Design of 20-MW Flywheel-based Regulation Power Plant

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The US Department of Energy is funding the design of the world's first 20-MW flywheel-based, regulation power plant under a contract administrated by Sandia National Laboratories. This paper will review the major aspects of the design work.

Working with an architectural and engineering firm, Beacon Power has developed a detailed drawing package for a generic 20-MW flywheel plant that can be used to obtain accurate bids from a design/build contractor. The design package includes conceptual designs and layout drawings, based on minimizing cost, optimizing performance and decreasing build time. The goal was to develop a design concept where 70% of the details of any plant would be based on this 'core' design and 30% would be customized in response to specific site conditions and local codes and building requirements. This type of design process, similar to that of large retailers, should allow for quick siting and construction.

The building design (shown in Figure 1) includes the overall building structure as well as the process cooling, power wiring, substation, work space, and storage. The following key items were evaluated during the design process:

- **Reliability—**Identifying parameters to help ensure that the design is consistent with proper and reliable operation over a 20-year design life.
- **Cost-performance—**Determining design features that maximize the cost-performance of the plant, considering the impact of systems, sub-systems and equipment on total energy efficiency, land cost, operations and maintenance cost, etc.
- **Cost performance comparison—**Comparing the costs associated with providing regulation for the traditional power plants and battery energy storage plants with those of a flywheel regulation power plant.
- **Siting, permitting, and construction**—Identifying processes and potential road blocks in obtaining required documents for beginning construction.
- **Renewable energy—**Considering adding photovoltaic (PV) modules to the roof of the plant, which can help offset some of the energy losses of the plant.
- **Optional plant designs—**Considering the pros and cons of facilities ranging from 1 MW to 40 MW.
- **Leadership in Energy and Environmental Design (LEED) rating—**Considering options for achieving LEED-NC rating.

Figure 1 - Rendering of 20-MW flywheel-based regulation plant.

The first step in plant design was to develop the base building block for the plant. Several modeling exercises were run to determine the minimum amount of space necessary between each flywheel module that would still

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allow space for preventative maintenance and inspection. Figure 2 shows the relative distance between each flywheel, electronic control module (ECM), process cooling, and power and communication wiring. Process cooling for the flywheels and ECM is run down the center of the aisle between the flywheels to minimize piping and connection lengths. The motor leads from the flywheel are attached to the base of the ECM which minimizes the length of the leads which, in turn, reduces costs and simplifies the connection process. Power then exits the ECM at the top of the unit through a 480-V disconnect to a 480-V bus duct. This routing minimizes electrical interference because it keeps the power wiring away from the communication wiring, which leaves the top rear section of the flywheel and is routed into the cable tray.

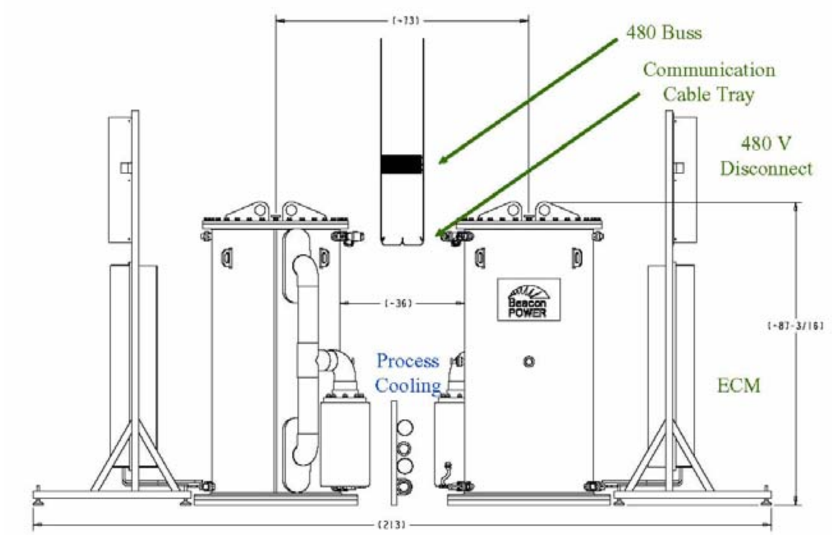

Figure 2 - Side view of flywheel layout.

Next, a four-flywheel block layout was used to ensure proper spacing between the flywheels and ECMs along the length of the row as shown in Figure 3. Using this as the baseline configuration, the configuration was increased to a 2-MW block (twenty flywheels) as shown in Figure 4. Ten 2-MW blocks are used to produce a flywheel plant capable of providing 20 MW of power as shown in Figure 5.

