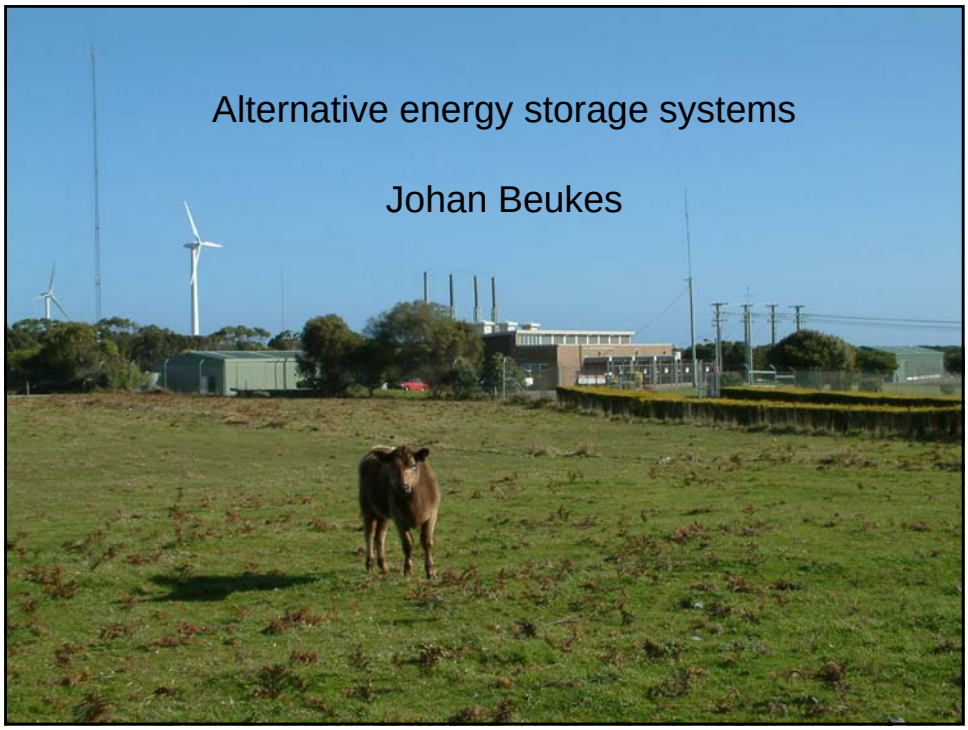


Overview

- Utility applications
- Requirements
- Capacitors
- Flywheels
- Compressed air systems
- Fuel cells
- Flow batteries
- Comparisons
- Application in network
- Other electrochemical systems

Utility applications

- Backup power during interruptions (standby)
- Match supply and demand (cycling)
  - Stress relieve on generators and transmission
  - Control frequency
  - Control voltage
  - Optimize losses
  - Optimal use of installed assets
  - Store renewable energy when available
- Improve voltage quality (cycling)

Requirements

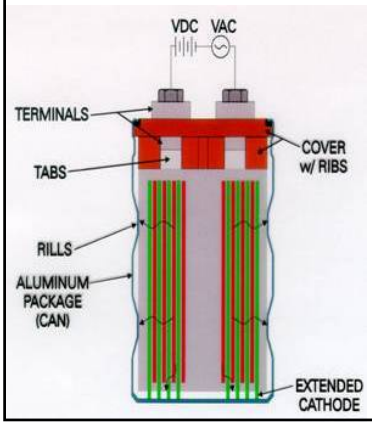
- Total cost of ownership
- Reliability
- Temperature tolerance
- Cycle depth
- Number of cycles
- Specific power
- Specific energy
- Round trip efficiency
- Standby losses
- Maintenance
- Environmental impact

Electrolytic capacitors

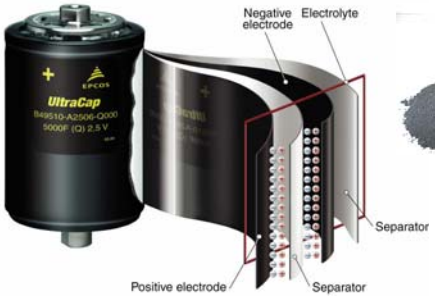
$$W(t) = -q(t)\int_0^d E(t)\mathrm{d}z = \frac{1}{2}\frac{q(t)^2}{C} = \frac{1}{2}Cv(t)^2 = \frac{1}{2}v(t)q(t)$$

$$\text{where, } C = \frac{\varepsilon A}{d}$$

- High specific power
- Low specific energy
- Life: 1 000 000 cycles, 15 years (45 ^{O}C)
- No maintenance
- High eff, no loss

