Product Overview

1.0 About VRB-ESS®

Pu Neng's VRB-ESS® is an electrical energy storage system based on the patented vanadium redox battery (VRB®) that converts chemical to electrical energy. Energy is stored chemically in different ionic forms of vanadium in an electrolyte. The electrolyte is pumped from storage tanks into cell stacks where one form of electrolyte is electrochemically oxidized and the other is reduced on either side of an ion exchange membrane. This creates a current that is collected by electrodes and made available to an external circuit. The reaction is reversible, and the electrolyte never wears out, allowing the battery to be charged, discharged and recharged a nearly infinite number of times.

Distinguishing features of the VRB-ESS® are:

- Product life exceeds 25,000 cycles at full power and 100% depth of discharge (DOD) and operational life greater than 20 years.
- Operation at partial states of charge (SOC) has no impact on life, allowing effective upward and downward ramp control.
- Fast dynamic response for transition between charge and discharge or between operating power levels as fast as 20ms.
- Proven performance and robust design yield high availability and low maintenance costs.
- System safety – systems are non-flammable and operate at low temperature and low pressure.
- The electrolyte can be fully recycled at end of project lifetime, saving cost and avoiding the expensive disposal costs other batteries.

2.0 System Description

Pu Neng offers two variants of the VRB-ESS®, defined by which version of the "Power Module" building block is used: the VRB-G2-HD or the VRB-G2-EX.

- **VRB-G2-HD MW-Class Power Modules** have a nominal rating of 250 kW AC, and have charge and discharge characteristics suitable for heavy duty, full-cycle energy management.

- **VRB-G2-EX MW-Class Power Modules** have a nominal rating of 340 kW AC, and have charge and discharge characteristics optimized for providing the maximum output power per unit cost.

Each VRB-ESS® can be combined with almost any volume of electrolyte, according to the requirements of a particular application. Typical configurations use four or six hours of storage depending on the application.

Performance specifications are summarized in the following sections:

- Section 1.1 describes the smallest possible system configuration, a single MW-Class Power Module;
- Section 1.2 describes the same characteristics for a 1MW power rating, incorporating multiple Power Modules in parallel configuration.

This document provides indicative performance figures only. Actual figures will depend on the intended application, environmental conditions, and options required at a particular site.

Each Power Module is composed of 12 stacks, pumps and controls. Tanks and power conversion system (PCS) are separate based on system energy rating.

2.1 System Characteristics – Single VRB® Power Module

Characteristic	VRB-G2-HD	VRB-G2-EX	Notes
Nominal output, AC	250 kW AC	340 kW AC	Active power only; see below for reactive component
Nominal output, DC	270 kW DC	365 kW DC	
Output, AC @ 95% SOC	250 kW AC	340 kW AC	
Output, AC @ 5% SOC	250 kW AC	265 kW AC	
Power factor	0.9		Defines rated reactive power
AC connection voltage range	400/480 VAC, 3-Phase		+/-10% variation allowable; voltages below nominal may limit power capacity
Response time	50 to 100ms		Excluding signal latency, fast response option available
Efficiency	80% DC, 70% AC		Nominal AC-in to AC-out, round-trip; efficiency varies as a function of operating conditions
AC connection frequency	50 / 60 Hz		± 5% variation allowable
AC current harmonics	Compliance with EN62103, IEEE519		
Operating ambient temperature	0°C to 50°C		Internal temperature regulated by active thermal management system. System must be installed within weather-protected enclosure or building.
Calendar life	20 years		Extended care package available
Cycle life	25,000+		Minimum value
Footprint, Energy Storage Options			
250 kW 4 hour	80 m^2	85 m^2	Indicative sizes; actual plant size will vary
250 kW 6 hour	85 m^2	90 m^2	

