WHITE PAPER

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PTT's Thermal Energy Storage (TES) Application Utilizes the Power Block Comprising Proprietary Turbo-machinery and PCHE Technology

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A PTT White Paper

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Introduction

Peregrine Turbine Technologies, LLC (PTT) is a turbo-machinery research and development company with proprietary technology in power conversion cycles. PTT was founded in 2012 for commercializing a proprietary thermodynamic cycle referred to as the partially recuperated or "Stapp" cycle, making use of a supercritical CO2 (sCO2) working fluid to achieve high efficiencies. PTT's thermodynamic cycle is specifically targeted for optimized performance using air-combustible fuels such as fossil fuels, biomass, municipal waste, and the like, but is heat source agnostic, making it an ideal platform for thermal energy storage (TES) applications.

PTT is teamed with Sandia National Laboratories (SNL) under a Combined Research and Development Agreement where PTT's new turbo-machinery designs and heat exchangers are being tested for performance. PTT has also been partially funded by the Air Force Research Lab (AFRL) and the Navy's Office of Naval Research (ONR) to develop a high pressure ratio sCO2 turbo-pump, which is now being tested at SNL. These components will be employed to demonstrate the performance and controllability of the TES system early in 2021

Process Description

PTT's Thermal Energy Storage (TES) application utilizes the power block comprising proprietary turbo-machinery and PCHE technology more completely described in the EPRI Novel Cycle Database [1]. Applied to energy storage the heat source and main heat exchanger, is replaced by the TES system. In the most cost-effective TES applications, the power block employs a high TIT recuperated Brayton cycle in close communication to the TES module, both of which are modular and containerized. TES capacity is determined by the number of TES modules in the system, and can be incremented in 10MWhe or 5MWhe units. The smallest increment is five hours of discharge at the full 1MWe rating, however, it can still operate in load following mode which will result in a longer dispatch period.

