

SYSTEMS AND METHOD FOR HYBRID ENERGY STORAGE**Field of the Invention**

5 The invention relates to the management of an electrical grid. In particular, the invention relates to the introduction of a hybrid energy system for improving the reliability of power supply.

Background

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In order to optimize generation assets for electrical grid operation, the availability of alternative energy sources is required. Factors to be considered include supply inertia, adding and subtracting generation assets, dedicated demand response and electricity storage. Each of these factors have varying levels of importance, and with the
15 introduction of different supply assets taking from a millisecond to 20 minutes.

Summary of Invention

In a first aspect, the invention provides a hybrid storage system for a cooling system,
20 hybrid energy storage system comprising: a thermal storage system; said thermal storage system arranged to provide cold energy to a cooling medium of the cooling systems so as to generate chilled water, and; an energy storage system; wherein said storage systems are arranged to operate cooperatively such that the thermal storage

system is arranged to discharge energy for continual or slow demand variability and the energy storage system is arranged to discharge for rapidly changing demand.

- 5 In a second aspect, the invention provides a method of supplying energy for a cooling system by a hybrid storage system, the method comprising the steps of: discharging cold energy for the generation of chilled water for slow demand variability by a thermal storage system, and; discharging power for rapidly changing demand by an energy storage system.

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- In a third aspect, the invention provides a method of control for an integrated cooling network comprising: receiving a predictive analysis of future demand; determining strategies for the discharge and recharge of a thermal storage system so as to optimize timing of either action relative to the predictive analysis; and monitoring and controlling
15 a discharge of a fast response energy storage system so as to ensure the availability of energy for discharge by the fast response energy system according to said predicted demand.

- In a fourth aspect, the invention provides a method of integration of an integrated
20 cooling network comprising: receiving predicted analysis of future demand for the cooling network; receiving optimization strategies for the discharge and recharge of a thermal storage system; and implementing said strategies so as to control hardware for

said cooling network as well as timing for discharge and recharge of the thermal energy system and/or fast response energy system.

Thermal storage systems (TSS's) are incorporated into a cooling system to assist the
5 chillers because it is not economic to maintain a desired level of service reliability by
purchasing and maintaining redundant water chillers. TSS's can be charged during the
periods when the electrical price is low, and discharged when the electricity price is
high or when additional cooling capacity is needed to meet a peak demand. The
flexibility to earn extra benefits beyond the compulsory service periods makes TSS's
10 more cost-effective than standby chillers which are seldom activated. In the meantime,
the reliability of the cooling system does not degrade as long as the TSSs are properly
designed and managed such that a certain level of ice or cooled water is reserved for
emergent demands.

15 On the other hand, rapidly introduced energy storage systems (ESSs), such as a battery,
are viewed as a viable option to enhance the electrical reliability of engineering systems.
ESSs are able to store electric energy that can be consumed to support chillers and TSSs
when there is a lack of electricity or when the electricity price is high. The first
functioning as a backup power source obviously improves the reliability of the cooling
20 system. The second functioning which stores more energy when the electricity price is
low and supplies the energy when the price is high brings additional economic benefits,
which is similar as in TSSs. The economic benefit can further increase if the ESSs are

also designed and operate to provide ancillary service like frequency regulation to the grid. This will become more obvious as the prices of ESSs decline.

The present invention, therefore, is directed to using the benefits of both TSS's and
5 ESS's, in combination, to provide both reliable and flexible supply for a cooling system as well as an electrical supply that can be introduced at very short notice, until the TSS has had sufficient time to service the required demand.

Brief Description of Drawings

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It will be convenient to further describe the present invention with respect to the accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible and consequently, the particularity of the accompanying drawings is not to be understood as superseding the generality of the
15 preceding description of the invention.