2.2 System Characteristics – 1MW Nominal Rated Power

Characteristic	VRB-G2-HD	VRB-G2-EX	Notes
MW-Class DC Power Modules required	4	3	
Nominal output power, AC	1,000 kW AC		Active power only; see below for reactive component
Output power, 95% SOC	1,000 kW AC	1020 kW AC	
Output power, 5% SOC	1,000 kW AC	800 kW AC	
Power factor	0.9		Defines rated reactive power
AC connection voltage range	400/480 VAC, 3-Phase		+/-10% variation allowable; voltages below nominal may limit power capacity
Response time	50 to 100ms		Excluding signal latency, fast response option available
Efficiency	80% DC, 70% AC		Nominal AC-in to AC-out, round-trip; efficiency varies as a function of operating conditions
AC connection frequency	50 / 60 Hz		± 5% variation allowable
AC current harmonics	Compliance with EN62103, IEEE519		
Operating ambient temperature	0°C to 50°C		Internal temperature regulated by active thermal management system. System must be installed within a weather-protected enclosure or building
Calendar life	20 years		Extended care package available
Cycle life	25,000+		Minimum value
Footprint, Energy Storage Options			
1 MW 4 hour	290 m^2	255 m^2	Indicative sizes; actual plant size will vary
1 MW 6 hour	310 m^2	270 m^2	

3.0 Performance Characteristics

Capacity and charging power curves of VRB system as below. Charging curves can be adjusted as required according to the application dispatch requirements. Note that the curves shown are for a nominal 1MW rated system power; performance figures can be scaled linearly according to the intended net rated system power.

Figure 1: Typical Charge and Discharge Profile, VRB-G2-HD, 4 Power Modules

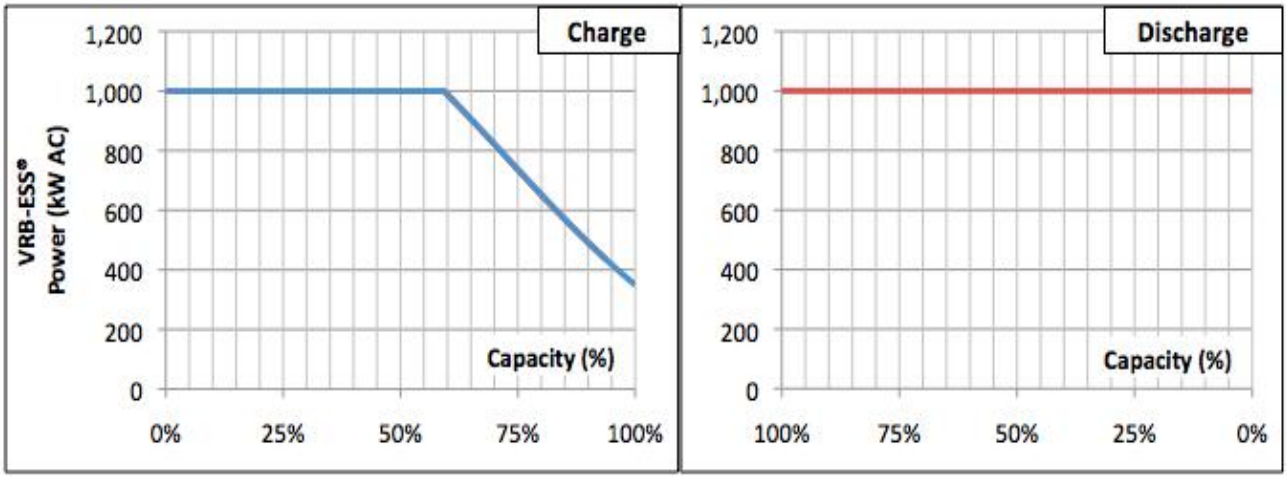
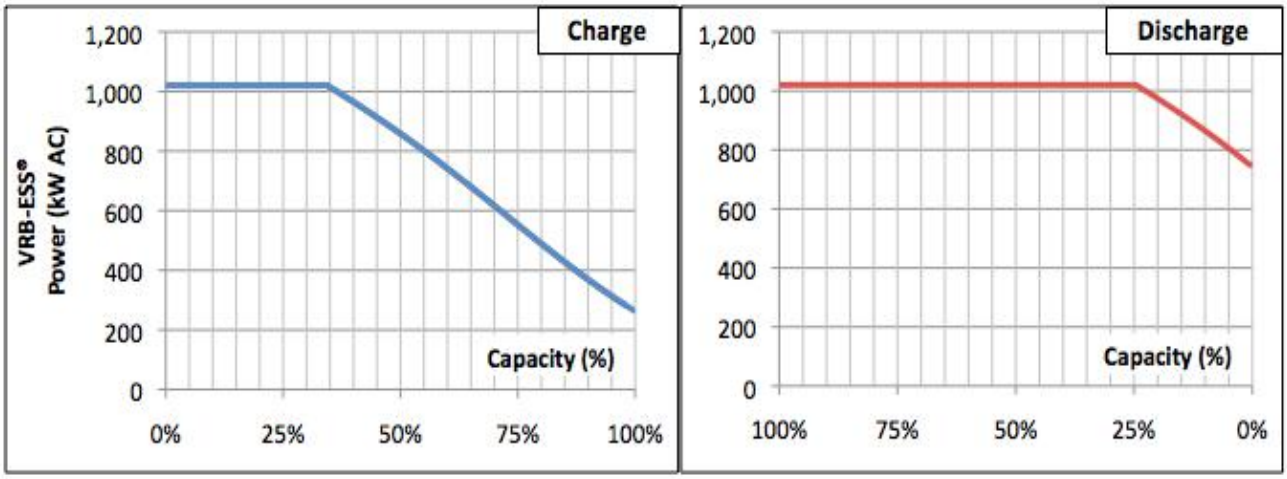


