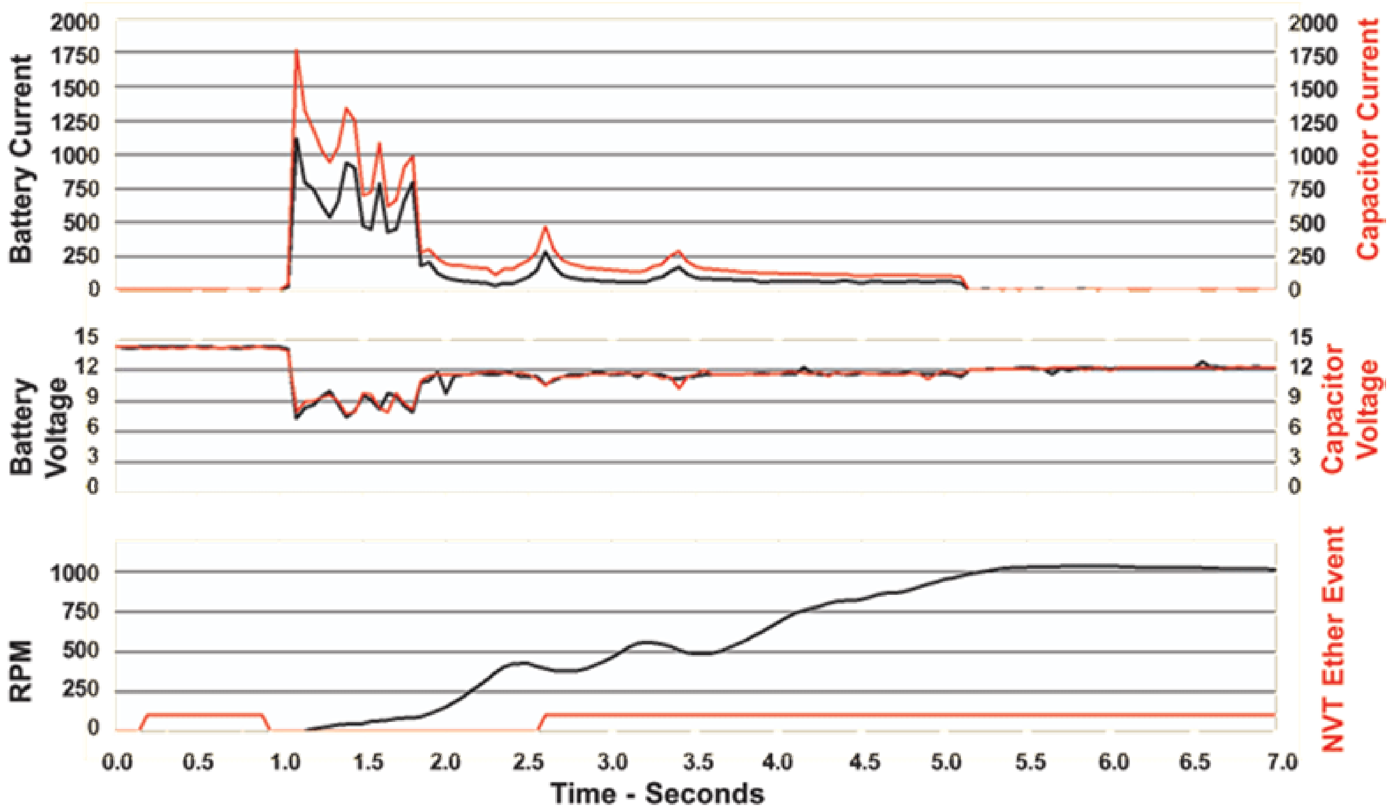
KBi DIESELMATIC NVT & KAPower Cold Test

These products will lower your operating costs and help relieve some of your biggest maintenance problems.