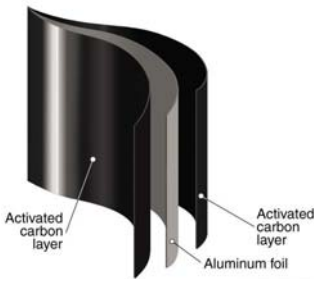


Ultra capacitors



- High specific power
- Specific energy 10 times EC
- Life: 500 000 cycles, 10 years
- 45 ^{O}C
- No maintenance
- High eff, no loss

- Activated carbon electrode material causes high energy content of Ultra Caps vs EC
- High specific surface area of about 2000 m^2/g and
- short distance between the opposite charges of the capacitors (2 ... 5 nm)



Beacon Flywheel

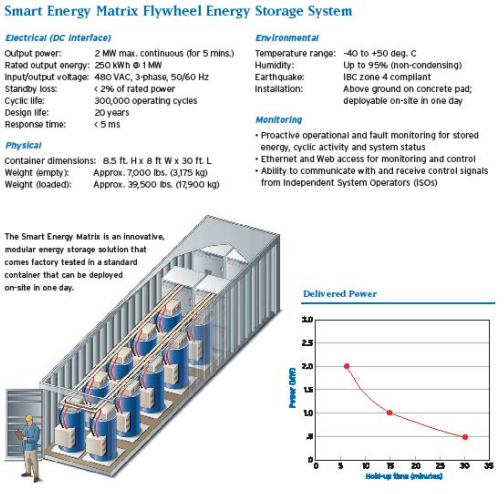
- Low specific power
- Low specific energy
- 20-year Design Life
- High Temperature Tolerance
- No maintenance
- 88% eff, 2% loss

Rotational energy as a function of moment of inertia and angular velocity

$$E_k = \frac{1}{2} \cdot J \cdot \omega^2$$

Optimise for angular velocity with the square relationship to energy
Composite materials, hydrodynamic or magnetic bearings, vacuumed

Beacon Flywheel



Smart Energy Matrix Flywheel Energy Storage System

Electrical (DC Interface)

Output power:	2 MW max. continuous (for 5 mins.)
Rated output energy:	250 kWh @ 1 MW
Input/output voltage:	480 VAC, 3-phase, 50/60 Hz
Standby loss:	< 2% of rated power
Cyclic life:	300,000 operating cycles
Design life:	20 years
Response time:	< 5 ms

Physical

Container dimensions:	8.5 ft. H x 8 ft W x 30 ft. L
Weight (empty):	Approx. 7,000 lbs. (3,175 kg)
Weight (loaded):	Approx. 39,500 lbs. (17,900 kg)

Environmental

Temperature range:	-40 to +50 deg. C
Humidity:	Up to 95% (non-condensing)
Earthquake:	IBC zone 4 compliant
Installation:	Above ground on concrete pad; deployable on-site in one day

Monitoring

- Proactive operational and fault monitoring for stored energy, cyclic activity and system status
- Ethernet and Web access for monitoring and control
- Ability to communicate with and receive control signals from Independent System Operators (ISOs)

The Smart Energy Matrix is an innovative, modular energy storage solution that comes factory tested in a standard container that can be deployed on-site in one day.

Delivered Power

About Beacon Power

Beacon Power Corporation designs, develops and delivers sustainable energy storage and power conversion solutions that provide reliable electric power for the utility, renewable energy and distributed generation markets.

Beacon Power Corporation
234 Ballardvale Street
Wilmington, MA 01887 USA

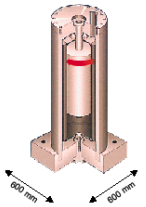
Tel: 1-888-938-9112
Fax: 1-978-694-9127
www.beaconpower.com

Beacon POWER.

0705

Urenco Flywheel

URENCO PQ Flywheel
Energy Storage System



Configuration

Two terminal constant voltage DC Flywheel Energy Storage System (FESS) complete with fully integrated high speed permanent magnet brushless DC motor generator.

