Autodesk® Sustainability Workshop
Design Process White Paper

Design Development Case Study: USS Megahelion™ Solar Tracking Drive

One of the best ways to learn about engineering design is to analyze the methods used in successful projects. One such success story is that of Utility Scale Solar, Inc. (USS). The project began when the future founders of USS began wondering why building solar energy power plants is still inordinately expensive. After extensive research, they discovered that the single biggest capital cost for a solar power plant is something as simple as a drive.

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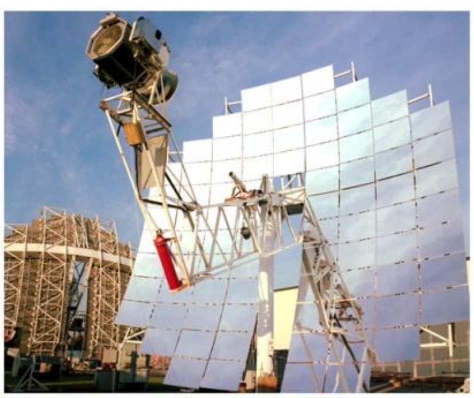
Identifying Project Scope and Objectives

Most forms of utility-scale solar power plants track the sun throughout the day using a panel with a mirror or photovoltaic cells. Concentrated solar thermal (CST) power plants use lenses or mirrors to focus a large area of sunlight and heat a working fluid that is used to generate and store electricity. One way of doing this is to use thousands of sun-tracking mirrors, called heliostats, to concentrate solar energy on a central receiver atop a tower. Another CST technology is dish stirling systems that consist of a stand-alone parabolic reflector that concentrates light onto a receiver positioned at the reflector's focal point. Another type of large-scale solar power plant simply uses very large photovoltaic (PV) panels that track the sun with either a one- or two-axis drive.

Solar Two CST Power Plant – Barstow, CA
Source: Sandia National Laboratory



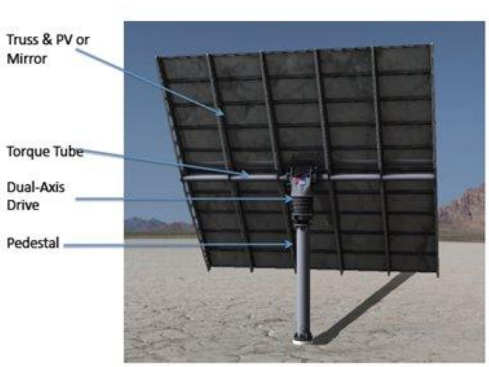
Dish Stirling system - Huntington Beach,CA
Source: Sandia National Laboratory

PV Panels at Nellis Air Force Base
Source: U.S. Air Force

Utility Scale Solar's founders considered the cost structure of these power plants and quickly realized that, in many formats, the largest single capital cost is the drive that positions the heliostat arrays. Research showed that for a typical CST power plant, the heliostat costs were 55 percent of plant capital costs—and that the drive accounted for 50 percent of that cost. They concluded that if they could reduce the cost of this drive, they could lower the cost of electricity generation in these plants to about 7.5 cents per kilowatt hour—about the price of electricity from natural gas and approaching the price of coal.

Both CST and PV-based systems require high torque drives, but the precision and range of motion requirements for CST tower systems are the most demanding. CST tower systems require highly precise, two-axis drive systems. USS decided to focus on this market, because a design that met these more stringent requirements could be used in any utility-scale solar configuration.

Cost-effectively and reliably tracking these large panels under wind loads is no small task. USS found that current systems were costly, fragile, and unmanageable. They found that the biggest contributor to the high costs of current drives is the precision-machined gear reduction components. There were few new approaches being pursued.



Basic Components of a Tracker
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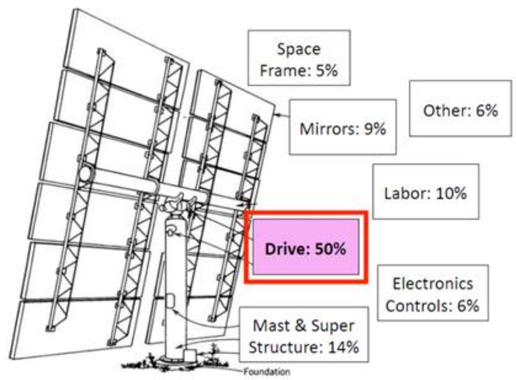


Largest Cost in a Heliostat: The Drive
Source: Sandia National Laboratory, 2007; Sargent & Lindy, 2003

Creating Engineering Requirements

Developing solid engineering design requirements is crucial to the success of any design project. USS spent a lot of time at the beginning of the design process reviewing research, talking to people in the industry, and discussing how their research could be translated into measurable design requirements.

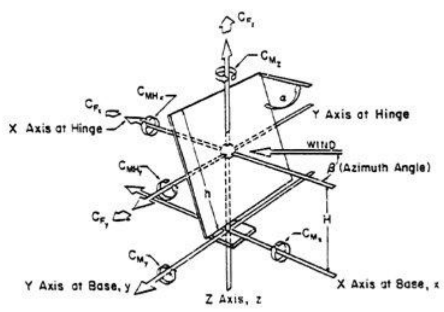
In addition to cost requirements, the team had to create ambitious but achievable technical requirements. While there are many methods for developing constraints and design requirements, one straightforward method is to simply identify gaps in current solutions.