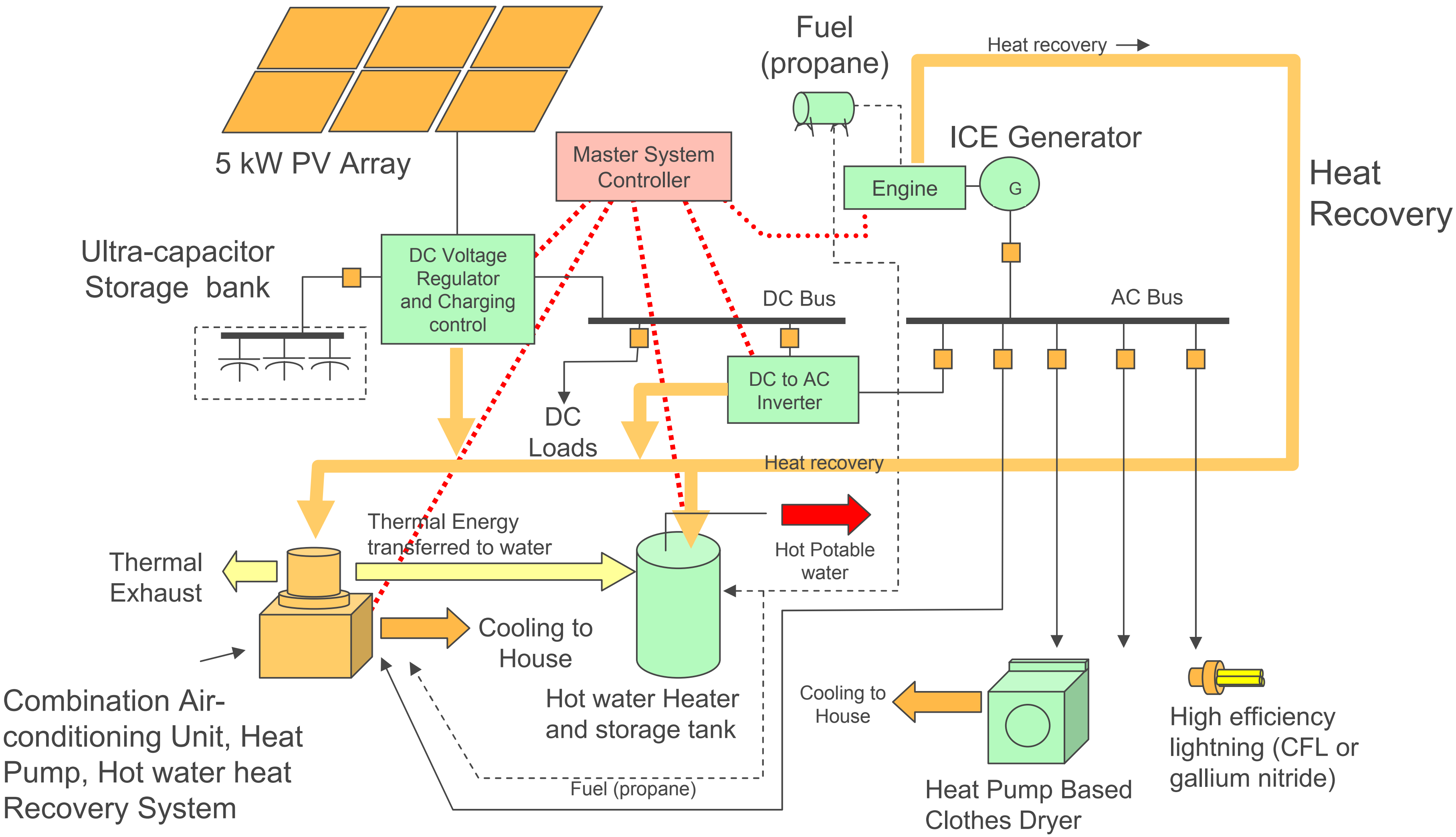
Test Date: 2-18-03
Test Temperature: -5°F (-21°C)
Cold Soak Duration: 22 Hrs.