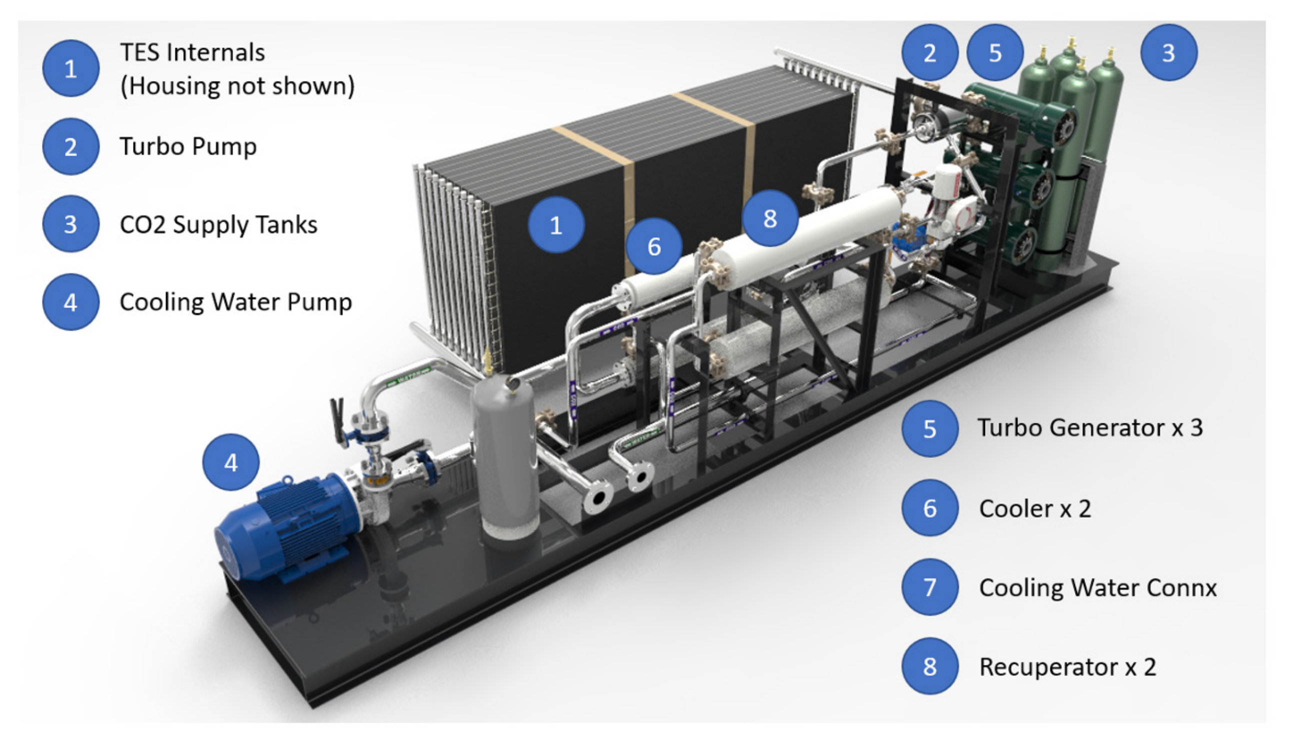

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Figure 1 – Schematic of the <technology provider> energy storage system

The TES system has three main operating states; Charge cycle, Standby - Dispatch, Discharge cycle, Standby - Emergency Dispatch. The charge cycle, where thermal energy is stored in the TES media, is achieved either by electric heating or high temperature waste heat recovery. Electric heating can either be direct or indirect, although direct will usually yield the highest round-trip efficiency.

The preferred thermal storage media employed within the TES utilizes a highly conductive porous block which behaves as a matrix to store a phase change material, typically a metallic alloy. The phase change material can be tuned to achieve phase change to liquidous by use of alloying elements. During the charge cycle, the heat is stored in the phase change media at 800C. The fully charged temperature can actually be as much as 50C above the complete phase change since the viscosity of the metal, which is now in the fluid state, is sufficient to stay retained in the pores of the matrix. The TES is preferentially heated from the turbine-connected end across the TES, to ensure that the maximum discharge power can always be achieved in case of partial charging or emergency dispatch.

When the system is exporting power, the Discharge mode, compressed sCO2 from the turbocompressor passes through the piping network embedded within the TES where heat is transferred to the working fluid. The heated sCO2 exiting the TES is then expanded over the turbine stages to drive the compressor and the three stages of turbogenerators. The system flows are monitored and controlled to deliver sCO2 to the turbine inlet at the design point conditions. Since the storage media is a phase change material much of the charge cycle is at fixed heat load with the media so the exit temperature remains constant for simplified control. During discharge there are two regimes where the TES is delivering sensible heat and the control system actively controls the flow to maintain design point inlet conditions to the turbine. It is also possible to export at a reduced power to extend the discharge period.

The TES is modular and so by adding modules can be designed for capacities in 5MWe blocks. The capacity is designed so that full turbine inlet temperature is maintained during dispatch so that rated power is delivered for the full duration. However, there is still a large thermal capacity remaining in the TES in the form of sensible heat. Thus, while it has completed the intended cycle it is still capable of delivering power in the case of emergencies, albeit not at its full rating. Running below rated power allows for emergency dispatch and can be initiated at any time. The output can be controlled to deliver a constant output for a fixed time, or to deliver the maximum output while constantly derating due to TIT droop. While running in emergency mode, the control system optimizes the turbine speed for the available TIT. A negative of running in this mode is that additional time will be required to restore to full charge. However, unlike Li-ion batteries, there is no damage or subsequent performance penalty to the system brought on by deep cycling.
There are two methods of charging the TES which are a function of the application. The two applications are:

- Time shifting electric capacity
- Controlled dispatch of Waste Heat

Storing excess or curtailed electric capacity is achieved by using a network of resistive plate heaters. This is the most efficient charging method since all of the energy delivered is stored in the TES. Depending on the connection architecture, the heaters can accept either DC or AC current. If the current is coming from the grid then AC is obviously preferred, but when connected to a renewable energy source it may be suitable to use DC if permitted, since it will eliminate inverter losses. Electric heating is also controllable, allowing for sector temperature controls that allow selective sector charging that permit emergency dispatch, even during the charge cycle. Electric heating also offers flexibility on charging rate, subject to the rating of the heaters used in the build. Thus, the TES can be designed for a short or long charge cycle depending on the anticipated source.

