Over the last ten years, the average cost and construction time of “greenfield” fossil fuel-fired power plants has been reduced by approximately 50%, even as their performance has improved. This is the result of technological changes and increased competitive pressures arising from the deregulation of power markets. This paper provides an overview of steps that have been taken by the power industry to respond to this challenge by designing and building standardized power plants based on sound technical solutions and optimized economics, with short preparation and construction times and a high degree of operational reliability. The paper deals with the key factors which have contributed to these changes: standardization of power plant designs; modularization; automation of power plant design; technological improvements; and the impact of these changes on design and manufacturing of power plants in developing countries. The paper discusses the advantages of the approach for the client and supplier.

Modularization Significantly Reduces the Costs of Thermal Power Plants. Compared with the customized approach for project design and construction, modularization can significantly reduce project-financing costs (by up to 10%) in three categories: detailed engineering and supervision, price contingencies and interest during construction.

Striving for “Tailor-Made off the Shelf”
The analogy of choosing between a tailor-made suit and a ready-made one illustrates the dilemma. Advantages and disadvantages of one over the other are experienced by both the customer and supplier. In the case of the power industry, “tailor” is the engineering designer and supplier of fossil-fired power plants. For many years, the market was one in which practically every power plant was designed and customized for the clients’ special requirements. Market price levels and project time schedules permitted this “tailor-made” concept.

Since the late eighties the market for power plants has changed dramatically. Market growth in plant additions has shifted from the industrialized countries in Europe, North America and Japan to the emerging countries in Asia and South America (notwithstanding...
recent tightening of investment flows). In these countries, utilities are typically faced with limited resources of capital that hamper their ability to deploy new technologies and to meet the power capacity addition requirements that can enable their countries’ economic development.

For the supplier of power plants, the key demands to be faced are project cost, construction time and risk guarantees (Figure 1). Project cost and construction time of coal and gas fired units have halved since the 80s. In relation to the construction and operation of these units, the supplier bears increased exposure to warranties and liquidated damages. To retain competitiveness, suppliers of fossil-fired plants have begun to develop and build standardized power plants based on sound technical solutions, optimized economics and repeated applications. Short preparation and construction times as well as a high degree of reliability during operation characterize these plants.

Developments Affecting the Costs and Commissioning of Fossil Fuel-Fired Plants

The Viability of Standard Power Plant Concepts

With only a few hundred power plants being ordered every year worldwide, global suppliers (less than a dozen), must generate and work from standard power plant concepts, which nevertheless have to meet a wide variety of operational conditions and requirements. The problem is complex since each client, even when refraining from substantial requests for individual design features, has nevertheless to specify its requirements in terms of characteristics of intended fuels, plant capacity, local ambient conditions of temperature and humidity as well as local emission standards. The client must then evaluate each supplier’s offer according to criteria of capital costs, efficiency, service, maintenance, etc. In some countries additional criteria such as cogeneration in combined heat and power plants (CHP) or district heating, as well as stringent conditions (e.g. available space, emissions, noise level, architecture, environmental permits) associated with the use of existing sites and their infrastructure must also be considered.

To determine the viability of using standard concepts for fossil-fired plants, a project database (developed by Siemens KWU) was used to analyze all combined, open cycle and steam power plants worldwide in terms of capacity (MW), fuel requirements, power system frequency and regional location. The database captures projected orders through 2005. The results of the analysis are described below.

Gas Turbine-based Systems 300-600 MW combined cycle plants seem to be the favored plant size in both 50 and 60 Hz markets (Figure 2). This is because utilization of more than one block improves economic viability, yet 300-600 MW fits well with the needs of most power systems and is relatively easy to finance.
Power systems in countries with relatively small installed generating capacity systems which require smaller capacity additions favor combined cycle power plants in the range 100 to 300 MW which can be easily accommodated with a large gas turbine and a steam turbine located on a single shaft. Countries with smaller grids or special grid requirements prefer multi-shaft combined cycle plants with several smaller gas turbines in the same power range combined with one or more steam turbines. In the case of more difficult fuels (e.g. fuels containing contaminants that affect their combustion) or customer preferences for robust, highly reliable technology, well-proven gas turbine products are preferred over more sophisticated units with higher efficiencies.

Countries with large grids and high power demand growth favor combined cycle plants in the range 600 to 2,500 MW which can be served by 2 to 6 parallel units either as single shaft or multi-shaft plants. For peaking power or power systems with very low cost fuels, gas turbines in an open cycle system serve the power range between 50 and 300 MW. Projections of orders shows the market fairly evenly divided between countries with 50 Hz or 60 Hz frequencies. However, given the projected growth in the U.S., the 60Hz market is now projected to have a moderately larger share than previously estimated. Power plant suppliers find it prudent therefore to have a product mix consisting of high performance GTs using natural gas as well as more robust plants using non-natural gas fuels.