Test Engine: 12.7 Liter with Trans. Prepared for Subzero Cold Starting

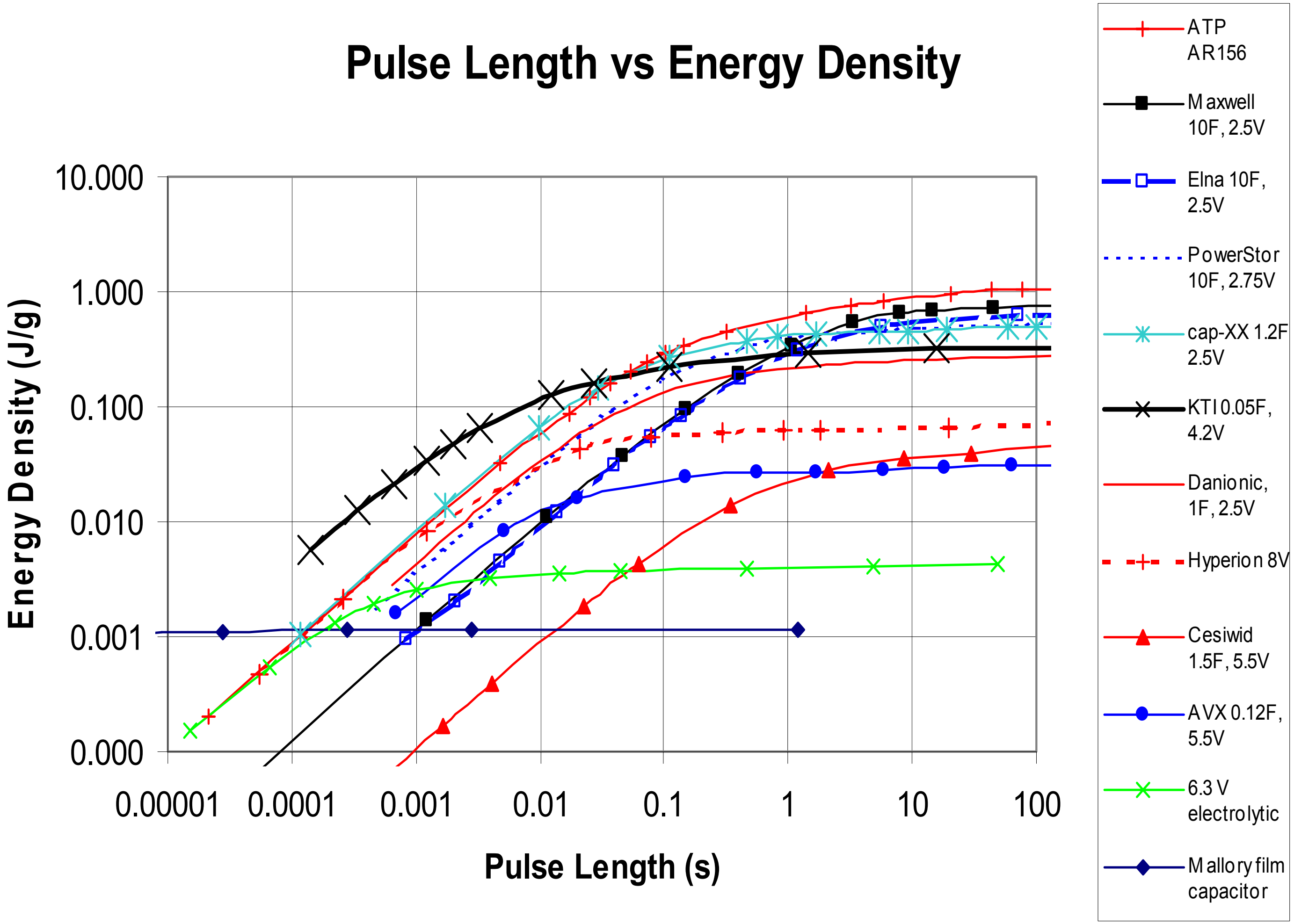
Capacitor: (1) KAPower 60 Kj
Battery: (1) Group 31



