Characteristics and performance of 1 kW UNSW vanadium redox battery*

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Abstract

Energy efficiencies of up to 90% are reported for the 1 kW prototype vanadium redox battery being developed at the University of NSW Solutions of 1.5–2 M vanadium sulphate in sulphuric acid are employed in both ½-cells, and over 85% of theoretical capacity can be utilised at discharge currents ranging from 30 to 120 A. Energy losses of 2–3% are expected for pumping of electrolytes, so that overall energy efficiencies of 87–88% should be achieved The vanadium battery thus continues to show great promise as one of the most efficient energy storage systems. The battery has already undergone over 100 charge–discharge cycles and further long-term testing is currently being undertaken.

Introduction

Concerns over the 'Greenhouse Effect', and intolerable pollution levels from vehicle emissions in major European and American cities, has led to increased activity from all sectors to give serious consideration to renewable energy systems and electric vehicles Renewable energy systems, based on photovoltaic arrays or wind turbine generators, require a means for storing energy so that the supply can better suit the demand

Traditionally, renewable energy has mainly been considered for fairly narrow applications, such as remote-area power-supply (RAPS) systems If concern over the 'Greenhouse Effect' proves to be justified, however, a dramatic shift away from fossil fuels will be seen in the future. Ultimately, this may lead to totally energy-self-sufficient households with solar panels

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on the roof, battery banks in the basement or garage, and an electric vehicle run on solar rechargeable batteries

Although this scenario might still be far into the future, there are many applications where more immediate energy storage solutions are needed These applications include

(i) load levelling;

(ii) RAPS systems,

(iii) emergency power systems (for office buildings, hospitals, and telecommunications),

(iv) traction (electric cars, trucks, buses, submarines, etc).

Traction is becoming one of the most important applications for storage batteries In response to government and public demands in Europe, America and Japan, a number of large car companies are setting up to manufacture electric vehicles Lead/acid, sodium/sulphur (Na/S), and zinc/bromine (Zn/Br_2) batteries are being tested in the new electric vehicle prototypes Nevertheless, these batteries all suffer from long 'refuelling' or battery recharging times and the inability to measure, continuously and accurately, battery state-of-charge (SOC)

The Vanadium Redox Battery which was pioneered at the University of New South Wales (UNSW), has been acknowledged as one of the most promising new energy storage systems for a wide range of applications

The advantages of redox flow cells compared with other secondary batteries are

- power rating and energy rating are independent
- energy, in the form of electrolyte, is stored separately from the battery
- they do not involve complex solid-phase changes during charging and discharging that result in shedding or shorting in conventional batteries
- shelf-life is, theoretically, unlimited
- they can be fully discharged without harm to the battery
- replacement and maintenance costs are low, particularly in the case of the vanadium redox battery, since the vanadium electrolytes have an indefinite life and only the battery stack would need replacement every ten, or so, years
- since all cells are fed from the same electrolyte reservoirs, all cells are at the same SOC
- it is possible to charge a battery at 2 V and discharge at 100 V without affecting battery life or performance
- capacity can be increased by increasing volume of solution reservoirs
- continuous SOC monitoring is possible with the use of open-circuit cells
- possibility of 'instant recharge' by replacing electrolytes

In fact, redox cell batteries are the only type of battery system that offers the possibility of 'instant recharge' This feature is of enormous significance in electric-vehicle applications where public acceptance will be more readily achieved if behaviour patterns do not need to be radically modified The vanadium redox battery electrolyte could be treated as a direct substitute for petrol, i e., a 'liquid-fuel' that can be regenerated indefinitely.