Output

Constant DC voltage output.
Transient response, full load
< 5ms (with no disturbance to DC voltage).
Adjustable output range 600 - 750 V DC
(other by request).
DC Voltage regulation -\+ 1% nominal.
DC Ripple < 2V.

Input requirements

Float voltage range 600 - 750 V DC.
Minimum under voltage threshold 600 V DC.
Minimum charging current required 5 A DC.
Average standby current 1.5 A DC.
Minimum recharge time from complete discharge 18 seconds.

Power Delivery

(Delivery times quoted are at 700V rated output).

Total energy stored 18MJ.

Duration	0.5	0.8	1.2	1.6	2.0	2.4	2.8	(Minutes)
Rating	100	88	80	74	66	59	50	(kW)

System dimensions

(Assumes flywheel & control system mounted separately).

Flywheel physical dimensions

Height : 1500mm (59").
Footprint:600mm x 600mm (24" x 24").
Mass: 1200kg (2640 lbs).

Control panel physical size

(Standard control panel)

Height 2200mm (86").
Footprint 600 x 600 mm (24" x 24").
Weight 300kg (660 lbs).

Efficiency

System efficiency better than 92% (1 Cycle).
Flywheel efficiency better than 98%.

Environment

Operating temperature range
-20 / +40 Deg C.
Non operating temerature range
0 / +70 Deg C.
Humidity 0 / +95% without condensation.
Altitude up to 1850m (6000 feet).

Standard features

Flywheel silent running / zero vibration.
LCD display & control panel.
RS-232 communications interface.
Automatic full system self test every 10mins.
Remote Alarm status contacts.
WinCom remote monitoring.

urenco
Urenco (Capenhurst) Limited

www.TheFlywheel.com

CAESS (Pnu Power)

- Low specific power
- Low specific energy
- 20-year Design Life
- High Temperature Tolerance
- No maintenance
- Low complexity
- 80% (11%) eff, no loss

Scroll technology

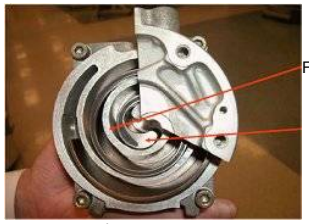
Ideal gas law for isothermal process and first law of thermodynamics:

$$PV = nRT = \text{constant}$$

$$W_{A\to B} = \int_{V_A}^{V_B} P\,dV = \int_{V_A}^{V_B} \frac{nRT}{V}\,dV = nRT\int_{V_A}^{V_B} \frac{1}{V}\,dV$$

$$= nRT(\ln V_B - \ln V_A) = nRT \ln\frac{V_B}{V_A} = nRT \ln\frac{P_A}{P_B} = PV \ln\frac{P_A}{P_B}$$

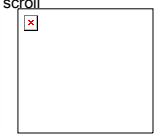
where, $P_A V_A = P_B V_B$ and so $\frac{V_B}{V_A} = \frac{P_A}{P_B}$



Fast response, only one moving part

High pressure air input

Fixed scroll



Orbiting scroll

Air pocket expands through sequence

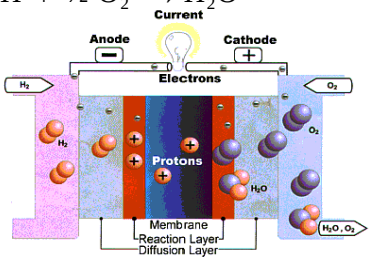
Fuel cell

(Plug Power 5 kW)

$$H_2 \rightarrow 2H^+ + 2e^-$$

$$2H^+ + \tfrac{1}{2}\,O_2 + 2e^- \rightarrow H_2O$$

$$H + \tfrac{1}{2}\,O_2 \rightarrow H_2O$$



- Independent sizing of power and energy
- No degradation of electrodes
- 45 °C
- Low maintenance
- 40% (11%) eff. no loss

plug power

Rugged, reliable design.

Flexible
Proton Exchange Membrane (PEM) Fuel Cell Stack – Proprietary fuel cell design delivers efficient, clean, quiet DC power. Integrated cell voltage monitoring provides continuous feedback for optimal fuel cell performance.
DC Power Conditioning – GenCore systems offer 48Vdc floating ground, 108Vdc floating ground or 120Vdc floating ground power conditioning to meet the needs of electric utility substations.