Hybrid thermal and EC capacitor for Off-grid Multi-Energy Based Home with PV

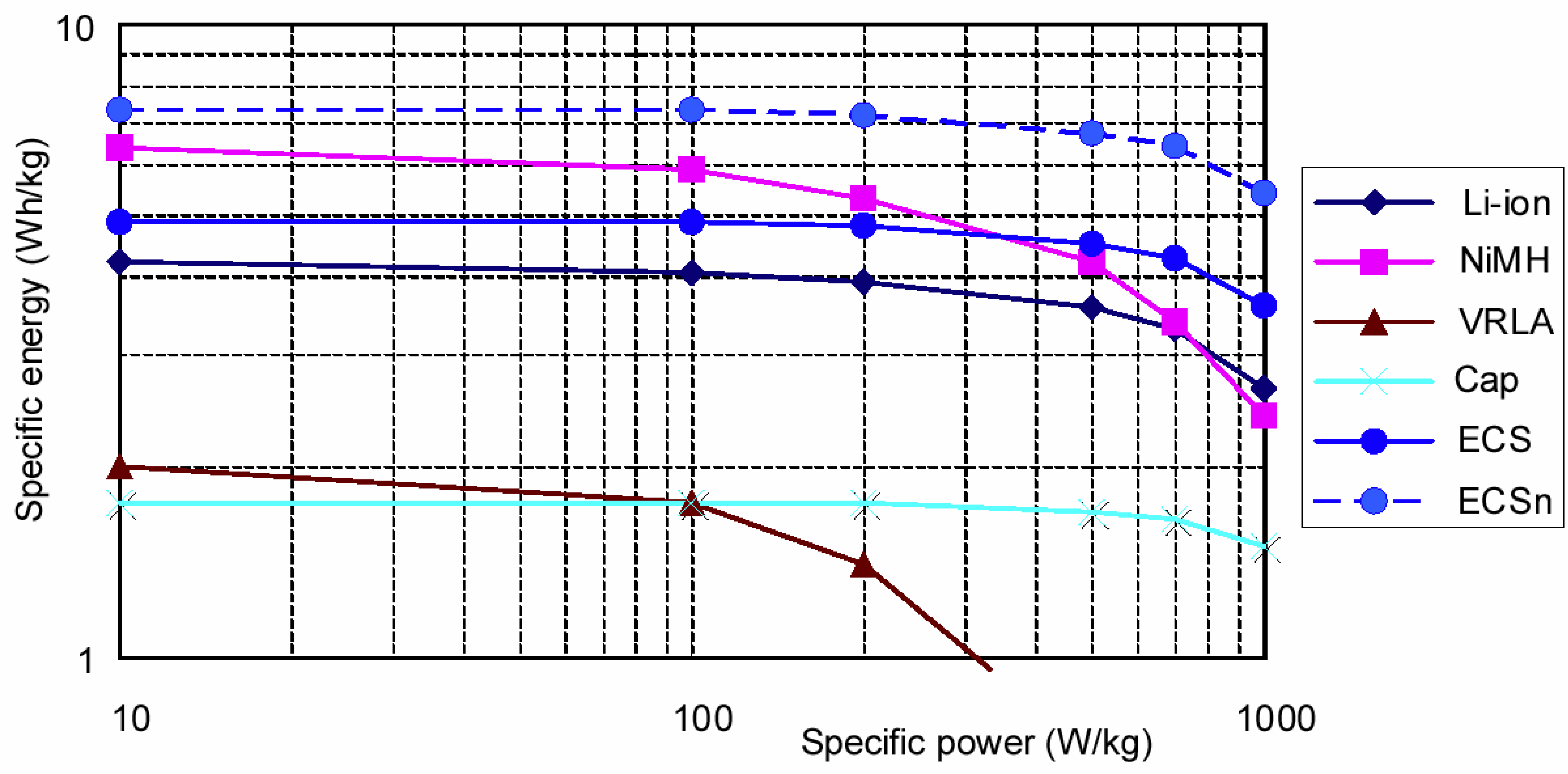


Advanced Topics: A "Pulsed Ragone" Plot



From Dr. John Miller, excludes resistive losses.

Advanced Topics:
"Ragone plots with life factors"



From Okamura, 11/02, Assumes DOD of Li-ion 7%, NiMH 10%, VRLA 5%, Cap 50%, and ECaSS capacitors (ECS and ECSnew) 75% [5]

Reference Chart - Typical Energy Storage Parameters for Available AC Bridging Power Systems

Bridging System	Types	System Rating[1]	Run time	Energy MJoule	Cost $/kW[2]	Watts/kg @ 15 sec[3]	kJ/kg @ 15sec
Lead Acid	Cranking	250 kW	30s	7.5	40-50	250-350	4-8
U-Caps	Traction	250 kW	10s	2.5	130	300	4
U-Caps	Pulse	250 kW	10s	2.5	150	500	8
LS Fly W	.9-3.6 kRPM	1340 kW	12s	16.1	250	200-250	3-3.5
HS Fly W	5-50 kRPM	250 kW	12s	3.0	100	200-250	2-2.5
Mag. Coil	SMES	600 kW	2	1.2	600	N/A	N/A