Figure 1 is a graph indicating a load reduction sequence according to one embodiment of the present invention;

20 Figure 2 is a schematic view of a hybrid storage system according to a further embodiment of the present invention;

Figure 3 is a schematic view of a hybrid storage response according to a further embodiment of the present invention;

Figure 4 is a schematic diagram of a hybrid energy storage system according to a further
5 embodiment of the present invention; and

Figure 5 is a flow diagram for the implementation of a hybrid energy storage system according to a further embodiment of the present invention.

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Detailed Description

The present invention is directed to a hybrid energy storage system comprising a fast acting battery, such as a lithium ion battery, and thermal storage integrated to the district
15 cooling chiller system that can reduce or increase demand for electricity in tandem with a source of intermittent energy like solar energy.

Thermal storage, both chilled water storage and ice storage, is widely used in district cooling systems. These are typically used to provide reliability in case of electrical
20 system failures or to arbitrage cost differences in use of electricity.

In one embodiment of the invention, the present hybrid energy system is configured to provide reserve service to the grid by committing a minimum power reduction. A load

reduction sequence is shown in Figure 1. The ESS 5 is triggered 15 on receiving a signal from a power system operator for load reduction. The nominal grid frequency in Singapore is 50Hz and if the grid frequency drops below, for example, 49.7Hz, the power system operator may send out the signal for load reduction. The signal may take
5 a number of different forms such as intermittency of electricity in the grid or triggered as a result of a cut-off of the electricity supply (tripping) by third party. It will be appreciated that a number of different reasons may also result in a signal being generated, including, for instance, a maintenance issue, system trial or a stress test of the system.

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In the idle state, the ESS is maintained at a state of charge according to a predetermined support time 20. For example, the state of charge may be 50%, 75% or 100%. The state of charge is ideally maintained at 100% to provide a longer support time.

15 The TSS 10 is triggered at the same time with the much slower rate of increasing supply accommodated by the rapidly implemented ESS. The TSS provides extended duration of load reduction.

20 Once the reserve service is triggered the processes of discharging the ESS to provide power to offset grid consumption, and discharge the thermal storage system are activated. The shutting down process of the chiller will commence, for instance while the network bypass flow is maintained between 0 to 200m³/hour and the network supply temperature is maintained between 4 to 5°C. The reserve service is then terminated on

receiving a second signal from the power system operator, and the signal may indicating that the grid frequency is back to nominal or that there is no longer intermittency of the supply. As a note “Network Bypass Flow” refers to the “bypass” chilled water flow supplying to the customers. An optimum value of ZERO is desirable to indicate a
5 balanced supply to all users. In practical, a value between 0 to 200m³/hr is acceptable. The “Network Supply Temperature” refers to the actual chilled water temperature supplying to the customers’ intake stations. A value of between 4 – 5°C is to be maintained in order to meet our customers’ needs.

10 Figure 2 shows an alternative embodiment, whereby the ESS 65 being used for frequency regulation 75 directly to the grid may be combined 115 with a TSS as a contingency reserve 80. Each TSS may contain an ice storage tank and a brine chiller, and the whole set of TSS’s are equipped with a group of cooling towers (CT’s) to cool down condensers of the brine chillers in TSS’s. The TSS’s may be scheduled 100 to
15 satisfy chilling demand but also provide contingency reserve 105 to the grid. Meanwhile, ESS’s are used to shift power demand from high to low price periods, participate in regulation market, and assist TSS’s in satisfying reserve service requirements. The integrated scheduling is optimized to minimize the electric cost of operating the system.

20 Accordingly, the hybrid energy storage for regulation and reserve services, as shown in Figure 2, provides a fast response 85 of ESSs to complement the slow response 90 of TSSs during the transient of a contingency reserve service.

Figure 3 shows a basic description of the system according to the present invention. A cooling system comprising a chiller 45 and a hybrid storage system 60, including an ice TSS and battery ESS. The chiller receives cooled water from a cooling tower 55, chilling the cooled water using mains supply electricity and supplying this through a heat exchanger 40 to end users 35. The chiller (brine chiller) may provide cold energy to TSS when the electricity price is low or cooling load is low. Practically, using a district cooling system (DCS), the ice TSS will also provide chilled water, with the infrastructure cost of the chiller 45 taking into account the involvement of the ice TSS.

