HOT STUFF

NEM reduces cost and improves efficiency for concentrated solar power generation.

By Ingmar van Dijk, Solar Team, NEM Energy b.v., Leiden, The Netherlands

Power tower research facility in Spain where NEM tests its heliostats PHOTO CREDIT: © PLATAFORMA SOLAR DE ALMERIA / CIEMAT.

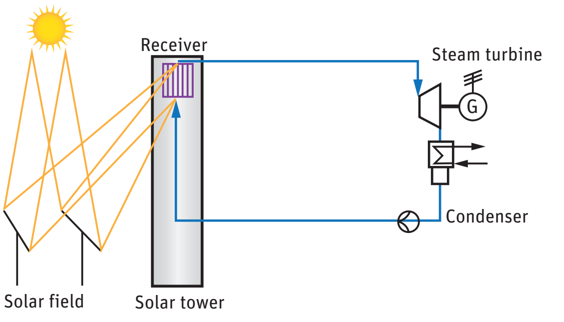
Advanced technology is playing an important role as the world looks for efficient and cost-effective sources of energy. Solar energy generation is growing, especially in sunny areas such as Africa, the Middle East, the Mediterranean and the southwestern United States. Photovoltaic (PV) energy has been a longtime leader in this field, but concentrated solar power (CSP) systems (which use mirrors or lenses to concentrate a large area of sunlight onto a small area to drive a heat engine connected to an electrical power generator) have been around for a long time and have now started to pick up steam. The U.S. Department of Energy (DOE) has offered roughly $5.89 billion in loans to four CSP projects, an amount greater than what it has offered to developers of photovoltaic projects[1].

CSP is experiencing rapid growth, with about 740 MW of global generating capacity added between 2007 and the end of 2010, bringing the total installed capability to 1,095 MW. NEM Energy b.v. is developing a power tower system type of CSP that uses a field of sun-tracking mirrors called heliostats to concentrate light onto a receiver on top of a tower. The difference between CSP and the more widely known photovoltaic form of solar power is that PV converts sunlight directly to electricity using the photovoltaic effect, while in CSP, concentrated sunlight is converted to heat. The heat can be used to directly produce steam, or a heat-transfer fluid can be used to store some of the heat to provide a buffer so that steam can be produced after the sun goes down. The steam, in turn, is used in a conventional turbine generator to produce electricity.

A key design challenge for NEM is increasing the stiffness of the mirrors to put as much reflected light as possible onto the target, called a receiver, without paying a cost premium. The company uses ANSYS Mechanical software within the ANSYS Workbench environment to evaluate the stiffness of large numbers of heliostat design alternatives. The results are fed into a ray tracing program that determines the energy generated by the design. This makes it possible to determine the performance-to-cost ratio of each design alternative without having to build physical prototypes. NEM is one of the top five producers of steam-generating equipment in

A key design challenge for NEM is increasing the stiffness of the mirrors to put as much reflected light as possible onto the target without paying a cost premium.

NEM can determine the performance-to-cost ratio of each design alternative without having to build physical prototypes.



Operation of power tower CSP plant shows how heliostats focus light on a central receiver that transfers heat to a fluid that, in turn, produces steam.

the world, and the company's experience in this area is a key advantage in developing CSP.

HELIOSTAT DESIGN CHALLENGES

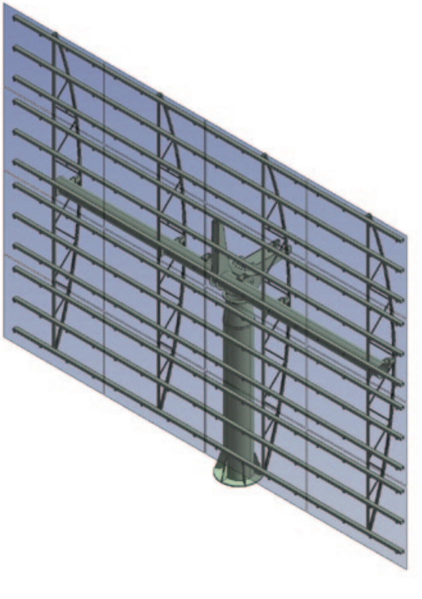
NEM's heliostat designs provide two-axis tracking of the sun. One axis rotates around a vertical pillar, which is supported by a foundation. The other axis rotates around a horizontal tube called the torque tube, centered on the top of the pillar. NEM's prototype provides approximately 60 square meters of mirror area. Cost is critical because a single power plant requires approximately 15,000 heliostats. The goal of heliostat manufacturers is to reduce the cost of manufacturing while achieving 25 years of service life and minimizing distortion to maximize energy generation. According to the Power Technology Roadmap and Cost Reduction Plan published by Sandia National Laboratories in 2011, the U.S. Department of Energy set a goal to reduce levelized cost of energy (LCOE) of CSP technology for a hypothetical 100 MW electric plant from today's costs of approximately \$0.15/kWh to a value of \$0.09/kWh or less in 2020. The DOE also set an objective to reduce heliostat costs from the current baseline of \$200 per square meter to \$120 per square meter.

Stiffness is a key factor in accomplishing these goals. Just a 1-degree rotation error for a heliostat 380 meters away from the tower results in a 6.6-meter tracking error, meaning that the reflected light is delivered 6.6 meters from the intended target on the tower. The structure also must meet building codes to ensure that it will maintain integrity during storms and earthquakes.

