

It is an object of at least one aspect of the present invention to provide a thermal storage system having integral means for predicting the charge state of batteries within an assembly.

It is an object of at least one aspect of the present invention to provide a thermal storage system having integral means for determination of relative energy levels within batteries within an assembly.

It is an object of at least one aspect of the present invention to provide a thermal storage system having integral means for protection of batteries within an assembly against over pressurisation. The Applicant has developed a novel and inventive thermal storage system comprising heat batteries having internal heat exchangers and PCMs wherein said system includes integral means for providing a variety of control measures including: overall system energy efficiency measures; measures of battery charging efficiency; determination of relative energy levels within batteries; and wherein said system provides protection of said batteries against over pressurisation.

Summary of the Invention

The Applicant has developed novel and inventive thermal storage system comprising heat batteries having internal heat exchangers and PCMs.

Accordingly to the first aspect of the present invention provides a thermal energy storage system comprising a thermal energy store ~~containing~~ comprising a single or a plurality of battery casings having internal heat exchangers and phase change materials and means for controlling the operation of said *thermal energy store*,

wherein each of said battery casing independently contains a battery comprising one or more heat exchangers anchored within said casing, a phase change material and means for protection against over pressurisation of said battery, and

wherein said controlling means is provided by a one or a plurality of sensors for the measurement of ~~temperature, and/or pressure, and/or power~~ at one or multiple points within the ~~system~~ thermal energy storage system and said controlling means is adapted to provide measurements of the charging and discharging circuit flow rate of the thermal energy storage system via one or more power sensors.

The controlling means may be an integral system controller.

The controlling means may be adapted to provide measurements of the charging and discharging circuit flow rates of said system via one or more power sensors.

The controlling means may be adapted to provide means for efficient charging of the individual batteries within the assembly via one or more input temperature sensors and one or more diverter valves.

The controlling means may be adapted to provide measurements of the energy stored within, and the power input of individual batteries within said system, and of the overall battery assembly via said one or more input temperature sensors.

The controlling means may be adapted to provide measurements of the energy delivered by each battery within the assembly and the residual energy in each of said batteries during discharging via one or more output temperature sensors.

The phase change materials within the system may be protected from contact with external contaminants or degrading components via the provision of sealed battery casings.

Claims

1. A thermal energy storage system comprising a thermal energy store comprising containing a single or a plurality of battery casings having internal heat exchangers and phase change materials and means for controlling the operation of said thermal energy store,
 wherein each of said battery casing independently contains a battery comprising one or more heat exchangers anchored within said casing, a phase change material and means for protection against over pressurisation of said battery, and
 wherein said controlling means is provided by a one or a plurality of sensors for the measurement of temperature, and/or pressure, and/or power at one or multiple points within the thermal energy storage system and said controlling means is adapted to provide measurements of the charging and discharging circuit flow rates of the thermal energy storage system via one or more power sensors.
2. A thermal energy storage system according to claim 1 wherein said controlling means is an integral system controller.
- ~~3. A system according to claim 1 or 2 wherein said controlling means is adapted to provide measurements of the charging and discharging circuit flow rates of said system via one or more power sensors.~~
- 4.3. A thermal energy storage system according to any of the preceding claims wherein said controlling means is adapted to provide means for efficient charging of the individual batteries within the assembly via one or more input temperature sensors and one or more diverter valves.
- 5.4. A thermal energy storage system according to any of the preceding claims wherein said controlling means is adapted to provide measurements of the energy stored within, and the power input of individual batteries within said system, and of the overall battery assembly via said one or more input temperature sensors of Claim 34.
- 6.5. A thermal energy storage system according to any of the preceding claims wherein said controlling means is adapted to provide measurements of the energy delivered by each battery within the assembly and the residual energy in each of said batteries during discharging via one or more output temperature sensors.
- 7.6. A thermal energy storage system according to any of the preceding claims wherein the phase change materials within the system are protected from contact with external contaminants or degrading components via the provision of sealed battery casings.
- 8.7. A thermal energy storage system according to any of the preceding claims wherein the battery casings are constructed contrasted from metals, alloys, plastics, composite sandwiches or composite materials.
- 9.8. A thermal energy storage system according to any of the preceding claims wherein the battery casings can withstand an internal pressure of from 0.0bar to 4.0mbar.

