DEMONSTRATION OF ENERGY STORAGE INTEGRATED WITH A SOLAR DISH FIELD IN WHYALLA

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Abstract

This paper describes progress towards a first-of-a-kind demonstration of an integrated solar dish and molten-salt storage system, using the superheated steam energy transport concept developed by Wizard Power. Superheated steam is used to charge an energy storage system with a single sensible-heat-storage medium (in this case molten salt), by restricting the steam conditions to the superheat region. The storage plant will deploy four of Wizard Power's Big Dish solar collectors at a purpose built facility in Whyalla, South Australia, and will be integrated with a two tank molten salt storage system.

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1. Introduction

In recent years, there has been renewed interest in energy storage systems coupled to solar plants. Perhaps the strongest driver for some degree of energy storage is to provide a closer match between solar plant output and electricity demand for grid connected systems – that is, "dispatchable power" - in particular during peak demand periods that typically occur in the late afternoon or early evening. The ability to integrate energy storage into the thermal cycle is a key point of differentiation between solar thermal and photovoltaics or wind technologies.

The two tank molten salt storage system is the most advanced energy storage system, having been demonstrated on both a tower system (Solar Two) [1], and a number of recent trough systems in Spain.

The advantages of coupling a high temperature heat source to a molten-salt thermal storage system are two-fold. Firstly, a high temperature range allows a reduction in the mass of salt required for a given total thermal capacity. Secondly, there are efficiency gains in the overall solar-to-electricity cycle due to improved power cycle efficiency at higher temperatures.

Direct heating of salt to a high temperature (~ 565°C) was demonstrated at Solar Two. Salt reticulation is relatively simple for a tower system, with drainage by gravity from the tower to the storage tanks and short pipe runs. Direct heating of salt may also be possible for solar dish fields; however, due to the distributed nature of the dishes in a field, avoiding the possibility of freezing salt in the pipes is more complex than for tower systems (although is likely to be favoured by recent advances with new salt mixtures [2]). Indirect heating of salt via an energy transport fluid is an alternative, typically synthetic oils for trough systems with salt storage. For higher temperature applications, there are no obvious candidates for energy transport fluids that can be handled with acceptable safety and remain liquid both at typical ambient conditions (hence avoiding the possibility of freezing when the system is not in operation) and at a temperature approaching the upper working temperature of the nitrate salt storage medium (~621°C).

2. Description of storage concept

Wizard Power has developed an alternative method of charging a molten-salt thermal storage system using superheated steam. Figure 1 shows the concept, which was initially proposed at SolarPaces2009 [3]. Superheated steam is used to charge an energy storage system with a single sensible-heat-storage medium (in this case molten salt), by restricting the steam conditions to the superheat region.

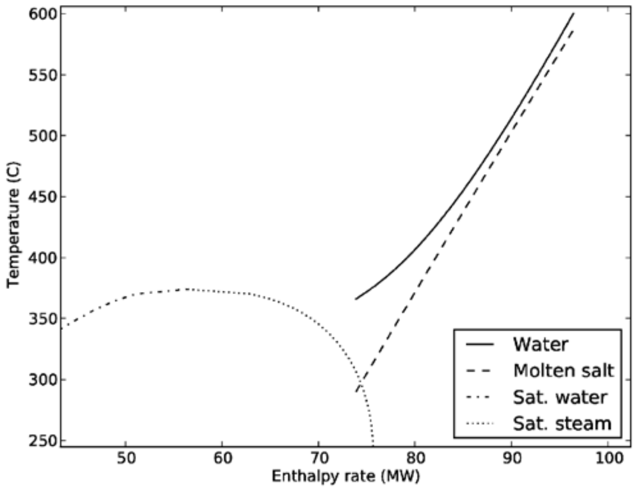

Fig. 1. Temperature-enthalpy diagram showing heat transfer to molten salt from superheated steam.

The temperature-enthalpy relationship for superheated steam is reasonably matched to that of nitrate salt at a range of pressures. This concept overcomes the 'pinch point' problem normally associated with the integration of molten salt storage with a direct steam generation system, as described by Steinmann et al [4].