As a means of frequency regulation or as a reserve service, power provided to the chiller may be diminished or cut-off depending upon the circumstances. The time lag for the ice TSS to meet the required demand of the end users 35 (or to meet that portion of demand ordinarily met by the chiller for a DCS) represents a gap in supplying that demand. Accordingly, an ESS is provided to offset grid consumption as a rapid response system. The ESS is arranged to act for a short period of time until the ice TSS is fully meeting demand, whereupon the ESS is withdrawn, and the chiller taken offline,

It will be appreciated that for frequency regulation, the “storage” aspects of the TSS and ESS provide cost optimisation opportunities, as the required power to provide the storage may be intermittent power supply, such as renewable power generation, or at least for the mains supply to supply the ESS and TSS at off peak rates. The reserve service is more obvious in that the combined TSS and ESS provide a synergistic balance between response time and long term supply reliability.

Figure 4 shows a hybrid energy storage system 120 according to a further embodiment of the present invention. Here the system is connected to a grid power supply 122 through a stepdown transformer 125 and low voltage switch gear 130. For main power supply, the ESS batteries 150 is connected to the low voltage switch gear 130 through an isolation transformer 135 and power conversion unit 140 for converting between AC and DC which is particularly essential for switching between charging and discharging loads. As for auxiliary power supply for control, the AEROS System Controller 143, UPS 147 and PDU 149 is connected to the low voltage switch gear 130 through an isolation transformer 165 and distribute through a low voltage distribution board 155. This auxiliary power supply is crucial to maintain the ESS 145 in operation for event data capturing. . The isolation transformers 135, 165 are used to isolate electrical noise and transfer electrical power between the low voltage switch gear 130 and power conversion unit 140, the power distribution unit 149. The power distribution unit is arranged to distribute the low voltage ancillary supply. An AEROS system is used as a controller for battery management with the uninterruptable power supply (UPS) 147 allowing the AEROS system 143 to continue operation during a short time event on a loss of the main power supply. The ESS 145 further includes a battery 150 which in this case is a lithium ion battery providing the stored energy.

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The operational control of the ESS 145 is through operator works places. The AEROS system 143 is connected to a local control panel 160 through connectivity & aspect

server 170 and finally connected to operator works places. This connection enables the operators to operate the ESS 145, Ice Tank 180 and Water Chillers 175 synchronously.

The hybrid energy storage system 120 is activated subject to certain implementation requirements such as an under-frequency relay to trip the load if grid frequency drops below 49.7Hz. Alternatively, implementation may be initiated for primary reserves or if a signal is sent by the operator for contingency reserves to reduce the load within a short period of time, for instance, 10 minutes.

10 This would reduce total electrical consumption by 400 kW immediately. The discharging of the thermal storage, and shutting down of chillers are done almost concurrently while maintaining the required bypass flow (0-200m³/h) and supply temperature (4 to 5°C).

15 The process therefore follows the sequence shown in Figure 5 whereby the grid frequency falls below the nominal value 185, which activates the signal from the operator 190. The ESS commences discharging at full capacity (400kW of electrical power) 195 with the thermal storage 180 commencing discharging 200. The chillers are progressively shut down with each chiller reducing the required capacity. For instance,
20 a 10MW_r chiller would approximately reduce the capacity by 1.5MW_e.

Operations are cumulatively maintained to meet the total offered load for the duration of activation of the hybrid energy storage system 210 until a recovery signal from the

operator for the designated load is received 215 whereupon operations are normalized for the chillers and the battery can commence recharging on the load being maintained by the TSS 220.

- 5 Thus, the embodiments shown in Figures 4 and 5 provide a practical implementation of the invention. It will be appreciated that alternative implementations are equally possible within the scope of the invention.