Many industries have waste heat that is discarded because there is no immediate use. Storing the heat for later dispatch as electricity is a second application for this technology. For this type of storage, a sensible heat media, where a thermocline exists, is preferred because the exhaust remains low for much of the charge cycle. Using phase change media, it lacks a thermocline and the exhaust temperature is high during much of the charge cycle. With sensible heat storage it is sometimes cost effective to add a recuperator to preheat the exiting charge air to improve efficiency. The system architecture and cycle selection require an optimization study. There are several sensible heat storage solutions, the selection of TES technology is a function of the waste heat stream and temperature. While the existence of a thermocline within the TES is a positive with respect to efficiency, it results in variable heat delivery. To overcome the changing energy input an active control system is employed to maintain the temperature and mass flow rate of the working fluid to the turbine. This is achieved by mixing the controlled TES flow with a bypass flow to achieve the desired temperature to the turbine inlet.

Waste heat recovery for electric generation suffers the same installation constraints that suppress widespread industrial utilization for simple process efficiency gains, and also the fact that each installation tends to be unique and requires dedicated application engineering. However, electric is more valuable than heat, especially if time of day metering or demand charge offset is considered, and so while not our primary focus, remains a possible opportunity. Electricity stored as heat is much simpler and our current focus. At a system level the components are all the same, negating much of the engineering work required for the charge system, the only application work required is to determine the capacity and charge rate based on site specific economic factors.

Technology Status

The technology of this solution should be considered in two parts; the power block and the TES. Only the TES will be discussed here, for details of the power block please refer to the Novel Cycle Database.

The preferred TES configuration employs a miscible gap alloy with a phase change temperature slightly above the cycle TIT design point of 750C. Two alloy configurations are in development, a low temperature with a phase change at 660C, and a higher temperature material with a phase change at 800C. Both chemistries have been fully characterized and successfully completed accelerated lifetime cyclic testing and thermal saturation at the upper limits of temperature to ensure containment and lifetime performance.

The TES bricks have transitioned from lab scale manufacturing to a production process that is readily transferrable. The bricks can be molded to the desired geometry to include any necessary features for thermal input and discharge. The bricks are also machinable, using conventional cutters and equipment, although it is costlier than molding into the final form.

The proof of concept (POC) technology demonstrator will employ the low temperature bricks. The main reason for this is to gain knowledge in design and build before finalizing the design which will employ higher cost materials. The POC testing is planned for 2021 Q2, and the materials are now on order.

While the technology readiness is now at TRL 3, the development plan will quickly move it to TRL level 6 by the end of 2021. A pilot plant for a 10MW PV field is being evaluated and if executed will move to a TRL 9 for PV time shifting by the end of 2022.

Benefits and Costs

PTT's TES conversion system employs sCO2 turbomachinery, which is very power dense and results in very low inertia rotors that can be ramped up much faster than equivalent rated gas turbines, however, they are not intended to compete with batteries for immediacy. A cost analysis indicates that PTT's TES is cheaper than batteries when the dispatch duration is greater than 4 hours at rated output. The cross over at 4 hrs will likely move as technologies evolve. Compared to batteries, the PTT's TES has a higher $/MW base cost for discharge capacity of less than 3 hours, but a very low incremental capacity cost ($/MWhe), so the longer the desired dispatch, the greater the advantage. Due to the capacity costs, there will always be some duration where the TES offers a lower cost than batteries. If fast-ramp discharge capacity is desired then the lowest cost solution would be a Li-ion/TES hybrid solution where batteries are used for immediacy and frequency support and the TES provides capacity.