This paper describes progress towards a first-of-a-kind demonstration of an integrated solar dish and molten-salt storage system, using the superheated steam energy transport concept developed by Wizard Power. The storage plant will deploy four of Wizard Power’s Big Dish solar collectors at a purpose built facility in Whyalla, South Australia, and will be integrated with a two tank molten salt storage system.

3. Description of the Whyalla Energy Storage Project

Wizard Power is currently implementing the Whyalla Solar Storage demonstration plant, which will showcase Wizard Power’s energy storage technology. The plant is located 4 km north of the township of Whyalla, South Australia. The Whyalla Solar Storage plant will be a pre-commercial demonstration of energy storage, with full integration, demonstration of start up and shut down procedures, ability to handle intermittent solar input, and deliver energy on demand.

3.1 Solar dishes

Four Big Dish units will be deployed at the energy storage plant in Whyalla. The Big Dish technology [5] was originally developed at the Australian National University, and is now being commercialised by Wizard Power. Construction of the first commercial new Big Dish prototype, known as “SG4”, was completed in July 2009, and construction of the first of the four Big Dish units on site 4 km from Whyalla has commenced (figure 2).

Fig. 2. The "SG4" Big Dish prototype on campus at the Australian National University (left, Aug 2009) and early construction work of Big Dishes in Whyalla (right, May 2010).

The Generation II Big Dish has an aperture of 489 m² and a focal length of 13.4 m, and employs altitude-azimuth sun tracking. The dish surface consists of 380 identical spherical 1.17 m × 1.17 m mirror panels. The mirrors panels are a steel skinned sandwich panel laminated with a mirror on one side. The mirror is a back surface silvered 1mm low iron glass mirror, with solar-weighted reflectance exceeding 94%. The panels are accurately formed, with average surface slope error around 1.3 mrad. The mirror panels can be used as structural elements, and have been integrated into the dish structure to contribute to the overall structural rigidity. The mirror panel design was developed as part of commercialisation of the Generation II Big Dish technology, and Wizard Power is in the process of establishing a dedicated production facility for high volume manufacture of the mirror panels. Optical characterisation of the SG4 prototype in September 2009 gave a geometric concentration ratio of 2240x at 95% capture [6].

3.2 Solar steam loop

Under design conditions, steam at 330°C and 120 bar (i.e. marginally superheated) is circulated to the dish field by a high speed centrifugal steam compressor, and the flow modulated at each dish to control the output steam temperature to 630°C (refer to figure 3). Steam is superheated in cavity receivers, consisting of a coil of stainless steel boiler tubes similar in design to the steam receiver employed on the first generation Big Dish prototype ("SG3") [7]. Details of the precise cavity geometry and material selection are not finalised. Under one sun conditions, each dish has a thermal output around 375 kW, hence the four dish field has a 1.5 MW thermal capacity and mass flow of 1.56 kg/s.

Molten salt is heated by the superheated steam from the solar field in the salt heater, which is a shell-and-tube heat exchanger, raising the salt temperature from 290°C to 565°C, and reducing the steam temperature back to the solar field inlet temperature (i.e. the steam remains in the superheat region).

The mass of fluid in the solar loop is controlled to maintain the design steam conditions depending on the solar insolation available. Liquid water can be added to the solar loop from the condensate tank in the power block to the steam separator. Conversely, steam can be bled from the solar loop back to the condensate tank to remove surplus fluid from the system.

Prior to a cold start-up, enough water is added to the steam separator to ensure that the feed pipe to the solar field can be filled with liquid. As solar energy transfers to the fluid, pressure rises as the fluid is vaporised. Pressure will continue to rise as long as there is condensate in the system, and hence some steam may be bled from the system to reduce the total mass in the solar loop until a steady state (assuming steady solar input) is reached. There is an incentive to minimise surplus fluid required for start-up, as it results in both energy loss and increased time lag in achieving design conditions. To minimise surplus water for the demonstration plant, a single dish is utilised at start up, and liquid is pumped to that dish alone via a dedicated and smaller