Reliable
Electrical Energy Storage – Maintenance-free system provides immediate response to power interruptions.
Fuel Storage System – Available in a variety of forms, hydrogen fuel storage is scalable to meet site and provider specific needs.

Robust
Thermal Management System – Freeze-tolerant design allows for operation from -40°C to 46°C.
Insulated Cabinet – Rugged design is finished with high-quality paint process that protects the exterior finish.

GenCore.

PRODUCT CHARACTERISTICS		5U48FG	5U108FG	5U120FG
Performance	Rated Net Output[1]	0 to 5,000 W	0 to 5,000 W	0 to 5,000 W
	Adjustable Voltage	46 to 56 Vdc (48)	111.8 to 126.8 Vdc (108)	126.9 to +136.2 Vdc (120)
	Operating Voltage Range	42 to 60 Vdc	111.8 to 132.0 Vdc	125.9 to +139.8 Vdc
	Operating Current Range (net)	0 to 109 Amps	0 to 44.9 Amps	0 to 39.9 Amps
Fuel	Gaseous Hydrogen	99.95% Dry	99.95% Dry	99.95% Dry
	Supply Pressure	80 +/- 16 psig (5.5 +/- 1.1 bar)	80 +/- 16 psig (5.5 +/- 1.1 bar)	80 +/- 16 psig (5.5 +/- 1.1 bar)
	Fuel Consumption	40 standard liters per minute at 3,000W	40 standard liters per minute at 3,000W	40 standard liters per minute at 3,000W
		75 standard liters per minute at 5,000W	75 standard liters per minute at 5,000W	75 standard liters per minute at 5,000W
Operation	Ambient Temperature	-40°C to 46°C	-40°C to 46°C	-40°C to 46°C
	Relative Humidity	0% to 95% Non condensing	0% to 95% Non condensing	0% to 95% Non condensing
	Altitude	-197 ft to 6,000 ft (-60 m to 1829 m)	-197 ft to 6,000 ft (-60 m to 1829 m)	-197 ft to 6,000 ft (-60 m to 1829 m)
Physical[2]	Dimensions	44" H x 26" W x 24" D (112 cm x 66 cm x 61 cm)	44" H x 26" W x 24" D (112 cm x 66 cm x 61 cm)	44" H x 26" W x 24" D (112 cm x 66 cm x 61 cm)
	Weight	400 Lbs (181 kg)	400 Lbs (181 kg)	400 Lbs (181 kg)
Safety	Compliance	FCC Class A	FCC Class A	FCC Class A
Emissions	Water	Maximum 1.75 Liters per hour	Maximum 1.75 Liters per hour	Maximum 1.75 Liters per hour
	CO, CO2, NOx, SO2	<1ppm	<1ppm	<1ppm
	Audible Noise	60 dBA @ 1m	60 dBA @ 1m	60 dBA @ 1m
Sensors[3]	Gas Hazard Detection	Included	Included	Included
Control	Microprocessor	Included	Included	Included
	2 LED Panel	Included	Included	Included
	Low Fuel Alarm	Included	Included	Included
	Communications[4]	RS-232C	RS-232C	RS-232C
		Digital Form C Contacts	Digital Form C Contacts	Digital Form C Contacts

[1] Output rated from -40°C to 42°C. From 42°C to 46°C, output decreases 2.5% per degree Celsius. Above 1,000 feet (305 meters), an additional de-rating of 1.5% per 1,000 feet applies.
[2] Excludes fuel storage.
[3] Optional sensors are available to detect Pad shear, water intrusion and tampering.
[4] Optional communications include MODEM.
Specifications subject to change without notice.

PLUG POWER INC.
HEADQUARTERS
968 Albany Shaker Road
Latham, New York 12110
Phone: 1.518.782.7700
Fax: 1.518.782.9060