Specifications and performance of 1 kW prototype vanadium battery

The 1 kW prototype vanadium battery was constructed according to the specifications given in Table 1. Large numbers of charge/discharge cycles were performed over a range of currents. The performance characteristics are summarized in Table 2 and Fig 1. A maximum in the overall energy efficiency of close to 90% is observed at a current of 30 A It should be

TABLE 1

Specifications for 1 kW vanadium battery

Electrode (felt) area (cm^2)	1500
No of cells	10
Membrane material	Selemion CMV (Asahi Glass)
Average cell cavity thickness (mm)	6 1
Electrode material	6 (nominal)
– felt thickness (mm)	0 3
– carbon plastic thickness (mm)	
Pressure drop through stack (kPa)	80
Electrolyte flowrate (l min^{-1})	6
Charging current (A)	20–60
Discharging current (A)	20–120
Nominal power at 75 A and 50% SOC (W)	940
Peak power at 120 A and 100% SOC (kW)	1 58
Electrolyte	1 5 M vanadium sulphate in 2 6 M H_2SO_4 (referred to V^{4+} state)
Electrolyte volume per half-cell (l)	12
Upper voltage limit, charge (V)	17 00
Lower voltage limit, discharge (V)	8 00

TABLE 2

Performance of 1 kW vanadium redox battery[a]

Charge current (A)	Discharge current (A)	Average power (kW)	Coulombic efficiency (%)	Voltage efficiency (%)	Energy efficiency (%)	Discharge capacity (A h)
20	20	0 28	92 6	95 0	88 0	–
30	30	0 41	97 8	91 6	89 6	40
45	45	0 59	99 0	85 1	84 3	42
60	60	0 77	98 4	82 5	81 1	41
45	75	0 94	95 2	81 9	78 0	40
45	91	1 10	97 0	80 1	77 7	41
45	106	1 23	97 5	76 4	74 5	41
45	120	1 33	98 2	73 2	71 9	41

[a]No of cells 10, electrode area (cm^2) 1500, theoretical capacity (A h) 48, tested July, 1990, peak power at 120 A discharge is 1 58 kW