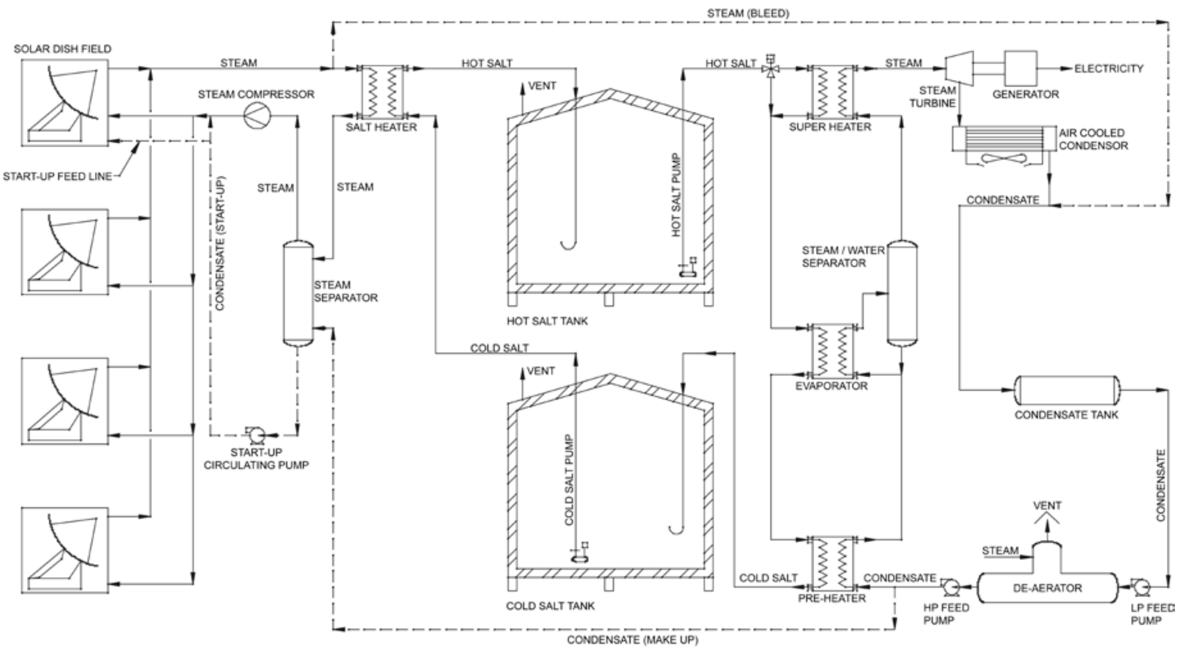

Fig. 3. Process Flow Diagram for the Whyalla Energy Storage project

diameter pipe line. For commercial scale plants, a dedicated liquid line is likely to be unnecessary as the large number of dishes gives a greater degree of flexibility.

During the start-up procedure, once a minimum system pressure set point is reached the steam compressor takes over from the start-up circulating pump and the remaining three dishes are moved on sun. The shut down procedure for the steam compressor is similar but in reverse.

3.3 Salt storage loop

The molten salt is a mixture of 60 % sodium nitrate and 40 % potassium nitrate (by mass). The two-tank storage system requires a “hot” and a “cold” tank, in this case at 565°C and 290°C respectively. To give a high level of flexibility for the purposes of the demonstration plant, both tanks are designed to tolerate the hot salt. The tanks are fabricated from stainless steel, each 4.3 m wide and 6 m high, and are insulated on the top and side walls with 375 mm of Rockwool and on the bottom with 350 mm of insulating bricks. The tanks are supported a little above the ground on a steel ‘raft’. The working capacity of the storage is 106 tonnes of salt, sized to allow 4 hours of continuous peak output from the power block without solar input. The 4-dish solar field will take approximately 9 hrs to replenish the thermal storage under 1 sun conditions. A commercial scale plant would likely have a significantly higher ratio of dishes to storage capacity, and hence a shorter time to charge the storage.