- 49-9. A thermal energy storage system according to any of the preceding claims wherein multiple battery casings can be stacked without intermediate supports.
- 5 | 14-10. A thermal energy storage system according to any of the preceding claims wherein said one or more heat exchangers are integrated loading and unloading heat exchangers which are anchored within the batteries and wherein the contact area between each heat exchanger and each battery casing is minimal.
- 10 | 12-11. A thermal energy storage system according to any of the preceding claims wherein the battery housing includes means for protection against over pressurisation via one or more pressure relief valves, or one or more pressure rupture discs.
- 15 | 13-12. A thermal energy storage system according to any of the preceding claims wherein the phase change materials utilised within the batteries have a solid to liquid phase change within a temperature range of from 0°C to 100°C and wherein the operative range of said phase change materials is between a 4 and 8 degree difference in temperature.
- 20 | 14-13. A thermal energy storage system according to any of the preceding claims additionally comprising means for phase change material expansion management wherein said means is in operative connection with a vapour barrier, and either a pressure relief valve, or a burst disc assembly.
- 25 | 15-14. A thermal energy storage system according to any of the preceding claims additionally comprising means for phase change material expansion management provided by external or internal volume compensation features, or by pressurised case design features, in relation to each individual battery within said assembly and wherein said means is in operative connection with a vapour barrier, and either a pressure relief valve, or a burst disc assembly.
- 30 | 16-15. A thermal energy storage system according to any of the preceding claims additionally comprising means for determining the energy inputs and outputs of, and the balance within, any individual battery (8) within the system via a series of sensors for the determination of Q_{IN} , Q_{ON} and Q_N wherein
- 35 | $Q_{IN} = [\Sigma (F_I \times \rho_I \times C_{pI}) \times (T_6 - T_{CFI} - T_{CRI} - T_4)] / 3600$; and
- | $Q_{ON} = [\Sigma (F_O \times \rho_O \times C_{pO}) \times (T_{10} - T_{DFI} - T_{DRI} - T_9)] / 3600$; and
- 40 | $Q_N = Q_{N-1} + Q_{IN} - Q_{ON}$; and
- wherein

Q_{IN} = Energy input to the battery during the last charge cycle;
 Q_{ON} = Energy output from the battery during the last discharge cycle;
 Q_N = Current stored energy in the battery;
 Q_{N-1} = Energy stored in the battery before current audit;
 F_I = Charging circuit flow rate;
 F_O = Discharging circuit flow rate;
 ρ_I = Density of charging circuit fluid;
 ρ_O = Density of discharging circuit fluid;
 C_{PI} = Specific heat of charging circuit fluid;
 C_{PO} = Specific heat of discharging circuit fluid;
 T_{CFT} = Battery X charging circuit flow temperature;
 T_{CRT} = Battery X charging circuit return temperature;
 T_{DFT} = Battery X discharging circuit flow temperature; and
 T_{DRT} = Battery X discharging circuit return temperature.

17. A thermal storage system substantially as provided by the arrangement as described herein and as illustrated in Figure 2.

18. A thermal storage system substantially as provided by the arrangement as described herein and as illustrated in Figure 5.

A thermal storage system according to any of the preceding claims wherein the control system is adapted to provide means for the determination of the status of the batteries within the system via the following series of algorithms:

e) If $Q_{IN} = 1$ and $\delta P \leq P_{L1}$ OR $Q_{IN} = 1$ and $P_{BC} \leq P_{AT}$ then:

- Battery case is not air-tight
- Activate appropriate alarm/warning
- Put this battery in standby mode i.e. stop charging

p) If $(Q_{IN} = 1 \text{ and } \delta P \geq P_{L2})$ OR $Q_{IN} = 1 \text{ and } P_{BC} \geq P_{L3}$ then:

- Battery case pressure is exceeding the maximum operating limit
- Activate appropriate alarm/warning
- Put this battery in standby mode i.e. stop charging

q) If $(Q_{IN} = 0 \text{ and } T_{BC} \leq T_E)$ then:

- Put this battery in charging mode $Q=1$ i.e. start charging
- SOC = 0

r) If $(Q_{IN} = 1 \text{ and } \delta T \geq T_{L2})$ OR $Q_{IN} = 1 \text{ and } T_{BC} \geq T_{L3}$ then:

- Battery case temperature is exceeding the maximum operating limit
- Activate appropriate alarm/warning