EUROPE
P.O. Box 880
7301 BC Apeldoorn
The Netherlands
Phone: 31 55 53 81 000
Fax: 31 55 53 81 099

www.plugpower.com

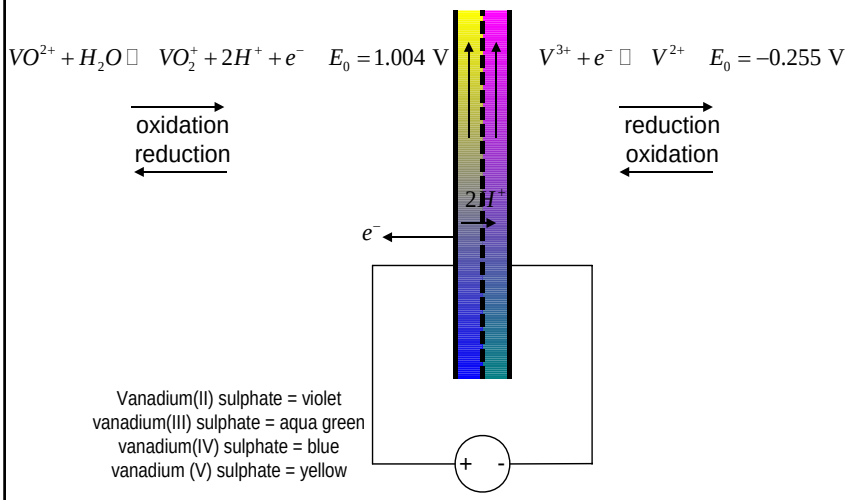
Flow batteries (VRB)

3.3 kW, 10 kWh

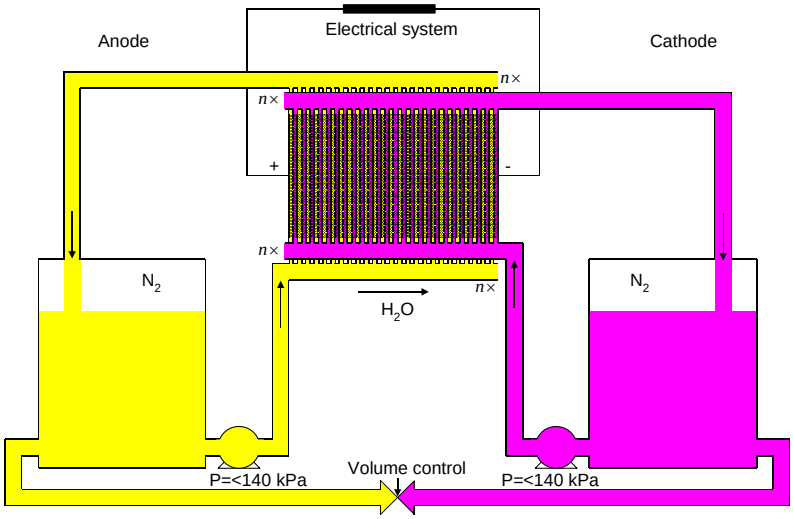
- Independent sizing of power and energy
- No degradation of electrodes
- High cycle
- 62-80% eff, 2% loss

- Low specific power
- Low specific energy
- Life: unlimited cycles, 15 years (45 ^{O}C)
- No maintenance
- Complex system

Flow batteries (VRB)