1. **Energy storage rating is ~10-25% higher than system rating to cover conversion losses.**
2. **Equipment first cost for energy storage element at rated time (life cycle cost not considered).**
3. **Weight used is for energy storage components of commercial product not theoretical.**

Reference Chart - Typical Conversion Technology Parameters for Available Bridging Power Systems

Bridging System Type	Power Converter Type[1]	Input/ AC Output Voltage	Output Regulate & Shape[2]	Conv. Eff.	Grid Isolation Method	Output Inter-Active[3]	Temp. Over-Load
Lead Acid	Inverter	400-570Vdc/480ac	PWM	95%	Static Switch	No	160%
U-Caps	Inverter	300-650Vdc/480ac	PWM	95%	Static Switch	No	200%
LS Fly W	Dc Gen/Invt	1800rpm/550Vdc	Dc Field	95%	Rectifier	No	N/A
LS Fly W	Induction Gen	1980rpm/480Vac	Ind. Gen.	96%	Series Choke	Yes	500%
LS Fly W	Induction M-G	1750rpm/480Vac	Sync W-P	84%	Mechanical	Yes	600%
HS Fly W	PM-Rect/Invt	H-F500Vac/480ac	PWM/filter	93%	SS & Choke	Yes	500%
HS Fly W	PM Gen/Rect.	400-800Vdc/800dc	Dc Field	94%	Rectifier	No	N/A
Mag. Coil	Dc to dc/Invt.	600Vdc/480ac	2x6P/filter	95%	Static Switch	Yes	230%

1. All converters are connected in parallel with the load except the LS Flywheel, Induction M-G.
2. Output voltage regulation and wave shaping when the system is isolated from the grid.
3. Output voltage stabilization is active in all operating mode, on grid, in transition and on standby.

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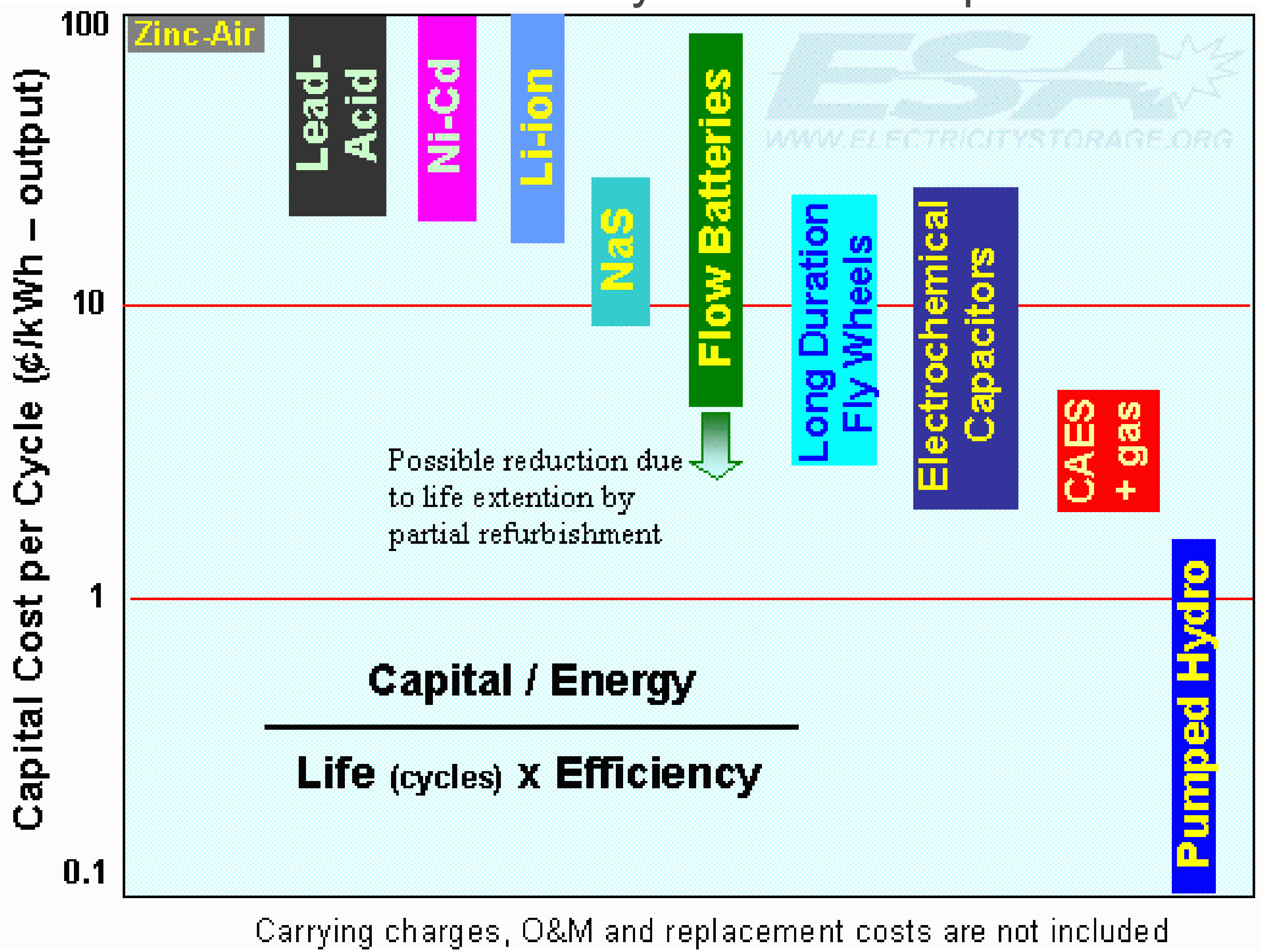
Reference Chart - General System Parameters for Typical Available Bridging Power Systems

