FACILITATING RENEWABLES

ROTATING MACHINERY PLAYS AN ENABLING ROLE IN ADVANCING GREEN POWER

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Over the last twenty years, the renewable field has been incorporating traditional turbomachinery technology as it strives to achieve utility scale. For instance, combined cycles powered by gas turbines are now seen as an integral part of the renewable build up, since they have the flexibility to crank up and quickly step in when renewable power dips due to natural causes. In geothermal projects, small increases in expander efficiencies can have a significant effect on overall project efficiency, making these more viable and able to use low-grade heat.

Wind turbines are now in an advanced stage of using turbomachinery concepts. Novel blade designs are helping developers focus on bird-friendly options. Engineering practice perfected in traditional turbomachinery is being applied to increase the reliability of wind energy systems.

A classic case of renewable enthusiasts waking up to what cutting edge turbomachinery technology can do is solar power, which has so far been focused on small photovoltaic cell development. The next wave, however, is going to be hybrid solar-fossil arrangements.

Solar power generation may only represent about 0.2% of current generation capacity in the U.S. But that is going to change fast. The Edison Electric Institute has stated that solar accounted for 13% of all utility announcements this year, up from 6% the year before.

Paula Mints, an analyst at Navigant Consulting notes that at least 1 GW of solar projects were announced just on the first day of the Solar Power International convention in Anaheim, California, in October. She predicts anywhere from 5 GW to 8 GW to come online over the next five years, though it will not sustain its annual growth rates of 51%, which have prevailed since 2001.

Conclusion: The solar express train is coming. The good news is that turbomachinery will be very much involved.

Our surveys show that hybrid arrangements are attractive to utilities due to the ability to use existing assets in solar projects, says Cara Libby, a solar project manager at Electric Power Research Institute (EPRI; Palo Alto, CA). "This includes natural gas combined cycle and pulverized coal designs."

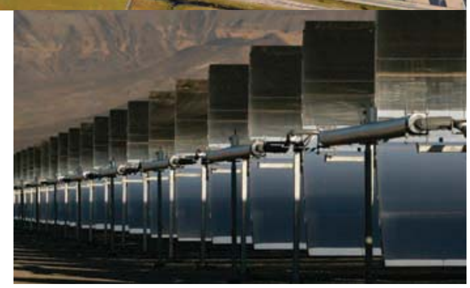

Figure 1: Florida Power & Light's Martin Plant (above) complex features 75 MW of solar that will work in conjunction with natural gas

Figure 2: A parabolic trough arrangement in Nevada

The heat is on

There are a couple of primary approaches to solar power. Photovoltaics (PV) use solar cells to convert the sun's rays directly into electricity. These are the flat panels one sees on rooftops. While they are deployed on residencies and commercial properties, utility scale PV operations are beginning to appear. As well as the DeSoto plant's 25 MW, there is 60 MW at a site in Spain, and a 62 MW facility under construction in Portugal. Grand plans for PV plants include 154 MW for Australia, and a 2 GW project in China that will be completed by 2019.

Of more interest to the turbomachinery industry is Concentrated Solar Power (CSP), also known as solar thermal. CSP harnesses concave lenses or mirrors to concentrate light into a small beam that is directed against a tube containing a working fluid of water or oil. The hot liquid is then used to operate a turbine

There is a wealth of technology options when it comes to CSP. Here are the two main ones.

A Solar Tower (or power tower) has an almost holy appearance due to the circular positioning of mirrors around a central tower. Two such towers have been built near Seville in Spain (one 11 MW and the other 20 MW). The mirrors direct heat received to the top of the 40-story tower where a steam turbine is located.

The turbine drives a generator to produce electricity. Heat is also stored in tanks for up to one hour via pressurized steam kept at 285°C and 50 bar. This subsystem is used to deal with cloud transients that interrupt normal solar plant operations. Four tanks can provide 50% load operation for the turbine. In addition, natural gas is burned to supplement power production, contributing about 12% to 15% of the total.

A parabolic trough is the most popular design, accounting for about 90% of commercial CSP applications, according to the analyst Mints. A 354 MW Solar Energy Generating System (SEGS) using this method is located in California's Mojave Desert and consists of nine smaller plants clustered together, operated by FPL subsidiary NextEra Energy Resources. SEGS combines a small natural gas turbine with a solar-steam turbine set up to supply power to Southern California Edison. Some 90% of the power comes from solar.

