EXPERIENCE IN INDIA/ASIA WITH SMALL-SCALE INDUSTRIAL STEAM TURBINES IN DECENTRALISED POWER PLANTS

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Abstract:

With the increasing prices of fuels, electricity and increasing public environmental awareness it is becoming more attractive for investors to build small power generation units, which use waste from their production as fuel for a small power plant or to install a small steam turbine to utilize an excess steam for electricity production.

The main focus of this paper is to examine some of the recent cogeneration projects in India and Asia where high-efficiency, single-stage, back pressure or extracting-condensing turbines with outputs of up to 2000 kW have been installed to power different industries and improve the economy of the plant operation. Experience with decentralised power plants in Europe will also be referenced.

The turbines are all characterised by simple modular construction for flexibility and ease of configuration and maintenance; their overhung design enables rapid transients.

The exemplified industries where these small power generation units can be installed include:

- Rice-milling, where rice husk is converted into useful energy;
- Vegetable oil milling, where oil waste is processed into useful energy;
- Wood-Fired Power Plants or Waste-Energy-Plants to assist in the disposal of urban wood waste, and the generation of heat and electricity;
- Heat-recovery applications
- Cogeneration Applications

The paper will examine the reasons for the choice of turbine model and the resulting impact of that choice on the particular industrial application.

In 2006, Siemens acquired AG Kühnle, Kopp & Kausch. With this acquisition Siemens extended its industrial steam turbine portfolio to provide efficient and cost effective solutions for small power generation units, which can be used in various industries and applications. Siemens continues to develop solutions for this market segment.
Introduction
The industrial power sector has witnessed a remarkable growth in the last couple of years. The global demand for power and energy continues to rise and related energy costs have kept pace. In fact, the efficient utilization of available energy sources has become essential. Many industrial companies are prospecting for opportunities and solutions for improving efficiency or reducing costs. Others simply rely on saving power supply, as in backward or remote areas where the free flow and quantum of power is constrained. This makes greenfield projects in remote areas interesting in order to secure own power requirements. Small-scale industrial steam turbines can be an instrument in meeting those targets.

Company history and locations
It was in June 2007 that the former AG Kuehnle, Kopp & Kausch (KK&K) became Siemens Turbomachinery Equipment GmbH, seven months after the formal acquisition date. KK&K was founded in 1899 and started the manufacturing of steam turbines in the early 20th century. In the last ten years there was a clear focus on turbomachinery, with steam turbines and compressors. The company was strengthened in the turbomachinery business by the acquisition of Schiele-PGW, HV-Turbo and TLT. The acquisition expanded the Siemens steam turbine and compressor portfolio in the lower capacity range, and increased the worldwide active fleet of turbines supplying power and steam for a variety of process industries. Including Frankenthal, the Siemens industrial steam turbine business has seven locations in five countries spread over the world.
Overview of Siemens steam turbine portfolio

The Siemens steam turbine business can now supply a comprehensive portfolio from a few kW (45 kW) up to 1900 MW. Siemens is market leader for industrial steam turbines from 5-200 MW and one of the leading suppliers in the utility segment. The newly created Siemens Turbomachinery Equipment GmbH extends the Siemens low-end range of turbines from 45 kW up to 10 MW. These innovative but economical pre-designed machines have a simple modular design which facilitates optimization of performance for the required application. They operate in diverse applications, from power generation, particularly cogeneration and renewable energy plants (biomass, waste-to-energy incineration, geothermal), through mechanical drive to gas expansion. Effectively these turbines cover the full load range up to 5MW and, by combining two machines in a parallel ‘Twin’ configuration, they can go up to 7MW. This unique technical solution allows controlled extraction and is a cost-effective and efficient multistage version of the single-stage steam-turbine design concept.

Classification of small-scale steam turbines (pre-designed)

Small-scale industrial steam turbines can be instrumental in meeting targets of improved efficiency or reduced costs in decentralised industrial power plants. Mainly designed as single-stage turbines in a range up to 5 MW and with rotor speeds up to 23,000 rpm, they are ideal for use in public electricity production as well as in industrial plants for driving generators or mechanical equipment such as pumps, compressors or fans.
The speed of single-stage steam turbines is generally notably higher than the speed of the driven equipment and they are therefore equipped with integral gear boxes. Integral gears keep the turbine relatively small, enabling a minimal floor space requirement in comparison with external gears. An additional advantage is that they allow the turbine rotor to operate at the high speed which is the key to superior efficiency.