**Coal-fired Steam Power Plant**  Only about 10% of steam power plants are projected to be ordered in 60 Hz markets in the period 1999-2003 (Figure 3). In the case of 50 Hz markets, the two most important power ranges are between 300 to 500 MW and 500 to 700 MW. The range above 700 MW with supercritical technology represents a small but growing share.

### A Standardized Approach

Basing their approach on such demand analysis of orders, equipment suppliers have developed standard plants. A standardized approach for combined and open cycle power plants is clearly more viable than for steam power plants. This is primarily due to:

- huge development cost limits all suppliers to a very restricted number of gas turbines for different power ranges.
- gas is a homogeneous fuel (compared to coal), so the designer does not need to take into account significant fuel quality variations

Siemens has defined twelve basic power plant concepts (Fig. 4); four of these are for open cycle gas turbine plants, six for combined cycle plants and two for coal-fired steam power plants (with sub- and super-critical technology). Each of these concepts covers a range of power, efficiency, and fuel specifications and also includes some modification for heat extraction. In designing these 12 basic power plant concepts designers generate the overall plant concept (design and lay-
Figure 4. Reference Power Plant Data

<table>
<thead>
<tr>
<th>Ref. Power Plant Type</th>
<th>Frequency</th>
<th>Output</th>
<th>Efficiency (%)</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gas Turbine Power Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GT PP 2.84.2</td>
<td>60 Hz</td>
<td>200-220 MW</td>
<td>33.5-34.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GT PP 2.94.2</td>
<td>50 Hz</td>
<td>300-320 MW</td>
<td>34.0-34.5</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GT PP 2.84.3A</td>
<td>60 Hz</td>
<td>340-360 MW</td>
<td>38.0-38.5</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GT PP 2.94.3A</td>
<td>50 Hz</td>
<td>480-510 MW</td>
<td>38.0-38.5</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td><strong>Combined Cycle Power Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GUD 1S.64.3A</td>
<td>50/60 Hz</td>
<td>100-105 MW</td>
<td>53.7-54.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GUD 1S.84.3A</td>
<td>60 Hz</td>
<td>250-260 MW</td>
<td>57.8-58.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GUD 1S.94.3A</td>
<td>50 Hz</td>
<td>360-380 MW</td>
<td>57.8-58.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GUD 2.84.3A</td>
<td>60 Hz</td>
<td>500-520 MW</td>
<td>57.8-58.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GUD 2.94.3A</td>
<td>50 Hz</td>
<td>700-760 MW</td>
<td>57.8-58.0</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td>GUD 2.94.2</td>
<td>50 Hz</td>
<td>470-480 MW</td>
<td>52.2-52.3</td>
<td>Gas/Oil</td>
</tr>
<tr>
<td><strong>Steam Turbine Power Plants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ST PP 300/450</td>
<td>50 Hz</td>
<td>2x300-2x450 MW</td>
<td>38.0-39.0</td>
<td>Coal</td>
</tr>
<tr>
<td>ST PP 500/700</td>
<td>50 Hz</td>
<td>2x500-2x700 MW</td>
<td>40.2-41.6</td>
<td>Coal</td>
</tr>
</tbody>
</table>

A first step towards a more flexible design is to provide options to the reference version for each major functional unit (Figure 5). For example, “via-ship” is the reference for the functional unit “coal supply” with delivery “via rail” as an option. Choosing the option in this case does not greatly change the remainder of the power plant. However, in the case of the functional unit “boiler”, the reference is a supercritical once-through boiler and the option a subcritical (drum-type) boiler. Choosing the option in this case requires modifications in the main steam line, ash handling, etc. Just as in the automotive industry, power plant designers have had to develop a limited number of platforms (basic power plant concepts) into which optional functional units and modules can be included as engines or special car seats are in a car platform, without signifi-

out), the system piping and instrumentation (P&I) drawings, the civil works, the design of the main components and major piping larger than 80 mm OD.

**Power Plant Modularization** Over the last decade, modular design, fabrication and construction of power plants has gained widespread acceptance worldwide. For the concept to be successful, the approach needs to be able to tailor each power plant as closely as possible to the client’s needs without requiring major redesign of key plant components. The subsequent question was how these conflicting requirements of standardization and customization could be molded into a successful approach. The Siemens’ approach to modularization is described.
cant changes to the platform itself. The key to flexible design lies in properly breaking down the power plant into adequate functional units and these units into modules such that most options will only directly effect a single module or, at the most, one or two in the surrounding system environment. This approach should permit requested modifications to be accommodated via selected options with minimal time spent on re-configuration.