Sunlight is directed from the mirrors at a central tube containing synthetic oil which can be heated to more than 400°C. This heat is transferred to water to drive a steam turbine.

Another large CSP deployment is Nevada Solar One (Figure 2) with a maximum capacity of 75 MW and an annual output of around 134 milion kWh. It is situated south of Las Vegas and was built by Acciona Solar Power.

Parabolic trough is a mature CSP tech-

A GEARBOX SUITED FOR JET ENGINES

Brian McNiff, a consultant for the National Renewable Energy Lab (NREL) and owner of McNiff Light Industry, points out that a wind turbine is very much a piece of turbomachinery, though reliability remains an issue. As a result, all the major gearbox manufacturers are required by wind turbine manufacturers to test and run in their gearboxes prior to installation.

McNiff designs lifetime endurance tests at NREL's Dynamometer facility in Colorado. These tests are done on a wide range of wind turbine drivetrains and gearboxes at various speeds, using low or high torque.

This sort of testing is done with aircraft turbines, which have much higher quality requirements. Every helicopter gearbox, for example, is run in like this to avoid initial reliability issues.

This imported practice means that wind gear boxes are run in gradually so that the torque is also increased gradually and contact surfaces are placed under stress in a controlled and gentle manner. "In the field, the torque is much too erratic so you cannot run in the gear box so well," says McNiff. "This practice greatly reduces the risk of micropitting and scuffing of the gear box contact surfaces."

Another area where he sees a bleed in from the traditional turbomachinery sector is in material quality grades and finishes. According to McNiff, wind has found it necessary to adopt the fine material quality standards of the aircraft industry. The steel being used in gearboxes, for instance, has to be high grade and relatively free of impurities. "People do not want to go near them for six months except to change the oil," McNiff adds.

Auxiliary systems used in wind have also borrowed heavily from the mainstream power industry. In the past, wind turbine used single motor drives for their yaw and pitch systems, but they now use multiple drives. The Mitsubishi 2.5 MW turbine, for example, has six yaw drives and the Siemens 2.2 MW has six. "We have learned these lessons from the machinery industry that it is vital to share the load," says McNiff. "This also helps to keep component size down."

nology and has the lowest risk, says EPRI's Libby. "But other solar technologies should also be evaluated on a project-by-project basis. Power towers, for instance, can offer higher overall efficiency."

Meanwhile, Man Turbo is supplying a steam turbogenerator set with an output of 50 MW for the Spanish solar power plant Andasol 3 in conjunction with Solar Millennium. The double-casing machinery train with intermediate superheating was rated for use in this solar thermal application. The water-steam cycle was optimized and the steam turbine adapted to achieve improvements in efficiency.

A portion of the solar energy generated during the day is conducted into thermal stores. This permits power production to be planned and facilitates solar electricity generation at night.

Andasol 3 is a parabolic-trough power plant being built in Andalusia, Spain. Parabolic reflectors covering an area of 500,000 sq. m concentrate the sun's energy to heat thermal oil circulating in pipelines to just under 400°C. This heats water to produce steam in a second circuit via a heat exchanger. The steam is used in a Man Turbo steam turbine to drive the generator, which then supplies the electricity.

While steam and even gas turbines have played a small role in existing CSP deployments, the industry could soon be seeing a whole new level of solar-turbomachinery partnerships in the near future.