Figure 2: Typical Charge and Discharge Profile, VRB-G2-EX, 3 Power Modules



4.0 Scope of Services Provided by Pu Neng

4.1 Standard Scope

- On-site support for assembly and installation of the VRB-ESS® (civil works, battery building, permitting, and utility interconnect to be provided by Purchaser)
- Commissioning of equipment by Pu Neng personnel
- Safety training for all on-site personnel and operators
- Battery management system (BMS)
- Power conversion system (PCS)
- Shipment FOB Tianjin
- Standard two-year warranty

4.2 Available Options

- Technical and economic feasibility studies, including application modeling and regulatory consultation
- Full-service assembly and installation by Pu Neng personnel and qualified contractors
- Complete project management services
- Operation and maintenance training
- Utility interconnection, power distribution and protection equipment
- Comprehensive site control and monitoring systems
- Extended warranties of up to 5 years
- Power factors to 0.7

5.0 VRB-ESS® Modes of Operation

5.1 Grid Connected Mode

The battery is intended to operate in Grid Connected mode in order to provide:

- Integration of intermittent renewable energy sources and avoidance of curtailment
- Peak demand management
- Relief of congestion on distribution networks
- Voltage support for local distribution networks
- Reactive power compensation
- Balancing services to the Grid network (ancillary services)

In Grid Connected mode, the supervisory control provided by the Purchaser will send a number of orders and set points to the VRB-ESS® through the standard communications interfaces. The VRB-ESS® will react according to the orders and set points received.

If a grid fault occurs which requires the VRB-ESS® to trip off line it will remain offline until instructed to reconnect in accordance with utility grid codes.

Communication implementation between VRB-ESS® and Purchaser's supervisory system for data collection may be established; extra hardware to assure this functionality, if needed, shall be provided by the Purchaser.

5.2 Microgrid Mode

The battery can be specified to operate in Microgrid Mode in order to provide:

- Balancing of energy supply/demand on islanded power systems
- Integration and smoothing of intermittent renewable energy sources
- Optimization of diesel genset systems to reduce fuel use, increase efficiency and lower maintenance
- Reactive power compensation
- Voltage and frequency support to maintain power quality