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Gravity Power Module Electricity Storage Proposal for SCE's Living Pilot

Overview: Pursuant to R.12-03-014, Gravity Power, LLC proposes the inclusion of a Gravity Power Module (GPM) bulk electricity storage demonstration plant in Southern California Edison's Living Pilot for test and evaluation as a Preferred Resource. Construction of a 1 – 5MW GPM could begin in 2014 and finish within 12-18 months, followed by operational tests and commercial service. At the completion of the test phase the GPM technology would be at DOE TRL 7, ready for implementation in larger scale systems. Thereafter commercial scale GPMs each capable of providing 40-1000 MW for several hours could be constructed as Preferred Resources to provide peaking or intermediate power plant capacity and superior ancillary services.

Background: A decision to close the San Onofre Nuclear Generating Station (SONGS) permanently was made in June 2013, leaving a capacity loss of 2,200 MW in the Orange County/San Diego County areas. On August 26, 2013, Southern California Edison (SCE) filed Track 4 direct testimony in R.12-03-014 calling for a balanced approach, including development of preferred resources, transmission, and conventional gas-fired generation to replace SONGS. SCE proposed a Preferred Resource "Living" Pilot to procure and evaluate the ability of Preferred Resources to meet Local Capacity Requirements. The Living Pilot will be designed to help inform electric system operators, transmission planners, and procurement entities about the ability and availability of Preferred Resources to perform where and when needed to meet local reliability, while ensuring grid stability and resiliency. Results of the Living Pilot would be incorporated into procurement requirements after 2014.

Electricity Storage: Over 99% of the grid electricity storage currently in use around the world is pumped storage hydropower (PSH). This technology has many advantages including large capacity, high efficiency, low cost per kWh, and excellent operational dynamics, i.e. ramping, load following and rotational inertia. These advantages made it the preferred choice for large scale electricity storage, but sites have become so difficult to find, acquire, and permit that it is now virtually impossible to implement PSH on a timely schedule. However, if a cost-effective PSH variant were available that eliminated the usual siting difficulties, it would likely become the preferred choice for large scale electricity storage for the foreseeable future. That is what Gravity Power can provide.

The Gravity Power Module: Gravity Power, LLC was founded in January of 2009 to develop the GPM electricity storage technology, which is superior to combustion turbine plants and other forms of electricity storage for large scale peaking, intermediate and ancillary services power. The basic GPM configuration is shown in Figure 1, and an expanded view of the power house in Figure 2. To store energy the GPM hydraulically elevates a massive piston inside a deep vertical shaft. On demand, the piston descends in the shaft and forces water back through the pump/turbine to generate electricity. The main shaft of a commercial-scale unit will typically be between 30 and 100 meters in diameter and 500 to 1000 meters deep, providing a power output of 40 to 1000+ MW for 4 hours or more, depending on requirements and the size selected. The GPM uses proven components and technologies for all major subsystems. The power system consists of a pump/turbine and synchronous motor/generator identical to those used in conventional PSH. Construction employs cement, steel and other abundantly available materials along with techniques and procedures long used in mining and civil engineering projects.

Operational Characteristics: From the system operators' point of view, a GPM operates like a modern PSH plant, with some improvements. Where PSH maximum power output decreases as the upper reservoir empties and pressure drops, GPM maximum power remains constant due to the unchanging pressure produced by the piston. The pump/turbine thus operates closer to its best efficiency point than is possible with PSH, resulting in better average efficiency. Peak round-trip efficiency will typically exceed 80%. The relatively short length of water conduits and low vertical speed of the piston will also allow a GPM to ramp up or down even faster than most PSH plants without risk of damage from water hammer. If needed, even a 1000MW GPM can ramp from zero output to full power in less than 20 seconds. Where high operational flexibility is required, a GPM can be configured to vary smoothly and rapidly over the full range from maximum pumping power to maximum generation power or vice versa.

Advantages:

- Land – GPMs have far lower land requirements than PSH or combustion turbine power plants—a 1000 MW GPM will fit on any three acre site where a deep shaft can be excavated.
- Environment – GPMs are quiet, produce no emissions, contain no hazardous materials, and don't interact with ground water. Unlike PSH, no water reservoirs are needed and there is minimal ongoing water consumption. These factors will greatly reduce permit delays, start-up costs and time to revenue.
- Production – No new component factories are needed, so it will be feasible begin construction of thousands of megawatts of new GPM capacity per year as soon as the technology is demonstrated and installed and operating costs are proven.
- LCOE – The Levelized Cost of Electricity will be substantially lower than combustion turbine peaking plants, even where gas is inexpensive.
- Renewable Support – Dynamic response is far superior to gas turbine power plants, providing better support for wind and solar power and higher quality ancillary services.
- Cost – GPM cost per kW and per kWh drops rapidly as unit size increases, due to scaling factors and economies of scale in both equipment costs and construction. For example, the power system for a 300 MW GPM (pump/turbine, motor/generator and associated equipment) costs just over twice as much as the power system for a 40 MW GPM. A 300 MW GPM will have an estimated overnight installed cost of less than \$1750/kW (\$437/kWh). At even larger scale GPM cost could drop to as little as \$200/kWh of installed storage. Construction methods, costs and schedules were developed by Babendererde Engineers of Germany, a highly experienced underground engineering firm, with corroboration from Hochtief AG, a large German construction subsidiary of the ACS Group of Spain, the world's largest construction company.