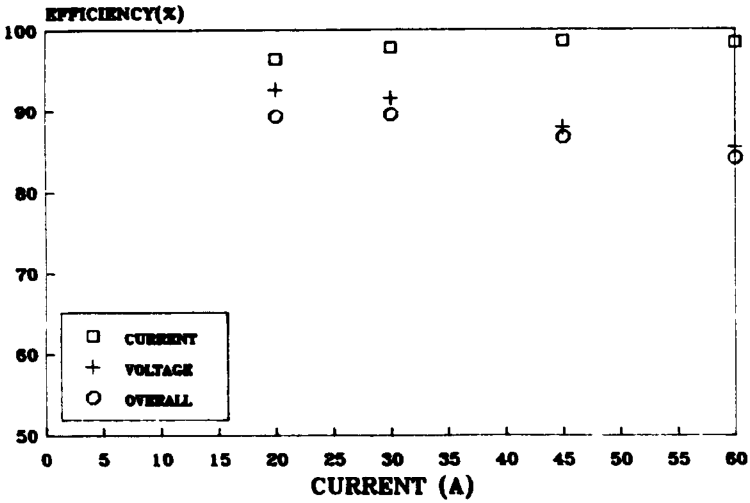

Fig 1 Performance of 1 kW vanadium battery

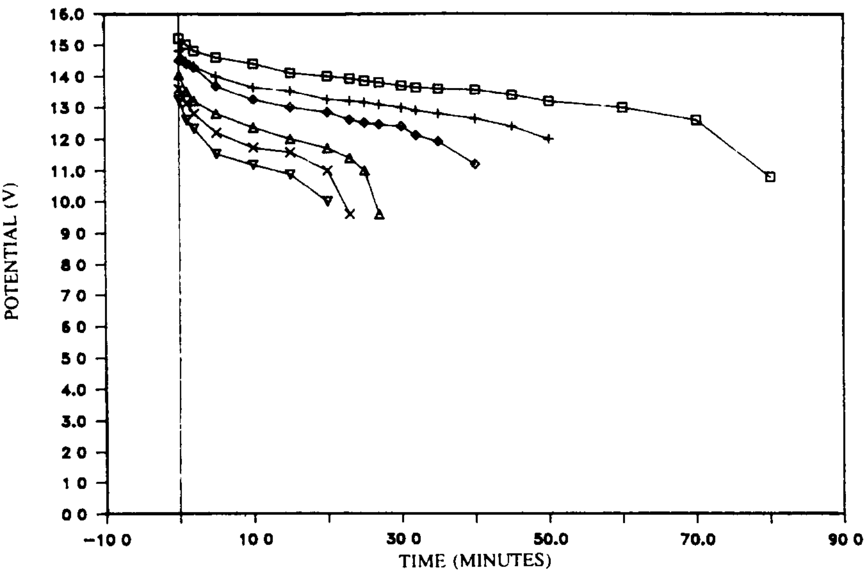

Fig 2 Discharge curves for vanadium battery at current of □, 30, +, 45, ◇, 60, △, 90, ×, 105, ▽ 119 A

emphasized that this overall energy efficiency of 90% does not take into account pumping energy losses that could account for up to 2–3% energy loss Even at 87% energy efficiency, however, the 1 kW vanadium battery is proving to be one of, if not the most, energy efficient energy-storage systems presently under development anywhere in the world

A further important feature of the 1 kW vanadium battery, which is also highlighted in Table 2, is that varying the discharge current from 30 to 120

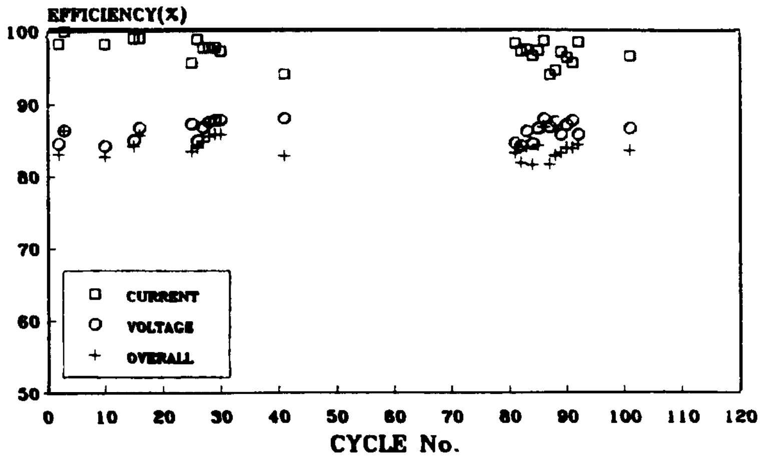

Fig 3 Coulombic voltage and energy efficiencies of vanadium battery

A produces an almost constant number of A h that is over 80% of the theoretical capacity of the battery A series of discharge curves obtained for the above range of currents is given in Fig 2 The average power produced at a discharge current of 120 A is 1 33 kW, while a peak power of 1 58 kW is achieved at this current The true peak power of the battery has not yet been established, however, due to equipment limitations From the slopes of the *I–V* plots, obtained at 75% SOC, the battery internal resistance was calculated as 3 14 and 3 44 Ω cm^2 for charging and discharging, respectively

The above battery has already been subjected to over 100 charge/discharge cycles and the efficiency has remained constant Figure 3 shows a plot of coulombic voltage and energy efficiency as a function of cycle number for a current of 45 A The slight variations in efficiency are due to temperature fluctuations; the highest values are obtained when the electrolyte temperature is approximately 35 °C.

Conclusions

From the results achieved to date, the vanadium redox battery continues to show great promise for a wide range of energy-storage applications Using projected costs for mass production of a 1 kW vanadium battery and assuming a cost of \$12 kg^{-1} for the V_2O_5, overall battery costs of between \$200 per kW h (for an energy-to-power ratio of 1) and \$66 per kW h (for an energy-to-power ratio of 20) have been estimated Combined with the high energy efficiencies already achieved with large 1 kW systems, therefore, the vanadium battery must be considered to be the most promising energy storage system for near term commercialization

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