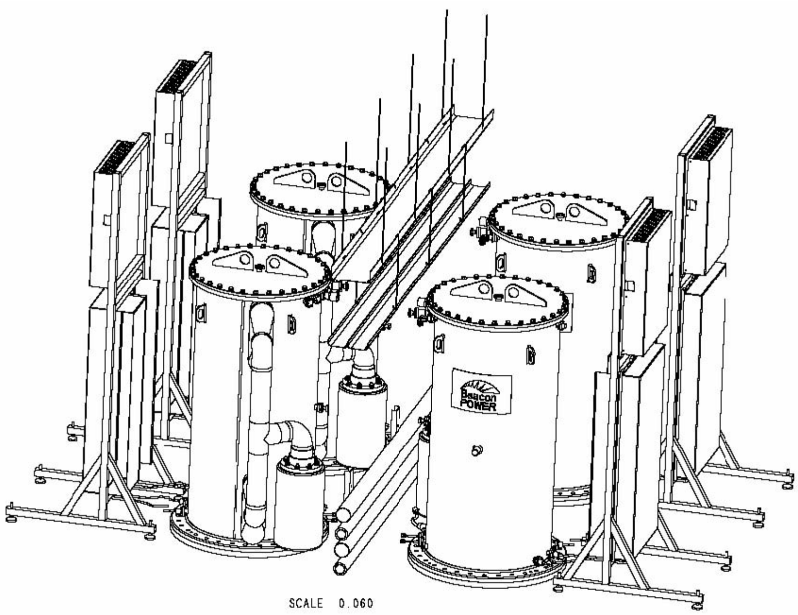

Figure 3 – Four-block isometric view.

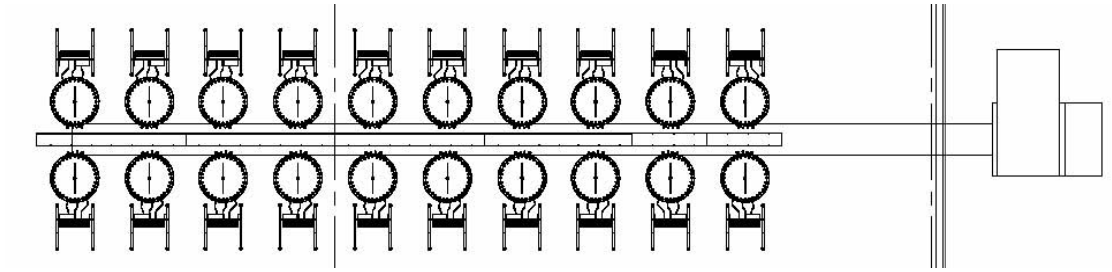

Figure 4 – 2-MW block (twenty flywheels).

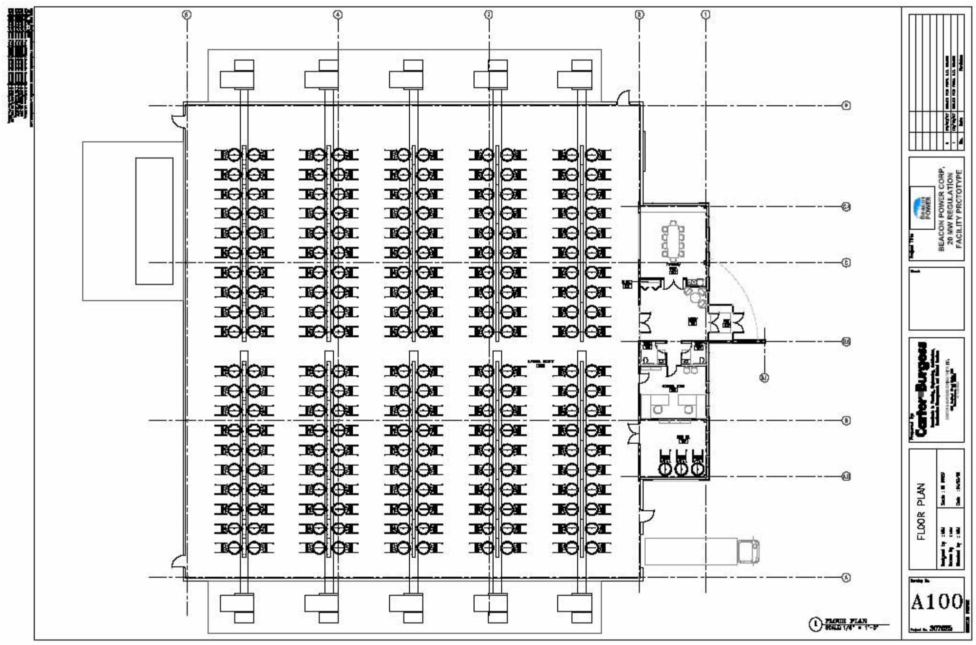

Figure 5 – 20-MW flywheel plant layout.