The alternative so-called overhung design, where the turbine wheel is not located between the bearings, has only one shaft seal, instead of the conventional two, which reduces losses via leakage steam. High-speed pumps and compressors are often connected directly to the turbine without the need of a reduction gear. This reduces the bearing losses and the costs for spare parts. The special rotor-bearing design allows extremely rapid start-up times to reach full load, even from cold start.
Three major operating principles are used with the pre-design segment: the axial-flow machine with a single-stage action wheel; the Curtis design with a single-stage radial wheel and, for condensing applications, the so-called condensing module, a two-stage design which improves the efficiency in condensing applications with higher heat drops.

**Design program and new nomenclature**

The relevant steam turbines in our portfolio for decentralised power plants are our frames AFA, CFR TWIN with power outputs up to 7 MW. For plants where higher electrical output up to 10 MW is required, or for combined heat and power generation schemes requiring two
or more regulated extractions for heating purposes, the highly effective in-line configuration Tandem-series has been specially developed.

![Design program for decentralised power plants](image)

As of January, 2008, the STE turbines will be marketed under new names in accordance with the Siemens standard trademarked nomenclature, SST\textsuperscript{TM}, where the SST stands for Siemens Steam Turbine and the number represents a scale of ascending size (but not specific output).

<table>
<thead>
<tr>
<th>New names</th>
<th>Former Types</th>
<th>Description</th>
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<tbody>
<tr>
<td>SST-010</td>
<td>EPM</td>
<td>Gas expansion turbines</td>
</tr>
<tr>
<td>SST-020</td>
<td>SPM</td>
<td>Direct drive turbine (wheel mounted on generator shaft)</td>
</tr>
<tr>
<td>SST-050</td>
<td>BF / AF / CF Series</td>
<td>Simple construction, low maintenance horizontally/vertically mounted single stage turbines.</td>
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<tr>
<td>SST-060</td>
<td>AFA / CFA / CFR ECM</td>
<td>A or Curtis wheel single stage turbines, overhung design Module utilizing one of AFA / CFA / CFR modules</td>
</tr>
<tr>
<td>SST-110</td>
<td>Twin</td>
<td>Assembly of two modules on double pinion gearbox</td>
</tr>
<tr>
<td>SST-120</td>
<td>Tandem</td>
<td>Assembly of two or more turbines connected to double-end-drive generator</td>
</tr>
</tbody>
</table>

![New names Siemens pre-designed steam turbines](image)

**Industrial applications and decentralised power plants**

We can find various applications for STE machines worldwide. Many of the references are in India, China and South-East Asia, because of the prevalence of small-scale industries in those regions, but are by no means geographically restricted. Particularly in these areas, however, there are many advantages to the customer and his community

Applications are many and various. Some of the most typical industries are exemplified in this presentation:
- Independent power producers, e.g. waste-to-energy or wood-fired power plants, may want to utilise existing fuel or energy;
- Paper mills or textile industries need reduced steam for production;
- Refineries and petrochemical plants might need redundancy as an alternative to electric motors or have waste steam available;
- The sugar industry needs mechanical drives during harvesting season.
- Rice milling and vegetable oil mills where waste is converted into useful energy
- Pharmaceutical or chemical plants use their remaining steam for power supply
- Steel mills with industrial waste heat recovery and supply of process steam
- Chemical and petrochemical plants using their exothermal heat for powering of TG-sets or mechanical drives

Fig. 9: Use of exothermal heat to power a steam turbine
Benefits of decentralised power plants

There are many aspects to thinking about more efficient use of power. Production costs in all energy-intensive industries are driven by the increasing energy costs of, for example, fossil fuels. Global warming is an issue which affects everyone today. Political pressure is imposed on the use of renewables, which normally appears as different types of financial support for such projects. Though governments develop energy policies which commit them to higher standards in energy efficiency, it is, at the end of the day, only financial incentives which make a major difference. The worldwide demand for electricity is increasing not only in the industrial sector but also in private households. Last but not least the availability of unused energy sources in industrial plants is a factor to take into consideration. All those issues make it worthwhile to think more about the efficient use of energy.