Similarly, for a combined cycle plant, the functional units are arranged around the main components, the gas turbine and steam turbine. Even though the gas turbine itself is a standard product, this functional unit can be broken down into modules such as the flange to flange gas turbine and quite a few other modules, depending on fuel, local conditions, NOx requirements and service requirements.

**Design and Use of Modules** Both for combined cycle units and for steam power plants, more than 100 modules are defined. These functional units are treated as “black boxes” for which space is reserved in the basic power plant. Since the modules for combined cycle and steam power plants overlap, approximately 150 modules are needed in one to four options. The overall
A large database of project-independent modules has been built up. Each module file contains the P&I drawings, geometric information, bill of quantities, isometric calculation, schedules and associated documentation. To some extent, these modules can be prefabricated. Sometimes these modules (e.g. switchgear panels) are designed to be shipped in standard containers to the plant site. If, for a given project, a module with a given option is used, then a simple computer command, more or less a mouse click, is sufficient to link the neutral module to the specific project.

**Preconditions for Modularization** To realize the economic advantage of the modular approach, the client needs to permit the supplier to use this approach in bidding for a project. The approach uses a small number of basic power plant concepts with a finite number of modules and is applied by a supplier to a major share of orders for new plant.

In addition, for each individual module, the plant supplier tries to reach a common understanding of its specification with a group of sub-suppliers (following the suppliers’ own procurement guidelines) so that each sub-supplier can provide its optimized technical solution within the space and system limits. Worldwide procurement can be achieved and facilitated by requiring each sub-supplier to achieve his task within the module boundaries.

**Technological Improvements** In addition to the factors described above, technological deployment has lead to performance gains and cost reductions. Use of supercritical technology has achieved efficiency improvements in the range of 2-5% for coal-fired plants, compared to sub-critical technology. Changes in the firing temperatures can significantly increase gas turbine output and efficiency of gas-fired plants.

**Automation of plant design** Computerization is the key to modularization because of the enormous amount of data generated, processed and shared between differ-
ent groups involved in the engineering of modular power plants. Typically, computer applications include 3-D modeling, computer automated engineering (CAE), computer aided engineering design (CAD), scheduling, cost calculation, construction control, procurement control, cost control and document management. This ultimately results in time savings in engineering and construction as well as increased flexibility for the customer. This approach is state-of-the art in the supply industry for fossil fuel-fired power plants. The approach of Siemens AG is given below as an example.

A computer tool for planning and logistics was developed using commercially available software. This is schematically shown in Figure 6. It includes the use of a data bank, 2D and 3D graphic information software, software for plant structure, plant construction and control as well as another software for communication and work flow management. The management system for data and documents is the hub where all data and documents are stored and from where people engaged in a project wherever their location can search, copy, mail and store their work inputs and outputs.

Development of this software tool, flow analysis and testing, including all work specifications, required about 250 staff-years and 2.5 calendar years. The training program for staff is considerable and ongoing. In addition the system requires rigorous and timely inputting of data, an aspect that very experienced engineers have difficulty coping with as they have to adjust long established practices to a new way of working.

Impacts on Design and Manufacturing in Developing Countries Early indications are that this approach, combined with the impacts of globalization will cause more design and project management work to shift to developing countries. Most of the major power plant suppliers, are building up capability to design and construct modular power plants in developing countries. For example, Siemens KWU has moved its project design and management for projects in Asia and Australasia to its regional office in Kuala Lumpur, Malaysia. Detailed engineering design work for Siemens’ thermal power plant projects will be carried out by a subsidiary located in New Delhi, India.

Most OECD power plant suppliers are actively sourcing suppliers in developing countries; some have organized vendor fairs, in countries such as China, Philippines, Malaysia, Thailand, Brazil and Argentina. Because of repeat orders, the modular approach provides a longer than normal period in which to evaluate potential component vendors.

Conclusions

The development and implementation of a new basic power plant concept for greenfield fossil fuel-fired projects with a defined number of modules responds to the worldwide trend towards considering electricity as a commodity. As with other commodities, the market will reward low-cost electricity producers and their suppliers:

- For the electrical utility, the concept has lead to significant reductions in project implementation time and cost as well as in project risk. In addition, plant availability has been enhanced through the provision of reliable optimized modules at least cost.

- For the supplier, the concept has been a key feature in maintaining competitiveness during a period of price decline.

- The modular structure can also be of advantage when investigating replacement power plants for existing sites needing rehabilitation in built-up areas where greenfield sites are in short supply.
This paper is one of a series on fossil fuel generation technologies. The others are on super critical, open cycle, combined cycle and integrated gasification combined cycle technologies. Issues that are pertinent in developing countries are addressed. The series has been prepared by staff at Siemens KWU in collaboration with the World Bank.

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