Beacon worked with Richard Gross PE, Inc., an interconnection consultant, to provide a reliability *vs.* cost analysis for the plant's power wiring and transformers. The initial baseline design included two 115-kV to 13.8-kV transmission transformers to ensure the most reliable plant operation. The results of the analysis indicated that a single transmission transformer would be sufficient and would have minimal impact on the plant's reliability while reducing its cost.

The plant uses two separate process cooling loops (see Figure 6), one for the ECMs and another for the flywheels. The ECM cooling loop is a higher temperature cooling loop where the inlet water temperature must remain below the ambient dew point temperature to prevent condensation on the cold plate of the ECM. The flywheel cooling loop requires less flow and lower temperatures. Two separate plumbing systems were compared—a centralized system with two large chillers located within the plant versus a decentralized system. For a similar cost the decentralized system, while a little less efficient, offers greater reliability due to its higher level of redundancy. The flywheel loop requires a refrigeration cycle chiller to achieve the lower temperatures required. A closed-loop system with a heat exchanger, located outside of the building, provides adequate cooling for the ECMs. In addition to cooling the ECMs the closed loop heat exchanger system provides cooling for the indoor chillers cooling the flywheels. With this setup, only a minimal amount of heat is released into the building.

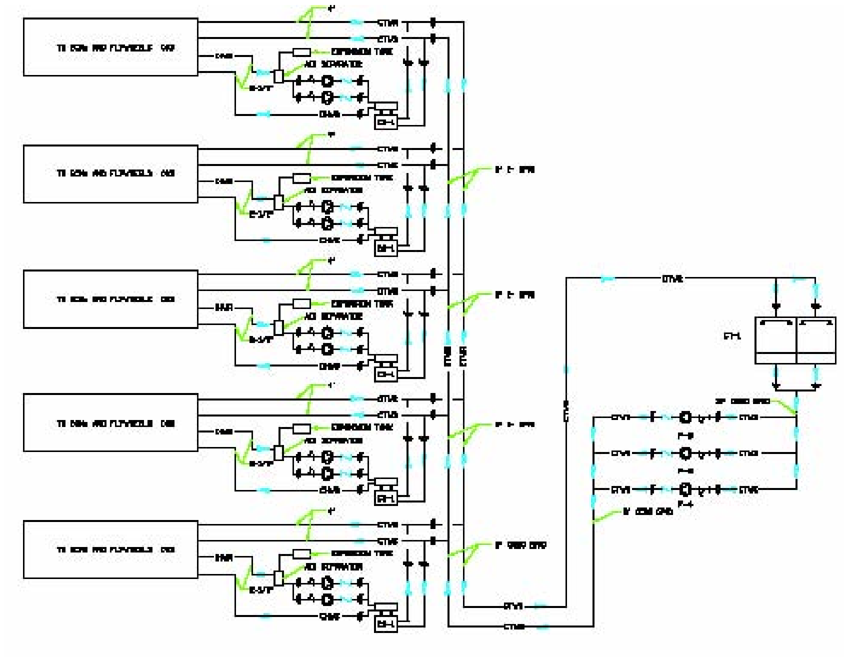

Figure 6 – Process cooling system.

To reduce first and operational costs, one of the primary design considerations was not to air condition the space in the flywheel portion of the plant. Based on Carter Burgess calculations, air conditioning in the building will not be required. At times, however, there will be a need to move air through the building to reduce the temperature. To accomplish this, a series of motorized windows and ventilation fans were designed into the front and rear of the building as shown in Figure 7.