Demonstration Project: A 1 MW GPM with a half hour of output can be constructed at a suitable site in South Orange County at a cost of ~\$6-10M. This unit would have a 20-foot (6 m) diameter shaft 400 feet (125 m) deep, and would use off-the-shelf power equipment. Construction would take 12-18 months. With a piston mass of nearly 5000 tons, it would be large enough to test and demonstrate all elements of the system, including shaft construction, piston construction and seals. It would also be large enough to provide realistic tests of ancillary service capabilities using grid-supplied control signals. Since the incremental cost of increasing GPM size is small, SCE could choose a larger demo unit to increase operational utility. For example, the estimated cost of a 5 MW GPM is only 2.3 times the cost of a 1 MW GPM. Subsequent to test completion it could continue in service to provide extended test data and commercial utility as an ancillary service unit. At demo test completion, GPM technology will be at a DOE Technology Readiness Level (TRL) of 7 (demonstration of an actual system prototype in an operational environment). Commercial scale GPMs each capable of providing 40-1000 MW for several hours could then be constructed as Preferred Resources to provide peaking or intermediate power plant capacity as well as superior ancillary services.

Summary: The GPM provides all the advantages of improved pumped-storage hydropower, without the siting constraints or negative environmental impact. It offers a new class of large scale electricity storage-based power plant to provide peaking, intermediate and ancillary service power. As GPM technology matures, its environmental and performance advantages, siting flexibility and cost effectiveness will allow it to replace simple cycle gas turbines and PSH, provide the increasingly fast ramping and backup needed to facilitate California's growing wind and solar power generation, and optimize the operation of existing base-load power plants.

Figure 1. GPM Design

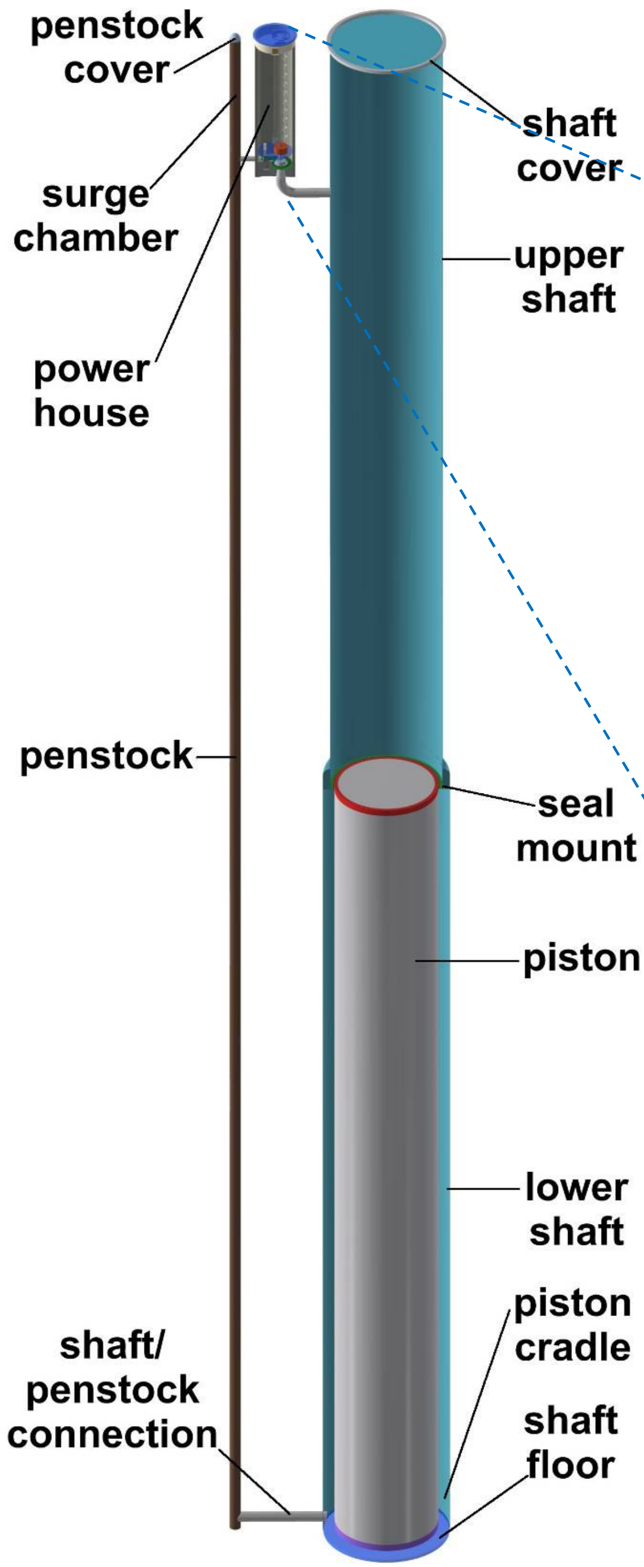

Figure 2. Power House Design