The low inertia of the turbomachinery means that starting with a TES is actually faster than with fueled version because the equivalent of the primary heat exchanger is already at temperature. A system start to full load is expected to be less than 1-minute, and will be demonstrated on the POC. However, faster starting, such as the <10 seconds required of emergency operations, is not necessary because the cost of battery support for immediacy and ramp-up is lower risk. The round-trip efficiency is dependent on the selected cycle and components employed, but using the recuperated cycle

PTT’s cycle deck indicates that round trip efficiencies of 45% can be achieved.

The mission profile for the TES is very flexible. Its charge/discharge rate is determined based on the expected availability of curtailed or excess supply to be time shifted. It is possible to have a charge rate that is many times higher than the discharge rate. It is also possible to have a charge rate lower than the discharge for extended duration discharge where utilization is low and the TES is only partially discharged. The beauty of the TES, because it has lower cost capacity, is that it can be built out for durations much cheaper than batteries.

Cycling of the system does not have an impact on life as with internal combustion machines. In fact, the limited thermal gradient associated with TES operations, extends the life of the system. There are low standby losses associated with thermal leakage from the TES, but with its intended daily cycles for time shifting PV peaks, this will be a minimum. Thermal leakage losses are expected to be <1%/day of stored capacity, and is also minimized by our heating strategy.

The TES generator can be deployed in 5MWe and 10MWe modular units at a charge rate that can be less than or a factor of five greater than the discharge rate. The 1MWe power block module is coupled to the TES to provide dispatches from 5MWeh and above. System costs are therefore dependent on the build configuration. Smaller capacities with faster charge times will be costlier than lager capacities with slower charge times. Due to the operating flexibility the driver for adoption of this technology will not be on $/MWh but its operating flexibility for deep cycling to capture revenue, its extended run time capacities, and the potential to have capacity that is poorly utilized because of the low cost of capacity.

With the power block as a repairable system and the TES as a passive thermal device the lifetime is that of typical turbomachinery, which is 20 years. However, there is nothing within the system that is life limited, this is purely for asset depreciation calculation to be used for ROI, which is much more influential factor than the capacity cost. In production the system will be competitive with batteries at a dispatch of 4 hours, and will provide a benefit for extended dispatch. When lifetime costs are considered, the doubling of the TES system life considerably improves cost of revenue and ROI, which is not obvious from the simple $/MWe and $/MWeh parameters.

Barriers and Challenges

There are no technical barriers to the deployment of the basic technology. Charging and discharging of the blocks has been demonstrated, insulation methods have been developed for similar thermal systems, suitable electric heaters are available, piping fabrication techniques exist, and the heat transfer characteristics are well understood. The development effort is in cost optimizing the system and packaging for energy density. While these are not barriers to the technology, reducing cost and increasing energy density will increase deployment opportunities. The POC will be completed in 2022 Q2 and provide details to improve the design of the higher temperature system. A field demonstration system is currently planned for 2023 to provide time shifting capabilities to a 10MW PV array. The proposed TES system is a 1MWe/15MWhe system, although the final capacity will be selected based on the economics.

The larger barriers to deployment are not technical but associated with economic factors [2]. While it is accepted that long duration storage is required to achieve the Net Zero vision, the policies and incentives are not integrated with rate design to facilitate their deployment. Additionally, if shifting for 4hrs is all that is desired then all of that can be achieved with batteries, leaving no incentive for longer duration dispatch. If long duration storage is to be available when required for high RE penetration, then policies that encourage its deployment must be enacted. This includes priority dispatch so they can increase utilization, which can be low for long event capacities which rarely occur. Time of day incentives to improve the ROI will also help accelerate adoption of this much needed technology.

References

[1] PTT sCO2 Closed Loop Brayton Cycle, D.Stapp, EPRI Novel Cycle Database.
[2] Issue brief: Long-Duration Energy Storage, Will McNamara, Jan 2021, SAND2021-0371