Battery assembly

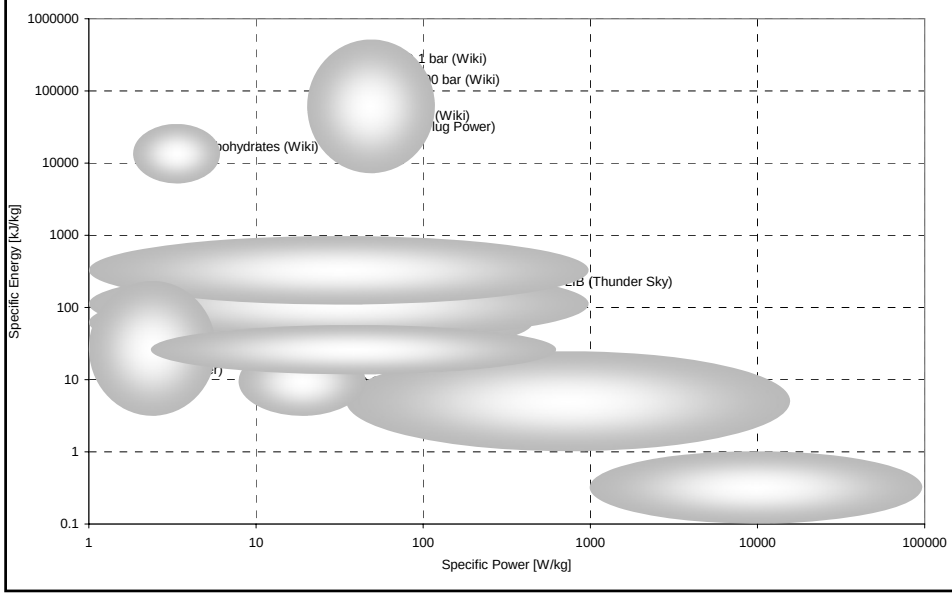


King Island installation

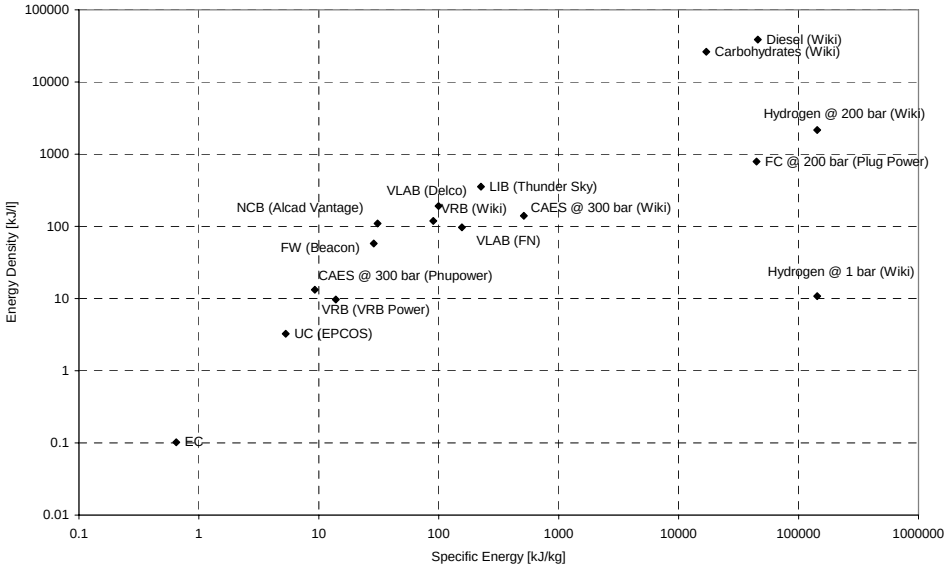
200 kW, 800 kWh

Overview

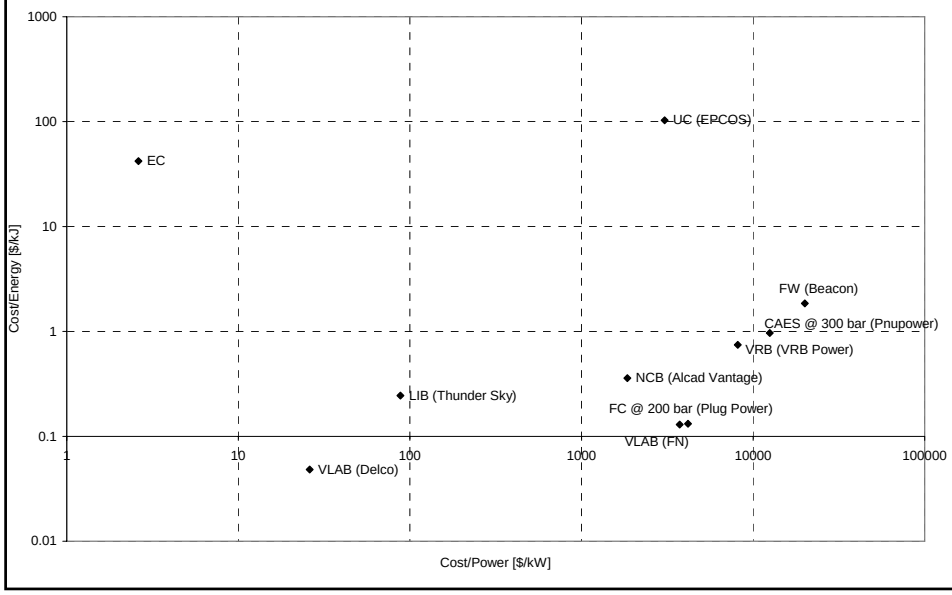
1 Wh = 3.6 kJ



Overview

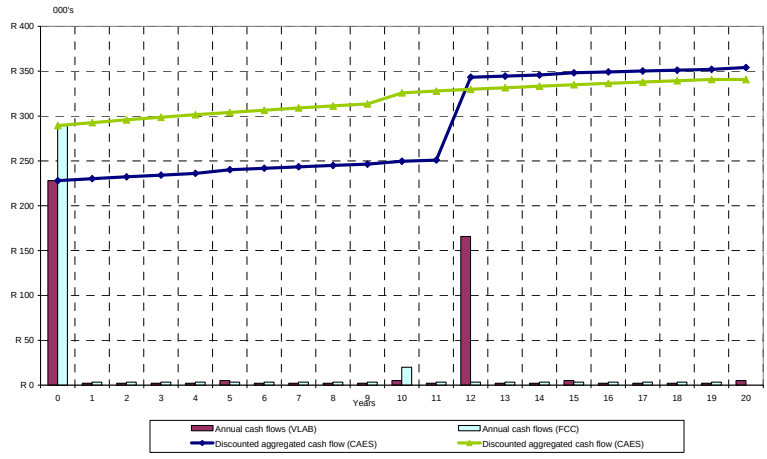


Overview of cost



Overview of cost