Bridging System	System Rating[1]	System $/kVA	Recharge Method	Charge Time (s)	R-T eff.	Stby Loss	Maint. Level[2]	Temp. Cond.[3]	Transfer Method[4]
Lead Acid	250 kVA	$ 345	Aux charger	3600	75%	1.5%	Med	Yes	T. Switch
U-Caps	125 kVA	$ 640	dc-dc covt.	30	98%	2.0%	Low	No	via Rectifier
LS Fly W	250 kW	$ 83	IM motor	240	93%	1.0%	Med	No	via Rectifier
LS Fly W	2200kVA	$ 341	W-R IM/ASD	120	96%	4.0%	Med	No	via Clutch
LS Fly W	35 kVA	$1,000	IM motor	60	84%	N/A	Med	No	Via M-G
HS Fly W	250 kVA	$ 335	PM motor	150	95%	2.0%	Low	No	T. Switch
HS Fly W	100 kW	$ 550	PM motor	40	92%	2.0%	Low	No	via Rectifier
Mag. Coil	750 kVA	$ 800	Sync inverter	90	97%	3.0%	Med	Yes	N/A

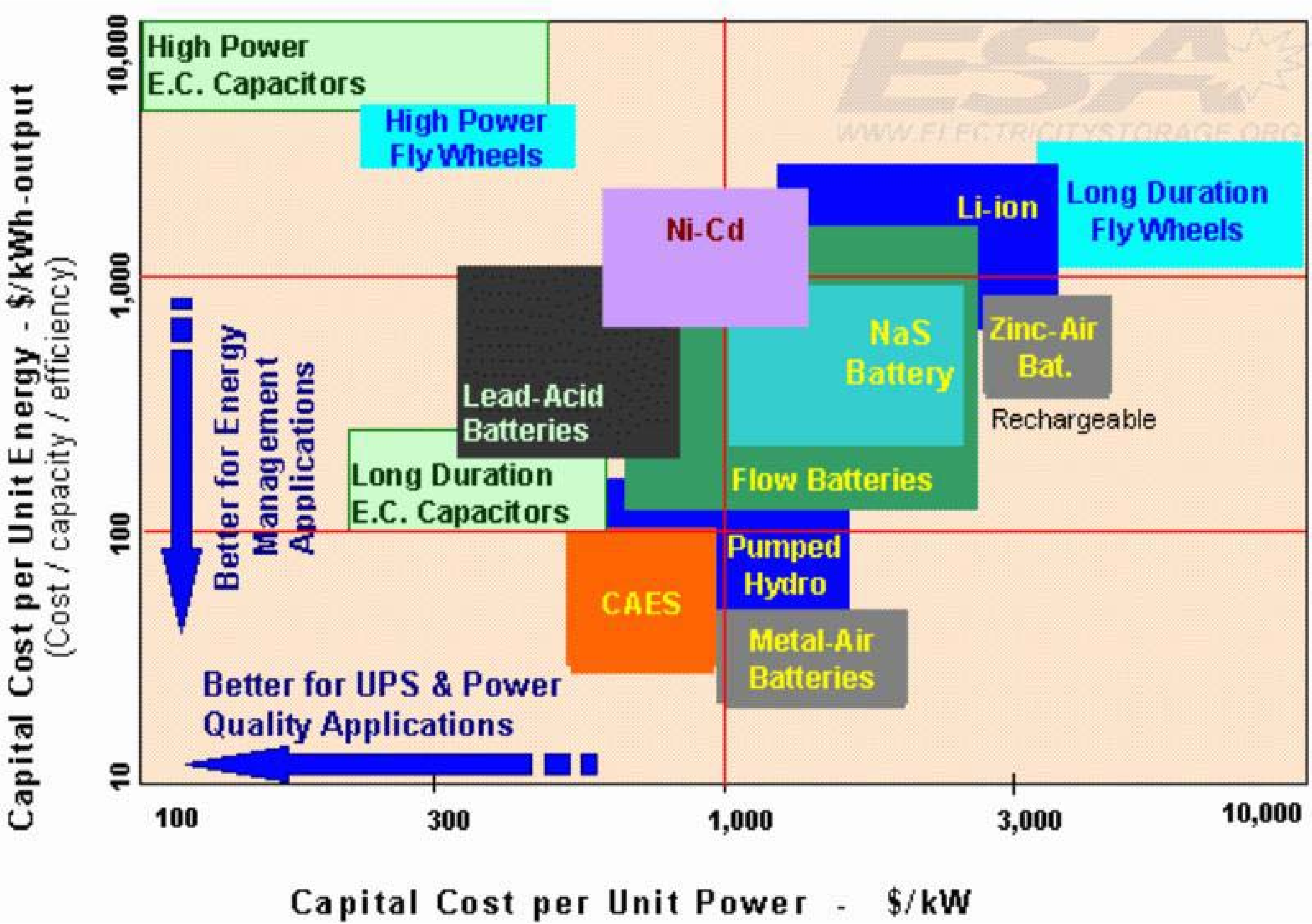
1. **Includes all the components constituting the overall system rating.**
2. **Subjective assessment based on components such as battery vs flywheel, air conditioning, and bearing types.**
3. **Temperature or environmental conditioning is used.**
4. **The device that allows connection to two power sources such as an automatic transfer switch, "T. switch."**

General Application Comparison Lifetime cost per kWh (from ESA)