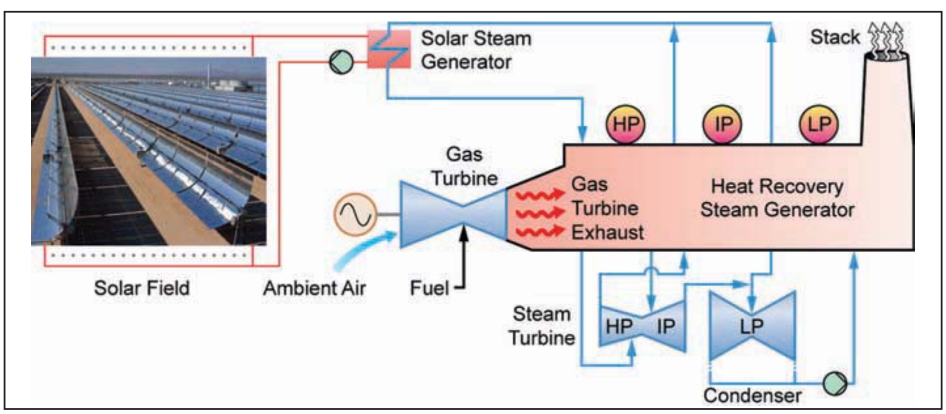

Figure 3: A hybrid system that uses solar power in place of duct firing

Hybrids serving utilities

Cris Eugster, Executive Vice President of CPS Energy — a municipally owned utility in Texas — plans to link up solar and wind in a hybrid arrangement. As wind blows mostly at night, and the sun shines during the day, he sees a possible synergy there which could work in the company's West Texas operations.

FPL is currently engaged in a more tangible project in Florida. Its Martin Plant complex (Figure 1) consists of over 2,800 MW. As well as a couple of 800 MW steam generating units, Martin includes two 480 MW combined cycle units and two 160 MW peakers.

At that site, the company is building the first hybrid solar facility to connect to an existing natural gas combined cycle power plant. Some 75 MW of solar will work in conjunction with natural gas as a means of displacing a certain percentage of fossil fuel usage.

At a cost of almost half a billion, this parabolic trough array will provide a heated working fluid to an existing steam plant. This will reduce the natural gas requirements at that facility which will have a net output of 1,050 MW. Around 180,000 mirrors will be spread across 500 acres, with construction to be completed by the middle of 2010.

Albiasa Corp. of Spain has announced a 200 MW hybrid project to be constructed at Kingman, AZ. Others in the pipeline of various utilities are scheduled for Victorville, San Joaquin and Palmdale — all in California.

The Albiassa project will pair a utility-scale CSP trough with an existing steam turbine, says Jesse Tippett, a director at the company. "You are going to start seeing turbine-based systems using all fuels including biofuels, with solar designed in from conception."

He believes the key driver for hybrids is as a means of intensifying the benefits, as well as mitigating the shortfalls of both sides. He laid out the pros of solar: it follows peak demand, 20-year fixed fuel costs, green. Fossil plants, on the other hand, have a much higher capacity factor and are based on proven technology. For example, solar provides most of its power between noon and 7 PM, with a peak in the middle of the afternoon. Baseload resources can be used the rest of the time.

A big plus for such schemes, at least in the U.S., might be an easier permitting process and lower installed costs. Hybrids are using land, resources and interconnectivity that are already in place. Hybrids should cost less than half a pure CSP operation, says Albiasa's Tippett.

USING LOW-GRADE GEOTHERMAL HEAT

Geothermal energy today includes combinations of electric power generation, heating and cooling. For electricity production, there are three basic types of geothermal power plants; dry steam, flash steam, and binary cycle. Interest in binary cycles has received a boost in recent times since these systems can use less expensive, lower temperature geothermal wells. The binary cycle power cycle operates at lower temperatures of about 225°F to 360°F.

While there are a large number of heat sources at this lower temperature, the potential thermodynamic efficiency is reduced, resulting in a high capital cost per kilowatt of power generated. Consequently, there is a great incentive to modify this cycle to achieve its maximum potential efficiency. In operation, these systems transfer the heat from the hot water to a secondary working fluid, usually an organic compound (refrigerant) with a low boiling point. This cycle is often referred to as an Organic Rankine Cycle (ORC).

The advantage of this cycle is that it is not necessary to operate the system at low, sub-atmospheric pressures, and associated high volumetric flow rates through the turbine and heat exchangers. In the ORC cycle, the pressurized organic motive fluid is vaporized in an unfired boiler heated by the hot water. The vaporized motive fluid is used to drive a turbine-generator, after which it is condensed, pumped back up to the turbine inlet pressure, and again vaporized in the boiler. The cooled water is injected back into the reservoir.

GeoTek Energy, LLC, a geothermal developer, and Concepts NREC, a provider of turbomachinery systems engineering, are developing a Gravity Head Energy System (GHES), which significantly increases the overall cycle efficiency by 20% to 30%. A major contributor to the improved overall cycle efficiency of the GHES is the application of a high-performance, compact turbo expander-pumping unit installed deep within the wellbore.