— Put this battery in standby mode i.e. stop charging

s) If $P_{AB1} \leq \text{ABS}(\delta P) \leq P_{AB2}$ OR $P_A \leq P_{BC} \leq P_B$ OR $T_E \leq T_{BC} \leq T_F$ OR $T_{EF1} \leq \text{ABS}(\delta T) \leq T_{EF2}$, then the battery is operating in zone AB (See Figure 6(a)) corresponding to zone EF (See Figure 6(b))

$$\text{SOC} = 100 \cdot m_{PCM} \cdot C_{p_s} \cdot \delta T_s / E_{TOT}$$

t) If $P_{BC1} \leq \text{ABS}(\delta P) \leq P_{BC2}$ OR $P_B \leq P_{BC} \leq P_C$ OR $T_F \leq T_{BC} \leq T_G$ OR $T_{FG1} \leq \text{ABS}(\delta T) \leq T_{FG2}$, then the battery is operating in zone BC (See Figure 6(a)) corresponding to zone FG (See Figure 6(b))

$$\text{SOC} = 100 \cdot (E_{SL} + F_{BC} \cdot G_{BC} \cdot P_B) / E_{TOT}$$

u) If $P_{CD1} \leq \text{ABS}(\delta P) \leq P_{CD2}$ OR $P_C \leq P_{BC} \leq P_D$ OR $T_G \leq T_{BC} \leq T_H$ OR $T_{GH1} \leq \text{ABS}(\delta T) \leq T_{GH2}$, then the battery is operating in zone CD (See Figure 6(a)) corresponding to zone GH (See Figure 6(b))

$$\text{SOC} = 100 \cdot (E_{SL} + E_L + m_{PCM} \cdot C_{p_L} \cdot \delta T_L) / E_{TOT} \text{ TABLE 2}$$

Symbol	Definition	Measurement
Q_{IN}	Battery charging state	1 = Active, 0 = Standby
δP	Rate of pressure change	Pa/s
P_{L1}	Minimum rate of pressure change limit	Pa/s
P_{BC}	Battery case pressure	Pa
P_A	Base reference pressure	Pa
P_{L2}	Maximum rate of pressure change limit	Pa/s
P_{L3}	Maximum battery case working pressure	Pa
T_{BC}	Battery case temperature	K
T_E	Base reference temperature	K
SOC	State of charge of the battery	
δT	Rate of temperature change	K/s
T_{L2}	Maximum rate of temperature change limit	K/s
T_{L3}	Maximum battery case working temperature	K/s
P_{AB1}	Rate of pressure change in zone AB — Lower limit	Pa/s
P_{AB2}	Rate of pressure change in zone AB — Upper limit	Pa/s
P_A	Battery pressure at operating point A in Figure 6(a)	Pa
P_B	Battery pressure at operating point B in Figure 6(a)	Pa
T_F	Battery temperature at operating point F in Figure 6(b)	K
T_{EF1}	Rate of temperature change in zone EF — Lower limit	K/s
T_{EF2}	Rate of temperature change in zone EF — Upper limit	K/s
δT_s	Temperature difference between battery temperature T_{BC} and	K

	minimum reference temperature T_E	
P_{BC1}	Rate of pressure change in zone BC — Lower limit	Pa/s
P_{BC2}	Rate of pressure change in zone BC — Upper limit	Pa/s
P_C	Battery pressure at operating point C in Figure 6(a)	
T_G	Battery temperature at operating point G in Figure 6(b)	K
T_{FG1}	Rate of temperature change in zone FG — Lower limit	K/s
T_{FG2}	Rate of temperature change in zone FG — Upper limit	K/s
F_{BC}	Scaling factor for — Zone BC	-
G_{BC}	Correction factor (Power & PCM)	-
P_{CD1}	Rate of pressure change in zone CD — Lower limit	Pa/s
P_{CD2}	Rate of pressure change in zone CD — Upper limit	Pa/s
P_C	Battery pressure at operating point C in Figure 6(a)	Pa
P_D	Battery pressure at operating point D in Figure 6(a)	Pa
T_G	Battery temperature at operating point G in Figure 6(b)	K
T_H	Battery temperature at operating point H in Figure 6(b)	K
T_{GH1}	Rate of temperature change in zone GH — Lower limit	K/s
T_{GH2}	Rate of temperature change in zone GH — Upper limit	K/s
δT_L	Temperature difference between battery temperature T_{BC} and upper temperature of the melting zone T_G	K

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