based on estimated cycle life and capital costs.



General Application Comparisons - Power and Energy Costs (from ESA)



General Application Comparisons - Round Trip Efficiency

- One of the major issues to be considered in evaluating energy storage options, is the amount of energy that is lost in the storage process. Below are estimates of the typical energy efficiency of the five energy storage technologies:
- Compressed Air 80%
- Pumped Hydro 75%
- Batteries 75%
- SMES 90%
- Flywheels 80%
- UCAP >90%

General Applications Comparisons – Cost of Storage for Bridging Power

Unit	Power Rating	Available Energy in megajoules at 100% load	Dimensions: WxDxH For storage cabinet	Weight (lbs.)	Average Sell
Lead Acid Engine Starting Battery Assembly	250 kW	7.5 mj (30 sec. max)	44" x 40" x 53" (54 FT^3)	3,180	$12,036
Deep Cycle UPS Battery Pack	240 kW	108 mj (7.5 min typical)	86"x 33" x 78" (128 FT^3)	9,800	$23,960
High Speed Flywheel	240 kW	2.9 mj (12 sec. max)	41"x 36"x 82" (70 FT^3)	2,800	$33,750
Kinetic Battery	240 kW	7.5 mj (30 sec. max)	TBD	TBD	$50,000 (est.)

MJ energy storage module specifications for 250 kW applications