The expander is driven by the high-pressure motive fluid flowing down the well by gravity that has been heated by up-flowing geothermal brine. The expander is direct coupled to a brine pump and therefore provides the required energy to pump the brine to the surface. This configuration eliminates the electrical loads associated with the motive fluid pump and the production well geothermal brine pump common to the conventional geothermal ORC system.

A special design feature of the expander pumping unit is the complete isolation between the hot brine and the motive fluid. This is critical in order to avoid crossover contamination between the two streams. Due to the downhole location of the expander pumping unit, reliability and access for maintenance are also key features to the design of the unit and overall GHES. The motive fluid discharge from the expander flows back up the well with sufficient energy to feed a surface mounted turbine-generator and produce power. The surface turbine is designed to operate at the synchronous speed of the generator. This eliminates the need for an intermediary gearbox and its associated losses, says Concepts.

Meanwhile, EPRI is conducting research in conjunction with seven major utilities. Libby says that solar steam can be integrated into the main steam supply, Heat Recovery Steam Generators (HRSG), feedwater heating, cold reheat or in cogen. She cites benefits such as lower fuel usage, minimization of regulatory pressures, earning plant revenues through renewable energy credits, achieving higher cycle efficiency and the potential for lower cost compared to standalone solar.

EPRI has conducted a couple of conceptual design studies on hybrids — one gas and one pulverized coal. "Natural gas combined cycle and plants with duct firing are ideal candidates for hybridization. You can replace inefficient burning with a free source of steam."

Nevada Energy, for example, has announced a hybrid project for its Chuck Lenzie Station natural gas combined cycle 1,240 MW. Some 95 MW of solar will be added and replace duct firing (Figure 3). Construction begins in 2011 with completion scheduled for 2014.

Pulverized coal, though, can also be attractive due to impressive emissions reductions. Tri-State's 245 MW Escalante Station in New Mexico will pair up pulverized coal with 36 MW of solar.

Siting, though, requires careful consideration. Solar requires a lot of space — about four to eight acres per MW according to Mints. Further, ideal installation conditions are restricted to areas such as the American West, the Middle East and parts of India.

"Integration designs depend on site specifics," says Libby. "If you have to bring solar hot fluid a mile, for instance, it can drive up costs. So siting is important."

Solar cannot just be tied into steam and away you go. There are plenty of problems to overcome, though none appear insurmountable. Justin Zachary, Manager of Technology at Bechtel Power Corp., says the requirements of solar are quite different and that normal turbines are not designed for solar.

A typical plant might have 2,000 starts over its typical life, says Zachary. "Solar requires 360 starts a year for 20 years."

Steam concerns

Zachary laid out a series of possible Integrated Solar Combined Cycles (ISCC) configurations for solar integration. In ISCC, a steam bottoming cycle is used in a combined cycle plant to convert solar thermal energy into electricity. Zachary proposes that the size of the steam turbine be increased by up to 100% compared to a conventional combined cycle set up.

Temperature plays a major part in the choice of a specific configuration. For example, parabolic troughs provide temperatures in the range of 370°C to 385°C, while solar towers offer temperatures up to around 500°C. At the higher range, the solar steam field generation is close to the main steam conditions and therefore easier to integrate. As such, it can potentially be fed directly into the turbine. At medium temperatures, on the other hand, the solar steam should go to the High Pressure (HP) superheater.

The most efficient use of solar energy at the medium temperatures provided by parabolic troughs would be in supplementing saturated steam generation, says Zachary. "The least efficient usage would be in feedwater preheating or steam superheating."

Zachary also took a look at how to integrate solar with standard Rankine cycle steam plants. At HP CSP, the steam could be directly mixed with the main steam from the boiler to the HP turbine at a subcritical plant. However, he cautions that direct integration of medium temperature CSP in coal-fired boilers would encounter complexity and require advanced controls.

Hybrid systems must include indepth analysis of the transient behavior of the entire system, says Zachary. "Lack of experience with utility-scale ISCC means that control schemes must be developed to protect component integrity. While predictable, the intermittent nature of CSP steam creates a new set of requirements for conventional equipment integration."

Cesar Hidalgo Lopez, a solar consultant at GarradHassan GL, agrees. "The control system of a CSP combined cycle plant would be extremely complex," he adds. TI