Torque

To actuate a 150 m^2 panel, and keep it in place when wind speed increases, the motor must produce extremely high amounts of torque. To determine exactly how much, the USS team turned to seminal research funded by Sandia Laboratories on optimal configurations and wind-load requirements for ground-based heliostats (Peterka, 1992). Hinge moments are required to tilt the panel up and down, while azimuthal moments are required to rotate the panel around the pedestal. These two moments determine the drive's torque requirements.

The Sandia research showed that 150 m^2 of surface area was the optimal panel size and that these drives must withstand wind speeds of 27 mph (12 m/s) under normal operating conditions. Most drives on the market are not capable of actuating a panel this large.

While wind speeds can reach 90 mph (40 m/s) where these drives are used, the arrays are programmed to automatically move to a safe stow position when winds reach 50 mph (22 m/s). To stow this size panel under the forces of a 50 mph (22 m/s) wind, requires a per-axis torque of 100,000 foot-pounds, or 136,000 Newton meters. Since these wind loads are so much larger than the equipment loads on the drive, the design would meet all of the other load requirements if it met this structural requirement for wind.



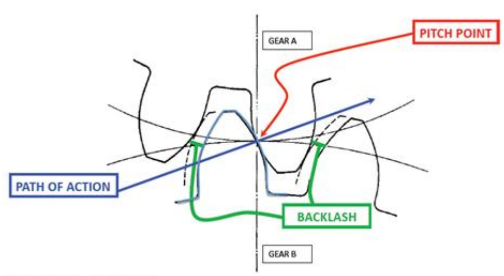
		Wind Speed		
Force	**Symbol**	**27 mph (12 m/s)**	**50 mph (22 m/s)**	**90 mph (40 m/s)**
Drag	Fx	4,200 lbs (1,905 kg)	13,826 lbs (6,271 kg)	6,999 lbs (3,174 kg)
Lift	Fz	2,940 lbs (1,334 kg)	9,678 lbs (4,390 kg)	10,499 lbs (4,762 kg)
Base Overturning Moment	My	102,939 ft-lbs (139,567 Nm)	338,186 ft-lbs (458,519 Nm)	247,751 ft-lbs (335,905 Nm)
Hinge Moment	MHy	25,317 ft-lbs (34,325 Nm)	81,648 ft-lbs (110,700 Nm)	93,768 ft-lbs (127,132 Nm)
Azimuthal Moment	Mz	29,537 ft-lbs (40,047 Nm)	95,256 ft-lbs (129,150 Nm)	9,377 ft-lbs (12,713 Nm)

Wind Loads on a Heliostat Array
Source: Peterka, J. A. (1992). *Wind Load Design Methods for Ground-Based Heliostats and Parabolic Dish Collectors.* Fort Collins, CO: Sandia National Laboratories

The conventional solution to achieve this amount of torque is with gear-based drive systems. Looking at these gear systems gave the USS design team additional insights into the design constraints.

Precision

These gear systems have powerful forces acting on them and so need to be machined with extremely tight tolerances. The result is very high manufacturing costs. All of the force is transmitted through the pitch point of the gears, an area of metal-to-metal contact usually about 60 mm^2. Even in designs with the tightest tolerances, these immense forces cause wear and unwanted backlash to the gear teeth. This wear leads to inaccuracies in the motor's ability to orient the panel to the sun. Accuracy of 0.5 milliradians is crucial for CST tower systems. This equates to hitting a 5 foot target from more than one mile away (1.5 meter target from 1.6 km away). A heliostat that misses this target is a wasted asset.



Schematic of Gears
Loads transmitted through Pitch Point

Maintenance

These high-precision gear-based motors are also difficult to maintain, especially in the harsh desert environments in which they are typically used. The maintenance crews of most large solar plants consist primarily of unskilled laborers, but maintenance on the high-precision gear-based units typically requires specialized labor and a machine shop for repairs. Furthermore, due to the tight tolerances, if any foreign matter such as sand or dirt works its way through the gear casing and into the gear systems, the damage will be catastrophic. At best, power plant operators can expect an expensive and time-consuming repair on the damaged gear system. At worst they can expect to replace the gear system.

Summary

Identifying these gaps left the USS team with the general objectives of high torque capacities, reduced manufacturing costs, and improved maintainability of the drive system. Once these general objectives were determined, USS attached specific metrics to them, as shown in Table 1. Armed with knowledge of measurable performance characteristics, USS began generating design concepts.