Prior to first fill, the salt tanks will be heated to a temperature near that of the molten salt to minimise thermal shock. Initial fill of the salt tanks will use a commercial modular salt melting system. In operation, the minimum temperature is maintained by the use of electrical heaters mounted horizontally near the bottom of the tank. The vapour space of both tanks is interconnected to minimise the introduction of ambient moisture during tank filling and emptying. Dry air padding is provided to both tanks, and will be set to a minimum flow to prevent ambient air ingress. Electrical heat tracing will be used to ensure salt lines, valves and vessels remain at a temperature higher than the salt freezing temperature.

At start-up of the solar field, salt flow from the cold tank through the salt heater commences when the temperature of the steam entering the salt heater exceeds the cold tank temperature. The cold salt pump initially runs at a minimum speed, and salt is returned back to the cold tank. Once the salt temperature reaches the hot tank temperature, flow is directed to the hot tank and mass flow is modulated via speed control of the pump to maintain this temperature.

On the power block side, circulation of hot salt can begin when the plant is in readiness for steam generation (preheated). To protect the heat exchangers from thermal shock upon start up, initially cold salt is blended with the hot salt (not shown figure 3), and the temperature is raised gradually from 290°C to 565°C. In operation, the overall hot salt mass flow is modulated by speed control of the hot salt pump such that the temperature of the salt leaving the pre-heater is at the cold salt tank temperature. The temperature of the superheated steam leaving the superheater is maintained to setpoint (530°C) by a modulating three-way flow control valve bypassing salt around the superheater. In this way the salt heating system can respond to the heating 'demand' from the power block.

3.4 Power block loop

Steam generation in the power block is via three separate heat exchangers in series. The preheater and superheaters are shell-and-tube heat exchangers, and the steam generator is a thermosiphon reboiler consisting of a shell-and-tube evaporator, and a steam / water separator vessel. The heating system is designed to deliver steam at 530°C, 100 barA at 4000 kg/hr.

For the purposes of the demonstration plant, the aim is to demonstrate the generation of high temperature, high pressure steam suitable for high efficiency power conversion in a commercial scale plant (say 100 MWe). Unfortunately, at a scale of 0.5 MWe, it is not possible to demonstrate high efficiency thermal-to-electrical conversion, as at this scale efficiency of turbines is low (isentropic efficiency around 50% compared to 85% for large turbines), and the impact of parasitic electricity draw is disproportionately great compared to a commercial power plant. Therefore, with the overall aim of demonstrating the technical and commercial viability of the storage concept, the first stage of implementation of the Whyalla Energy Storage plant will demonstrate steam quality appropriate for a commercial scale power plant, but will exclude the turbine. In a second stage, it is proposed to use a Siemens SST-060 steam turbine/generator, with inlet steam conditions as stated above and exhaust steam at 1.1 barA and 209°C, to deliver around 560 kW at the generator terminals. Air cooling is used to sub-cool the exhaust steam to 100°C. Other equipment includes a condensate tank, de-aerator, and high and low pressure pumps as shown in figure 3. The power block is fitted with an electric start-up heater (not shown in figure 3) which provides steam for preheating major plant items such as the turbine, de-aerator and the heat exchangers.

3.5 Other operation modes

The Whyalla Energy Storage plant is designed to have a number of alternative modes of operation other than the base case described above (these are not shown in figure 3). The solar field can operate generating steam directly from condensate, in either stand-alone mode through an additional air cooled condenser, or alternatively coupled directly to the power block. In addition, the solar field can operate in a hybrid mode, charging the salt storage system and then providing marginally superheated steam direct to the steam generator in the power block.

4. Conclusion

This paper describes progress towards a first-of-a-kind demonstration of an integrated solar dish and molten-salt storage system, using the superheated steam energy transport concept developed by Wizard Power. The aim is to prove the technical and commercial viability of the concept through the development and operation of a demonstration plant in Whyalla. Construction of the dishes has commenced on-site in Whyalla, and construction of the first stage of the plant is expected to be complete during 2011. The plant will combine four Big Dish solar collectors with a high temperature two-tank molten salt system, and demonstrate that high temperature steam suitable for high efficiency power conversion can be generated on demand using dish technology – and that the intermittent nature of the solar resource is not a barrier to large scale, highly efficient power production.

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