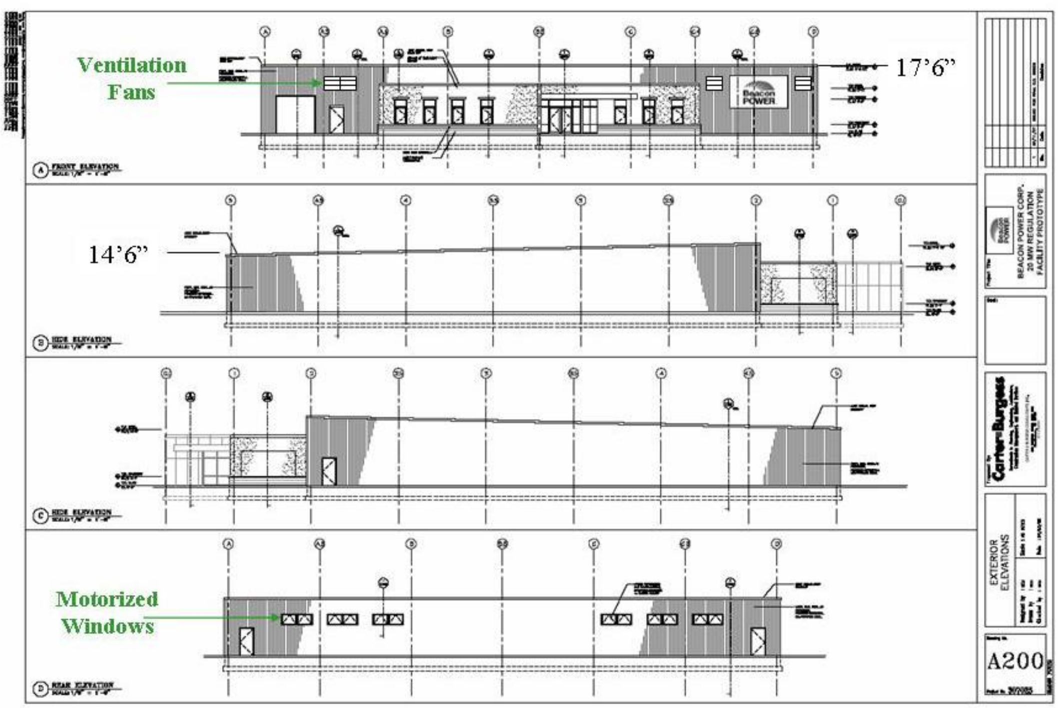

Figure 7 - Plant elevation showing ventilation.

The plant is designed to minimize the amount of construction time necessary. The flywheel section of the building was designed to allow for construction with a pre-engineered building (built off site and assembled on site). To ensure the widest applicable design, the design team assumed a site for the plant that was in a rural area with little to no city services and a 115-kV transmission line nearby. These assumptions required the design of a substation, a storm water management area, and drove setback requirements. Figure 6 shows the basic site layout. The criteria given in Table 1 describe the optimal site requirements for the fastest possible construction.

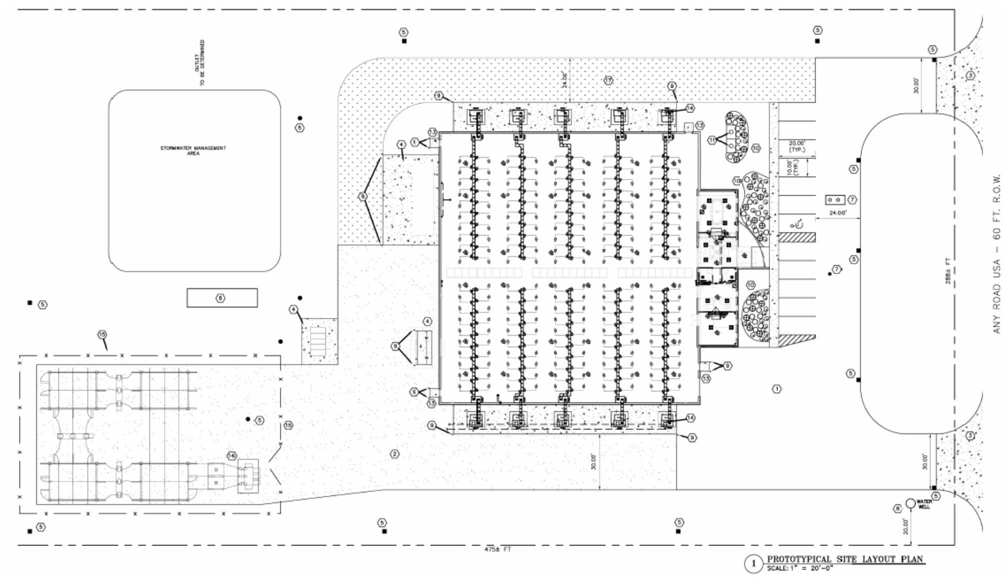

Figure 6 – Stand-alone site layout.