LCC comparisons between a 2 kW Pnu Power CAES system and a 288 Ah VLAB system



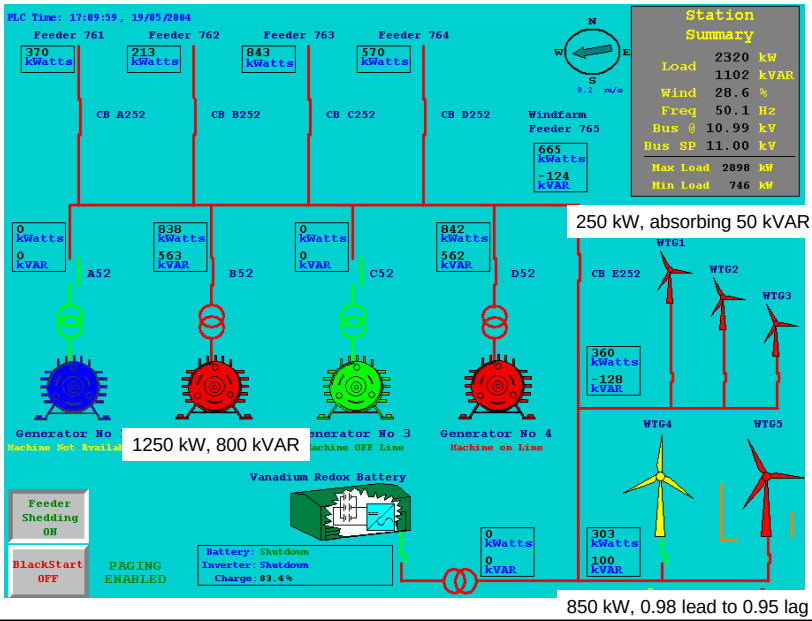
Castle Valley Installation

Castle Valley Installation

King Island installation

System overview

System overview



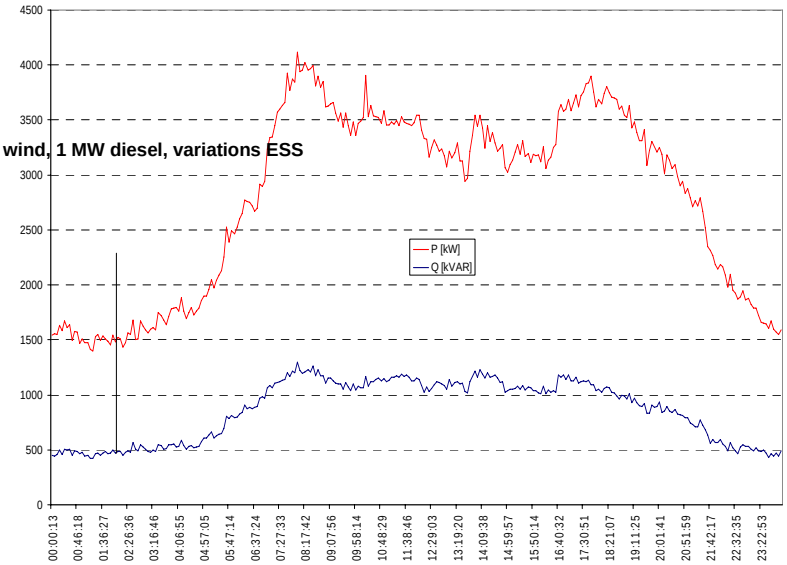
250 kW, absorbing 50 kVAR

1250 kW, 800 kVAR

