Advances in Gas and Steam Turbines

Seeking higher efficiency and lower emissions

Increasing competition and mounting environmental concerns are forcing manufacturers of turbines, both steam and gas, to strive for significant qualitative and quantitative improvements in performance

Supercritical Steam Turbines

Competition from combined cycle plants has put considerable pressure on the manufacturers of steam turbines to bring about improvements in the efficiency levels. Utilities across the world (especially private developers) committed to burning coal want this higher efficiency without sacrificing on availability but at the same time minimising the lifetime operating costs.

The improvement in overall performance of steam turbines for thermal power plants can be brought about largely through two kinds of advancements. One, by improvement in mechanical efficiency by reducing aerodynamic and leakage losses as the steam expands through the turbine. Two, through improvement in thermodynamic efficiency by increasing the temperature and pressure at which heat is added to the power cycle.

The steam temperature can be raised to levels as high as 580 to 600 ^{O}C and pressure over 300 bar. Under these conditions, water enters a phase called supercritical with properties in between those of liquid and gas. This supercritical water can dissolve a variety of organic compounds and gases, and when hydrogen peroxide and liquid oxygen are added, combustion is triggered. The turbines based on this principle are called supercritical turbines. These turbines offer outputs of over 500 MW. Some manufacturers are planning to build and commission steam turbines of 800-1,000 MW output in the next few years.

These supercritical turbines can burn lowgrade fossil fuels and can completely stop No_x emissions and keep So_x emissions to a minimum. For example, lignite or brown coal has a high water content. So it is normally not used for power generation. Yet when lignite is added to water that has been heated to 600 ^{O}C at a pressure of 300 bar, it will completely burn up in one minute while emitting no No_x and only 1 per cent of its original sulphur content as So_x. This also eliminates the need for desulphurisation and denitrification equipment and soot collectors. Although large amounts of energy are required to create supercritical water, operating costs could be significantly different from existing power-generating facilities because there would be no need to process gas emissions. The demand for cooling water is also reduced, almost proportionally to the increase in efficiency.

Currently, supercritical power plants reach thermal efficiencies of just over 40 per cent, although a few of the more recent plants have attained 45 per cent. A number of steam generator and turbine manufacturers around the world now claim that steam temperatures up to 700^{O}C ("ultra" supercritical conditions) are possible which might raise plant efficiencies to over 50 per cent, but by using expensive nickel based alloys. Because supercritical water is so corrosive, expensive nickel alloys must be used for the reaction equipment and power generators.

The main competition to supercriticals is from new gas turbine combined cycle plants which are now aspiring to an overall efficiency of 60 per cent, making a huge difference in generating and life–cycle costs. However, the new gas turbines will release exhaust into waste heat recovery steam generators at temperatures above 600 ^{O}C, thus necessitating the use of the same high chromium steel and nickel alloys as are used in the more highly supercritical coal-fired plants.

But there continue to be doubts about the economic benefits of takings steam temperature above 635 ^{O}C, particularly when the costs of nickel-based alloys are taken into account. The extra costs of using nickel based alloys can probably be compensated by reductions in the amount of material required through thinner tube walls and smaller overall dimensions of both plant and site requirements. Efforts are also afoot to develop materials which can with stand high temperatures and pressures to improve thermal efficiency.

However, increased live steam pressure may lower potential for improved performance due to the implications of the auxiliary power consumption. In addition, increased pressure leads to a loss of thermal flexibility and this can also increase costs.

One way around this economic burden is to integrate a large industrial gas turbine into the steam cycle. This yields thermal efficiencies of well over 50 per cent and also introduces substantial fuel flexibility advantages. Supercriticals are beginning to be employed in combined heat and power plants as well.

Irrespective of Kyoto and the dash for gas, the combustion of coal to generate electric power around the world is actually increasing rather then decreasing. Moreover, anxiety about adequacy of future natural gas supplies is also turning attention towards coal-fired power plants once again. However, environmental and economic pressures to achieve higher levels of efficiency are driving utilities the world over, especially in countries which are heavily dependent upon coal as the major source of energy, to invest in supercriticals. Russia, Japan, the US and some European countries like Germany and Denmark are already using this technology extensively. In recent years, South East Asian countries like China, Taiwan, South Korea and Australia have also shown interest in supercriticals. In India too utilities like NTPC are considering using this technology to achieve higher efficiency levels in their new thermal plants.

Advanced Gas Turbines

The increasing competition in the gas turbine market is forcing equipment manufacturers to improve efficiency of their systems. Each one of the major players – GE, Westinghouse, ABB, Siemens – is engaged in a serious effort to develop advanced gas turbines.

The goal of these efforts is to develop high-capacity, low-cost, high-efficiency gas turbine systems with lower environmental emissions than existing units. The new turbines are aimed at operating at efficiencies of 60 per cent or greater.

The main features of these advanced gas turbine are:

- More efficient compressor stages with transonic blades.
- Higher firing temperatures.
- Advanced material to support higher hot gas path temperatures.
- Advanced cooling techniques to support higher hot gas path temperatures.

In the US, the efforts of GE and Westinghouse (now owned by Siemens) are being aided by the Department of Energy (DoE) under its advanced turbine systems (ATS) programme. The DoE has been pushing for advanced technology that would be both more efficient and cleaner than existing gas-fired systems. DoE is also funding the efforts of two more companies in developing advanced gas turbines. These are Allison and Solar. While GE and Westinghouse are working on 300 MW class units (Which will give outputs of 400-420 MW in the combined cycle mode), Allison and Solar are developing smaller units in the 5 to 15 MW range.

The specific objectives of DoE's ATS programme are:

- Efficiencies greater than 60 per cent on natural gas for large-scale utility turbine systems or a 15 per cent improvement in efficiency for smaller industrial systems.
- NO_x emissions lower than 9 ppm and CO and unburned hydrocarbon emissions lower than 20 ppm, without post-combustion clean up
- Fuel flexibility – potential to use coal derived and biomass fuels.
- Busbar energy costs 10 per cent lower than the best available turbine systems (in 1992) meeting the same environmental standards.
- Reliability, availability and maintainability equivalent to, or better than, current state-of-the-art systems.

GE and others are reportedly employing single-shaft, closed-loop steam cooling systems for their next generation advanced gas turbines. Closed-loop steam cooling utilises the superior heat transfer characteristics of steam compared to air and also enables better integration between gas and steam turbine cycles.

These turbines will operate at about 2,600^{o}F, an estimated 300 degrees hotter, than existing systems. To achieve this, new ceramic coatings, turbine-blade alloys, seals and cooling methods have been developed.

GE claims that its new "H" generation combined cycle turbine system will provide power plants with significant savings due to reduced fuel consumption. The time to recover the initial investment in a 400 MW plant, for example, could be reduced by as much as 20 per cent.

Unlike aircraft engines, which only have air for cooling, a combined cycle system has a ready supply of steam. In the "H" technology turbine, this steam is captured and used for cooling in the closed loop system.

The advanced gas turbines have also ushered in new technologies in related equipment like triple/four pressure heat recovery steam generators, reheat steam turbines, etc. with these advances, the per MW capital cost has come down drastically and so have operation and maintenance costs.

The battle for technology edge is expected to intensify over the next few years with the ultimate goal of achieving higher efficiency levels. Higher efficiency also translates into lower costs for consumers. It should be noted that, in the last five years, the price of turbine systems in the international markets has dropped by as much as 30 per cent.

Not only is a high-efficiency power plant more economical to operate, the fuel saving also requires fewer plants to be built to serve the growing demands for electricity.

Reference book:
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