The benefits of decentralised power plants for an IPP (independent power producer) are obvious:

- Security of energy supply is increased, and independence from the national grid
- Saving primary energy consumption as own sources like heat from an exothermal process can be used to supply premium energy in the form of electricity
- Own demands for electricity and process steam can be satisfied
- Transmission and distribution losses are reduced
- Transport costs and logistic problems are reduced as small-scale power plant can use the fuel from the immediate vicinity
- Energy bills are reduced and surplus electricity can be sold to the grid
- Additional profit can be made from selling GHG Certified Emission Reduction (CER) and from selling by-products (e.g. ash from rice-husk burning in Asia)

**Turbine requirements and constraints**

Power production is normally not the core business for customers of small-scale industrial steam turbines. To concentrate on their main product they need reliable, low-maintenance equipment for the power production. That means that to be successful with such decentralised power plants, the following requirements drive the project.

A problem frequently faced by end-users is the mismatching of equipment to the type and nature of their plant operations. So as regards the operational modes of the production on the customer side it is very important to clarify whether the turbine matches the specification (e.g. rough conditions, changing steam flow, start-stop operation,...). In fact, the integration of the turbine is not very easy: the design must be adapted sufficiently to allow easy integration into the plant and process.

Pre-designed steam turbines allow operation with ordinary steam parameters, which makes them extraordinary for use in decentralized power plants. The ability of these machines to run...
with dry saturated steam offers the opportunity to decrease investment costs as peripheral equipment such as superheaters can be minimised. Many customers are afraid of the high-speed rotors (running above first critical speed), which are necessary to achieve higher efficiency. This can be compensated by showing the experience on the manufacturer’s side (compressors always have high speeds and use the same gearbox, turbochargers in cars are smaller but run at even higher speed). Pre-tested machines give the customer the necessary confidence that the delivered machine at site is working properly. In addition, erection and commissioning times can be shortened. It has to be taken into account that many industry owners have very limited expertise and skills in practicing small-scale cogeneration techniques. This could be compensated by engineering companies doing the planning on behalf of the customer. Nonetheless, the operating of the machines should simply meet the requirements in decentralised plants. Remember the operation is not the customer’s main duty and core business. His staff should be able to run the machine without deep training being necessary and do not need to be experts in turbine operation. That alone keeps personnel costs low. Those low requirements are good arguments for small-scale turbines. In most cases this would be a long-term investment. So the financial aspects make a good case for power production from small-scale turbines. Future developments have to be taken into account but cannot be predicted easily. It is therefore preferable to have the potential for future changes in duty. Pre-design implies easy adaptation and low revamping costs.

**Experiences in Europe and transfer to other regions**

**Decentralised biomass plant, UK**

This Biomass Farming for energy is a proposal for a 2-megawatt power plant for the generation of electricity fuelled by energy crops. This is enough to run 2000 average households. The main fuel, miscanthus grass will, be grown locally offering diversification opportunities and long-term fuel supply contacts for up to 60 farms. A local Growers Group has already been established to co-ordinate fuel supply. Miscanthus is a non-invasive, sterile, perennial grass grown and harvested on local farms within a 25-mile radius of the plant. The Biomass Power Plant is designed to ensure there will be no additional noise nuisance above existing background noise during 24-hour operation.

Emissions have been voluntarily set to a higher standard than the regulatory requirements for air quality. There will be no visible steam pump or odour emitted from the stack and performance will be monitored by Stafford Borough Council. The plant saves 1 tonne per
hour of CO2 which would be emitted by generating electricity from fossil fuel. This plant design and concept is fully transferable to other regions in the world in the same manner.

**Decentralised waste-to-energy plant, Italy**

Besides the well known thermal incineration with dissipation Pyrolysis is a new and forward-looking process in the European waste-to-energy industry. It is an environmentally compatible process, permitting, with a purely thermal process, the transformation of compounds and of organic complex materials to simpler products. The pyrolitic process is different from the combustion process in a conventional incineration application, but the Rankine cycle itself is unchanged.