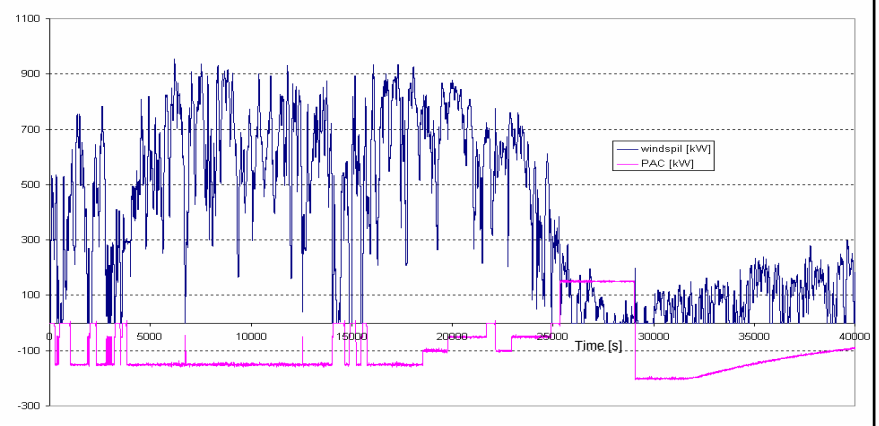
850 kW, 0.98 lead to 0.95 lag

Matching load to generation

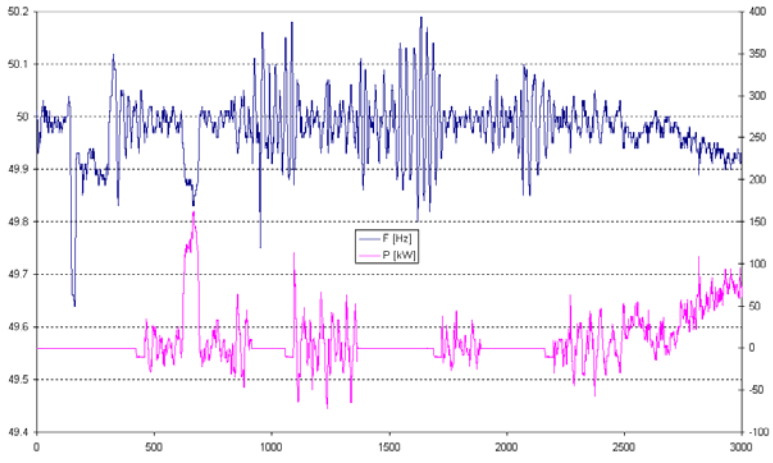
500 kW wind, 1 MW diesel, variations ESS



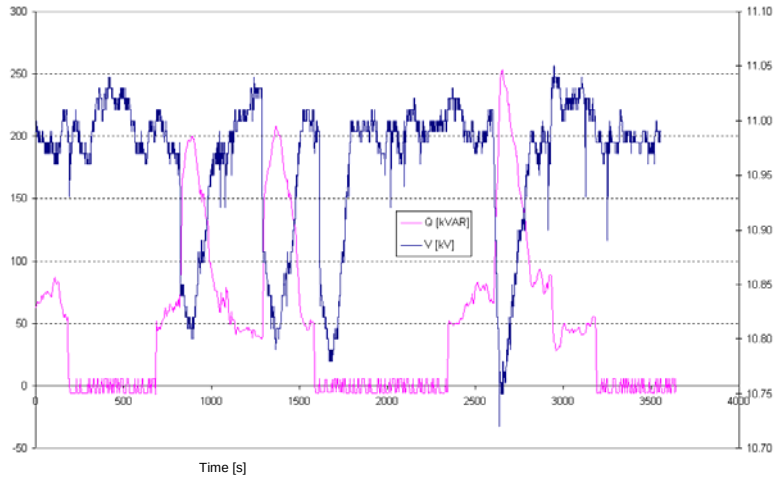
Matching load and generation



Frequency control



Voltage control



Voltage and frequency control