Table 1 - Site selection criteria

Site Topography	Minimal grade change throughout site.
Available Utilities	Public storm drain Public sanitary connection Public water connection Telephone
Electrical	Substation with 20-MW capacity
Parcel	Vacant. No demolition/site preparation required.
Geotechnical	Suitable bearing capacity without 'over cutting'. Material could also allow for infiltration of storm water if acceptable by municipality.
Municipal Requirements	Minor relative to landscaping, screenings, building materials, etc.
Zoning	Industrial/Light Manufacturing –Typical. Allow for construction of facility without requiring rezoning, variances, etc. Some situations only require administrative review by the municipality.

Sandia National Laboratories performed a renewable energy assessment focusing on benefits of installing photovoltaic modules on the roof of the power plant to offset the daily energy losses of the plant for two sites, one in Southern California and another in Central Massachusetts. The results are shown in Table 2.

Table 2 - Potential PV Savings

	Fixed Array	Single Axis
Southern California	1.8%	2.3%
Central Massachusetts	1.5%	1.8%

Carter Burgess reviewed the building design to determine LEED rating that can be achieved by the flywheel regulation plant. A summary of their results is provided in Table 3. Based on the scores, the flywheel-based regulation plant could achieve a silver-level LEED rating and, possibly, a gold-level rating.

Table 3 – LEED-NC Rating Summary

	Potential Points	Yes	?	No
Sustainable Sites	14 Points	8	1	5
Water Efficiency	5 Points	3	2	0
Energy & Atmosphere	17 Points	6	1	10
Materials & Resources	13 Points	6	3	4
Indoor Environmental Quality	15 Points	9	3	3
Innovation & Design Process	5 Points	1	0	4
Project Totals (pre-certification estimates)	69 Points	33	10	26

LEED-NC Ratings	
Platinum:	52-69 points
Gold:	39-51 points
Silver:	33-38 points
Certified:	26-32 points

The cost for the flywheel plant as designed is estimated to be in the $10-12 million range. The target plant cost is $5 million. Due to the difference, Beacon Power is currently designing a substation-style plant (shown in Figure 7) that is expected to meet the target cost. In the substation design, the flywheels will be mounted in pre-cast housings and assembled into 1-MW modules (as shown in Figure 8) that contain all the necessary plumbing, electrical, and communications wiring. The modules can then be assembled into a complete plant on site without constructing a new building, which will greatly reduce onsite construction and the time necessary to build the plant.

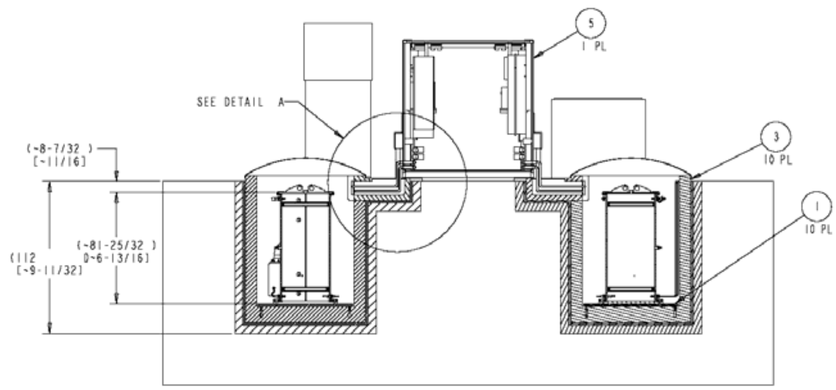

Figure 7 – Substation design cross section.

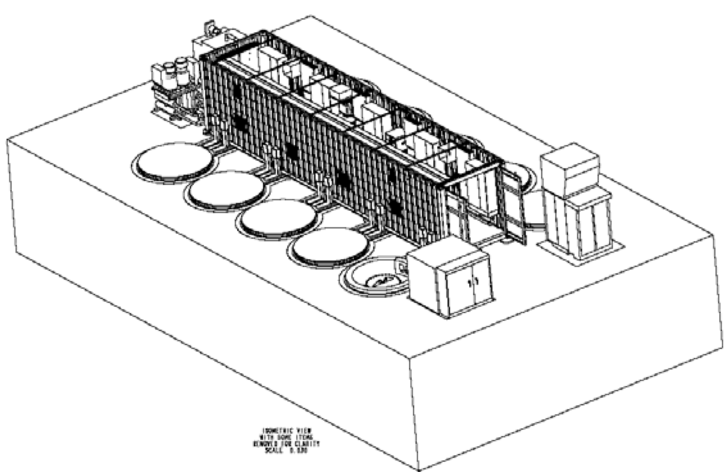

Figure 8 – 1-MW substation module.