In the power block the hot fumes exiting from reactors of pyrolysis or from the combustion have a considerable energetic value. The products can be utilized as an energetic thermal source for feeding recovery boiler to produce steam, which can be expanded in steam turbine to produce electric energy.

In a typical Italian waste-to-energy plant the client selected the SST-110 (TWIN-CA 56) steam turbine with a high-pressure and a low-pressure part working according to the multistage principle. The high pressure steam coming from the reactor is reduced in a high pressure turbine down to an extraction pressure of 5.5 bar providing steam for an internal consumer of the plant. The remaining steam is reduced in the low pressure condensing turbine down to 0.2 bar. The turbogenerator set is designed for a normal power output of 4800 kW, feeding the internal consumers of the plant and supplying the remaining electricity into the
national grid. With the advantages of the existing modular steam turbine concept, Siemens is able to tailor the turbine exactly according to customer needs using pre-designed components.

![Diagram of SST-110 (TWIN-CA 56) in a waste-to-energy plant](image)

**Fig. 13: SST-110 (TWIN-CA 56) in a waste-to-energy plant**

**Project references in India and Asia**

**Heat recovery in a non-ferrous (NF) Metals Smelter and Steel Mill**

A steel mill in China, one of the biggest refined steel mills in the world with around 40,000 employees, has three converters. Via waste-heat boilers on each converter, the heat recovery produces saturated steam with live steam pressures between 10 and 19 bar. The total steam amount between 80 t/h to maximum 300 t/h is expanded in five steam turbines with generators 10 kV 50 Hz to an exhaust pressure of 0.4 bar and condensed in water cooled and air cooled condensers.

The advantage of distributing the steam on five machines is obvious. The turbines are decentralised and installed next to the converter in order to transfer the available heat source directly without distribution losses. Redundancy with five steam turbines is obviously higher than with one centrally installed steam turbine. Additionally, kilometers of steam piping are avoided, which would have to be installed to bring the steam to the central machine.

The total maximum decentralized electric output of the five turbogenerators sets is 30 MW, which is sent to the grid. The amount of steam and electrical energy produced depends on the
steel production cycle, which fluctuates heavily. The steam turbines are specially designed to follow the steam fluctuation.

The installed steam turbines are 1 x SST-060 (AFA 6 G6a), 3 x SST-110 (TWIN AFA 66) and 1 x SST-120 (Tandem AFA 6 G6a – AFA 6 Db)

![Heat recovery in non-ferrous metal smelter and steel mill](image)

**Cogeneration in a pharmaceutical industry, India**

A client involved in the pharmaceutical industry is manufacturing bulk drugs. Normally, bulk drug manufacturers have a boiler in their plant to generate low-pressure steam for drying the powders. The boiler used to be very small, as the steam required, ranged from 3 bar to 1 bar. The problem which kept this industry for long on its toes was the requirement for continuous power, to prevent outages, which would lead to wastage of costly material. The company was one of the first Siemens clients in this industry sector: he selected a large pressure-boiler and utilised the reduction in steam pressure from 43 bar to 3 bar to generate power for his plant in a straight back-pressure turbine, which at the same time provided the required steam for his various processes. This enabled the client to save diesel costs, the diesel generator being relegated to standby for additional or emergency power in the event of turbine loss. The Siemens SST-060 (AFA 4 G5a) was integrated as part of a retrofit, and successfully put into operation within a week, with minimum modifications of the plant itself. The steam turbine is operating trouble-free and generating the assured power of around 1,600 kW.
Decentralised Sulphuric Acid Plant, Rajasthan, India

A sulphuric acid plant for the commercial production of acid for the chemical industry was the first project in India to which Siemens supplied the first condensing SST-110 (TWIN) turbine. The turbine is operating trouble-free and the plant generates power for the whole site in island mode operation. At the time the plant was built there was no external power supply, and the power requirement had to be self-generated. Designed as an extraction condensing machine, the turbine is able to provide extraction steam of 8 bar for process purposes.