Table 1: Design Requirements

Requirement	Metric
High power (torque)	• 100,000 foot pounds of torque per axis (135,581 Nm) • Resist 340,000 foot-pound base overturning moment (461,000 Nm)
High precision	• Capable of maintaining less than 0.5 mrad error per axis RMS in wind speeds between 18–27 mph (8–12 m/s).
Reduced manufacturing costs	• Drive cost of less than $\$165/m^2$ for a levelized cost of energy at or below 7.5 cents per kilowatt hour
Improved maintainability	• Capable of being maintained by unskilled labor • 30 year service life in desert conditions • Tolerances loose enough make the system impervious to dust and temperature changes

Concept Generation and Refinement

USS's concept, the Megahelion™ Drive, is a simple, elegant single-axis solution that can be combined to create a dual-axis tracker. USS engineers began by exploring existing methods for creating large amounts of torque. They found that almost all methods use one of two principles: mechanical reduction or conventional hydraulic cylinders. By exploring fluid mechanics, and using the same principle that allows a tire to support a car with only 30 psi, they created a concept that seemed ideal. Instead of gears and motors, they used bladders, a pump and control valves to create a fluid power drive with open tolerances. By enclosing these bladders in a drum, they found they could create a relatively compact design that met all of their design requirements.

Once the single-axis concept was proven, and before the company began using Digital Prototyping software, USS began refining it using an iterative build-test method. A new prototype would be built from scratch over the course of roughly 10 weeks. The new prototype would be tested and different deformations measured. The deformations would be used to gauge the stress found at different points in the prototype. With knowledge gleaned from the last generation, USS would start this cycle over. This resulted in six prototypes of the single-axis drive system. Although it was a cumbersome, expensive "trial and error" method, it yielded the basic design that is being developed today for production.

Some of the benefits of this design are that it's simple to manufacture and the tolerances required are greater than 1 mm. This makes the initial drive cost much lower. These forgiving tolerances have the added benefit of making the drive much more resistant to sand, grit, and corrosion—and easier to service. Also, because the fluid power system is an inline direct drive, it is very precise (0.2 mrad error), has only three moving parts per axis, and is more robust because the forces are distributed over a larger area.

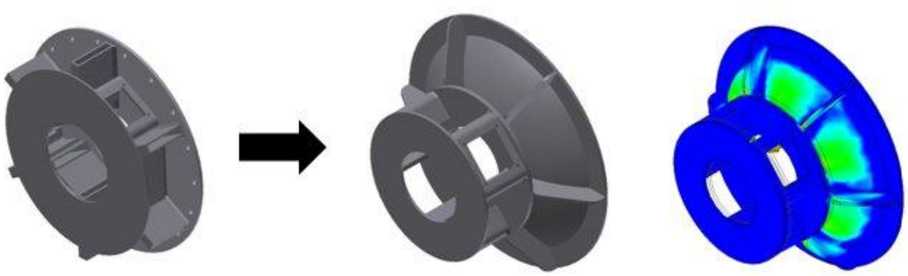
Utility Scale Solar Megahelion™ Drive
US & International Patents Pending
Image copyright 2010 Utility Scale Solar, Inc.

Digital Prototyping

As USS began development of a dual-axis design based on this drive concept, the company became an Autodesk Clean Tech Partner and began using Autodesk® Inventor® software to create digital prototypes of their concepts. This was a significant improvement to the design process and has saved USS many thousands of dollars and months of development time.

A digital prototype is a digital simulation of a product that can be used to test form, fit, and function, thereby reducing the need for physical prototypes. By building a digital prototype, the designer can visualize how parts will fit together before they are physically made. Not only does this save materials and labor, it allows a much more flexible design process. Different parts of the design can be combined and tested in different assemblies—without destroying or disassembling the old iteration.

USS used built-in simulation and finite element analysis (FEA) capabilities of Autodesk Inventor software to see not just how things would fit together, but also how they would move and behave once assembled and loaded. This reduced clearance issues when the time came to begin building a physical prototype. FEA capabilities enabled the design team to simulate loads on the computer and understand how parts would deform and fail. As a result, USS was able to build lighter, more cost-effective drives.



Digital Prototyping Flat and Hemispherical Drive End Caps
USS Megahelion™ Drive
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For example, the design team used Autodesk Inventor to optimize the end cap of the design. End caps are significant contributors to the overall mass of the drive and are complex to manufacture. The original design used a flat end cap that was less effective at containing pressure than a curved hemispherical cap. After simulating various options, designers optimized the hemispherical design for thickness, depth, and rib pattern, leading to a 30 percent reduction in material use and saving about 500 pounds of steel per dual-axis drive. For a power plant with 1,000 arrays, this simple design change would save 250 tons of steel.

Conclusion

Utility Scale Solar has been able to create a powerful, precise, and reliable tracking drive that drastically reduces the cost and complexity of producing the very high torques necessary to power large solar arrays. The company was able to accomplish this by identifying unmet needs in large-scale solar power plants, scoping the problem to solar tracking drive cost and performance, establishing solid engineering requirements, and following an iterative digital and physical prototyping process. The company continues to build on these early successes and is currently prototyping and improving its next generation of products.

References

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About the Authors

Paul Burgeson - Purdue, M.E. student

Jonathan Blitz – CTO, Utility Scale Solar

Adam Menter - Autodesk Sustainable Design Program