NEM engineers apply ANSYS Mechanical in the ANSYS Workbench environment to optimize heliostats from performance and cost standpoints. The design concept is defined in CATIA® V5 and imported into ANSYS DesignModeler. The heliostat contains 16 mirror segments, or facets.

As these facets are only a few millimeters thick and have large surface areas, they are very well suited for the use of shell (mesh) elements. An added benefit of shell elements over solid elements here is that shell elements can export rotation angles, which are very important to properly study the deformation behavior of the heliostat. The rest of the structure is meshed with solid elements.

NEM heliostat prototype



Finite element model of heliostat created in ANSYS DesignModeler

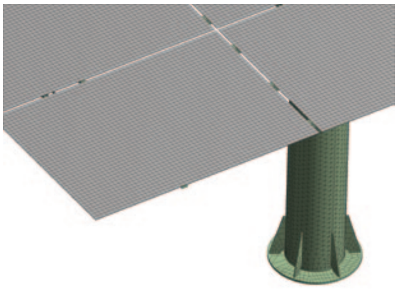
AUTOMATIC CREATION OF CONTACTS

With 200 different geometric bodies making up the heliostat, it is an enormous job to manually create contacts, so NEM engineers use ANSYS Workbench to automatically add more than 1,000 contacts using a 5-mm tolerance value. They model bearings as general joints with translations fixed and rotation free. Some of the contacts that are automatically created are removed to allow the bearings to rotate. The linear drive is a very complex part whose internal operation is not relevant to the stiffness of the mirrors; it is replaced by a very stiff spring to simplify the model and reduce computational time.

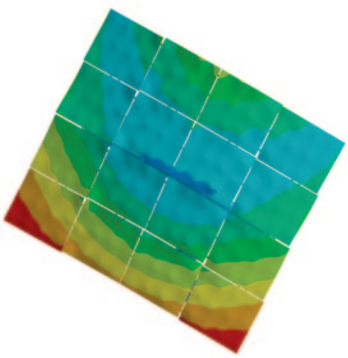
The edges of these mirrors can experience large forces due to airfoil effects when the wind blows against the side of the structure. NEM engineers slice the mirror surface into a number of subareas and apply forces to each of these areas based on the results of wind tunnel testing. A gravitational load is also applied and a boundary condition is used to model the support of the heliostat by the foundation.

NEM uses plastic deformation calculations on small sections of the model to account for permanent deformations of the structure. These effects normally are very small and have minimal impact on overall structure deformation, but they require a considerable amount of computational resources to perform this nonlinear analysis. NEM engineers typically perform plastic deformation on small sections of the structure to ensure that the permanent deformation is small enough that it will not affect the accuracy of the linear analysis used for structural predictions.

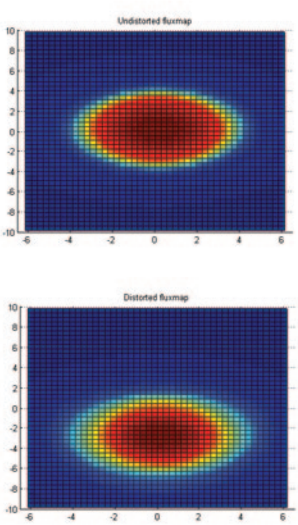
NEM engineers use ANSYS Parametric Design Language (APDL) command snippets to evaluate the model at different angles and wind speeds as part of a batch process. In a typical case, they set up a routine to run the model 50 times, which generates perhaps 50 gigabytes of output. The output is then exported to a ray tracing routine, which NEM engineers wrote in the MATLAB® programming language, that determines the impact of the structural deformation on the light reaching the receiver. The results are presented in the form of a flux map that shows the amount of energy received in different areas of the receiver. These results, in turn, are used by another MATLAB routine to calculate the potential amount of electricity that can be generated by each heliostat design. The R&D team compares these results to the projected manufacturing costs for the particular design to calculate its return on investment.



▲ Mirrors were meshed as shell elements.



▲ FEA results show deformation of structure.



▲ A MATLAB routine converted deformation into flux maps that show energy reaching receiver in tower. An ideal flux map (top) is produced by a perfectly stiff structure; flux map on bottom shows a more realistic case.

FUTURE PLANS

NEM plans to introduce computational fluid dynamics (CFD) with fluid–structure interaction (FSI) to model the interaction of the structure with the wind. FSI can improve analysis accuracy by applying the properly interpolated force on every node in the structure and by accounting for the impact of structural deformation on wind flow. Furthermore, FSI will substantially reduce the need for wind tunnel testing, which costs up to approximately 10,000 euros per day. Physical testing of the final design, however, is required as part of the certification process.

The company expects to increase its use of bucking analysis to reduce the weight and cost of the heliostat support structure. It is no secret that a tubular structure becomes stronger and lighter when you increase its diameter and reduce its thickness, but eventually you reach the point at which buckling becomes a critical failure mode. Buckling analysis can help to determine how far NEM can go in making the pillar and torque tube thinner, with the goal of reducing the steel mass of the structure while maintaining its strength.

Driving the steel mass down and designing stiffer optical systems is the key to delivering clean, cheap and reliable energy from the sun. Finite element analysis is helping NEM engineers to improve performance and reduce cost of the company's heliostat designs at a much faster pace than could be accomplished solely by building and testing prototypes.

Reference

[1] Wang, U. The Rise of Concentrating Solar Thermal Power. *Renewable Energy World*, **2011**, June 6.

With 200 different geometric bodies, it is an enormous job to manually create contacts, so NEM engineers use automation features in ANSYS Workbench.