As an alternative the steam turbine could be coupled directly to a compressor and replace the electrical motor in order to save electricity. Complete trains with turbine, compressor and generator/motor are solutions for exothermic processes where the plant is started with the motor driving the compressor. When the process is running and producing enough exothermal energy the steam turbine takes over driving the compressor and the electrical motor is discharged.
Steam turbines in the sugar and comparable industries

A sugar factory produces a huge amount of bagasse out of its total crushing. This renewable waste is mainly used as a fuel source to provide process steam for the mill and electricity for own consumption or typically sold to the electricity grid. The sugar mill thus eases the load on the public grid and increases the profitability of its own plant. The resulting CO\textsubscript{2} emissions in this process can be regarded as equal to the CO\textsubscript{2} which the sugar plant needs during its growing phase. The sugar mills are independent from the national grid and are able to cover their own consumption. The prerequisite to this independence is the use of steam turbines with the following requirements: reliable and trouble-free, economical operation and easy maintenance. The steam is produced in boilers fired with the bagasse, at pressure and temperature higher than required in the process. It is expanded in the steam turbine, producing electricity, and then it is led into the process, where the energy contained in the exhaust steam is utilized in different ways. This is a very typical concept for backpressure steam turbines with common steam data of 32 bar, 380 °C and an exhaust steam of 1.5 to 2 bar. In the last few years, the Siemens facility in Baroda has provided many solutions for the sugar industry in the power range of 1200 kW. Steam turbines also gain particular importance as a topping turbine for generation of electricity in the extension and modernisation of sugar mills, when a new pressure-boiler plant is installed, and the existing steam turbines retained unchanged.

Besides the sugar industry, the Baroda facility provides solutions for the vegetable oil industry, rice mills or distilleries.
Bagasse fired sugar plant, Nandurbar, India

Shree Krishna Khandsari sugar mill is located in Taloda in the Nandurbar district of Maharashtra and had started its operations in the year 1973. Beginning with a production capacity of 200 tons per day (tpd), the factory since then has grown to the present capacity of 1100 tpd. Thriving on quality and supported by a committed workforce of 300 employees, it has managed to endure the competition posed by other sugar mills located in the nearby vicinity. The factory also produces Khandsari sugar with molasses as a by-product for use in other applications. The sugar cane is procured from suppliers nearby in Maharashtra and as the demand for the sugar product is high, the factory has excellent future prospects. Currently catering only to the domestic market, the factory is already planning for a distillery in the near future.

The turbine supplied to Shree Krishna Khandsari is used for captive consumption while the steam generated is used for the sugar process. The turbine is normally used for a period of five months mainly between November and March when the sugar crop is available. Apart from the cane crusher and sugar manufacturing unit, the steam turbogenerator set is the main equipment at the mill.

The steam, having an exhaust back pressure of 1.5 kg/cm$^2$[g] is used for sugar manufacturing process. The remaining power generated from the turbogenerator set is used for the house load of the plant. The SST-050 turbine, supplied from Vadodara has a nominal output of up to 3MW. In-house bagasse is used as fuel, which allows power to be generated at a very economical price compared to the charges paid to the electricity board.
The new turbogenerator was part of a refurbishment to help the customer to cope up with the increasing power requirements of the plant. It has improved the reliability of the complete sugar plant, and in turn has enabled the mill to be totally independent from the state grid (MSEB, Maharashtra State Electricity Board), which is plagued by constant frequency fluctuations as well as power shortage.

![Image: SST-050 at Khandsari sugar mill](image)

**Fig. 17: SST-050 at Khandsari sugar mill**

**Conclusion**

Growing energy demand and rising energy prices make investment in small-scale turbines economically viable. These turbines use proven, established technology where change is not radical, but consists of continuous technical improvements. As there is no indication that there is any development which could render the small-scale turbines obsolete, investing in energy production with a reliable small-scale turbine will be a sensible and lasting decision.

In the interest of plant operators, the main criteria for selecting adequate equipment can only be determined by the answers to the specific questions on technical standard and integration, economic operation, quality and quality control of the manufacturer, easy maintenance and fast troubleshooting capability.

From the national point of view, industrial island production means that national governments are liberated from part of their power generation investment burden, new markets for local energy equipment suppliers and manufacturers are created, more jobs are created and there is less environmental pollution.
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