Simulating steam turbines for power generation

1000 MW in the Test Lab

Figure 1: A steam turboset.

Figure 2: Rotor blades of a steam turbine.

Modern digital control systems for power generation steam turbines have very complex control functions. Testing turbine control functionality during commissioning is time-consuming and expensive, so the obvious solution is to use a simulator in the test lab at an early stage of the project. This also has the advantage that critical cases can be tested with no risk to the plant, and any faults can be detected by standardized tests and remedied at an early stage – important factors for ensuring high quality standards.

Modern Steam Turbines for Maximum Efficiency

More than two thirds of Germany's electrical power is produced by steam turbine generators. The situation is similar all over the world, and forecasts indicate that steam turbines will continue to play a significant role in power generation in the future. Reliability and efficiency are essential for maximum economy and minimum environmental impact. With over 40 years of experience, Siemens builds steam turbines ranging from a few MW to 1,900 MW electrical power. Today, with steam turbine temperatures of up to 600 °C and pressures of approx. 275 bar, power generation efficiencies of over 48% can be achieved. The fuel can be utilized even more efficiently with heat extraction. And when a steam turbine is combined with a gas turbine, efficiencies of over 60% can even be reached – a value that was thought to be impossible only a few years ago.

Turbine Control for Increasing Requirements

Reliable operation depends on a modern turbine control system that is engineered for each plant. The complexity of functions has steadily increased: software function plans of over 500 pages are not unusual.

Figure 3: Large steam turbine power plants are automated with the T3000® turbine control system from Siemens AG.

In Germany, ambitious goals for transitioning to renewable energy impose tough requirements on the power plants operating in the electrical grid. The increasing amount of fluctuating energy fed in from regenerative sources rarely matches consumer demand. And because there is a shortage of suitable electrical power storage, power plants have to be able to adjust their output to demand quickly. This requires control technology that can reconcile these requirements with the process constraints of steam turbines. The only way to cope with the complexity and high quality requirements is to use suitable simulators during development and to design the control technology to fit each specific power plant. If the control system has been optimized in the test lab, it can be commissioned more quickly, cutting costs and avoiding life-shortening tests with the actual turbine. Moreover, no power plant operator would ever risk trying out untested control functions on a turbine.

Simulating a Steam Turboset

Testing the control system requires not only a model of the steam turbine, but also models of the generator and the electrical grid, so that all the functions can be tested realistically. A typical steam turbine consists of a high-pressure (HP) section, an intermediate-pressure (IP) section and a low-pressure (LP) section, which together drive a common shaft. The steam produced in the boiler (steam generator) first flows through the main steam valves into the HP section. Then it is superheated again before being fed through the intercept valves to the IP and LP sections. The steam cools in the condenser and the water is fed back to the steam generator via the feed water pump. The generator converts the shaft's mechanical energy into electrical energy and feeds it into the electrical grid via a transformer. The simulation model must therefore contain all these components, plus a simplified model of the electrical grid. This is essential in order to simulate normal operation, from starting up the turbine to its rated speed, to synchronizing the generator with the electrical grid, to loading the turbine to rated power. If other power plants drop out, the steam turbine's performance has to be increased rapidly and automatically

> "The dSPACE Simulator together with the MATLAB/Simulink models fulfills all our requirements. We can easily switch between different turbine types and load a plant-specific parameterization. Now, in the test lab, we can detect and solve problems that would otherwise not have shown up until commissioning."

Michael Schütz, Siemens AG

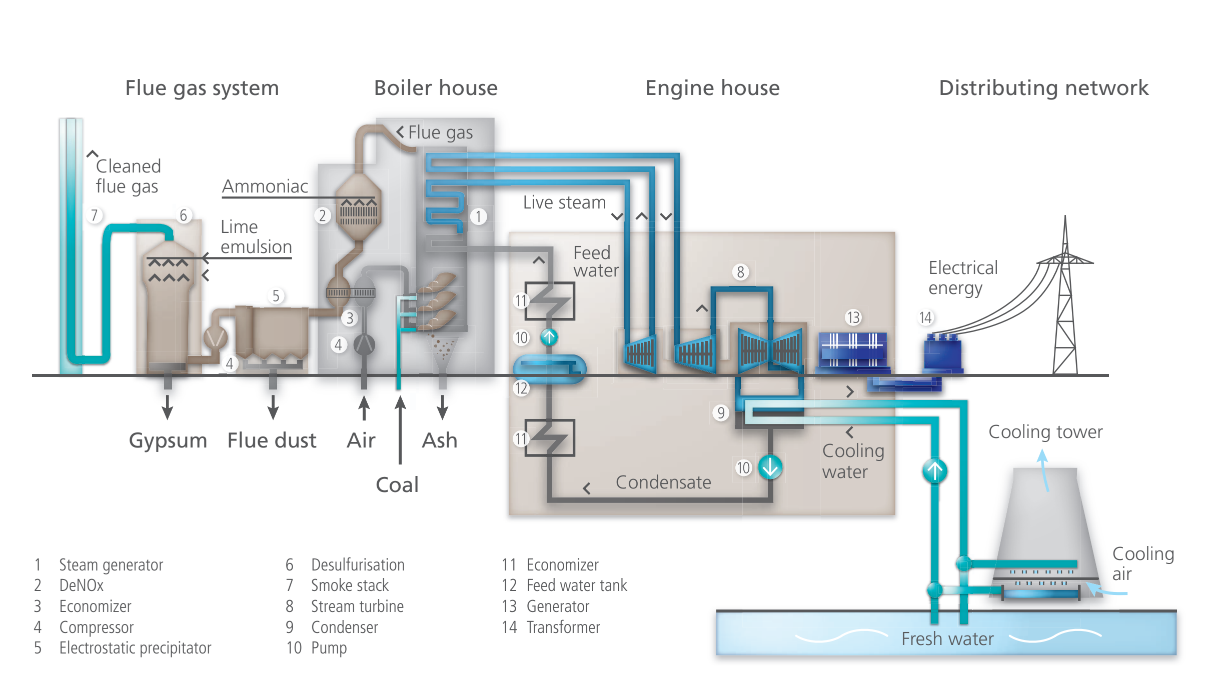


Figure 4: Overview of a modern steam power plant.

to support the grid. If an unexpected malfunction separates the power plant from the grid, load rejection has to be performed without tripping the turbine.

Requirements for the Real-Time Simulator

Siemens engineers drew up specifications for the real-time simulator that would simulate the steam turbine.

- Validated, modularized models of all Siemens steam turbine types
- Simple, plant-specific parameterization
- Real-time capability with a step size of 1 ms for fast transients
- Signal conditioning for direct connection without adjustment to the control system
- Flexible adaptation options
- Convenient human-machine interface for sequence control and documentation
- Interface to MATLAB®/Simulink® for exchanging models and the results of simulation or measurement

The dSPACE Simulator

Siemens chose a flexible dSPACE system. With the DS1005 PPC Board, it is no problem to compute the model of the steam turboset with

Figure 5: To test the digital control system, the simulator and the control system exchange signals such as the speed, power, main steam pressure, and actuation and position feedback for each valve.

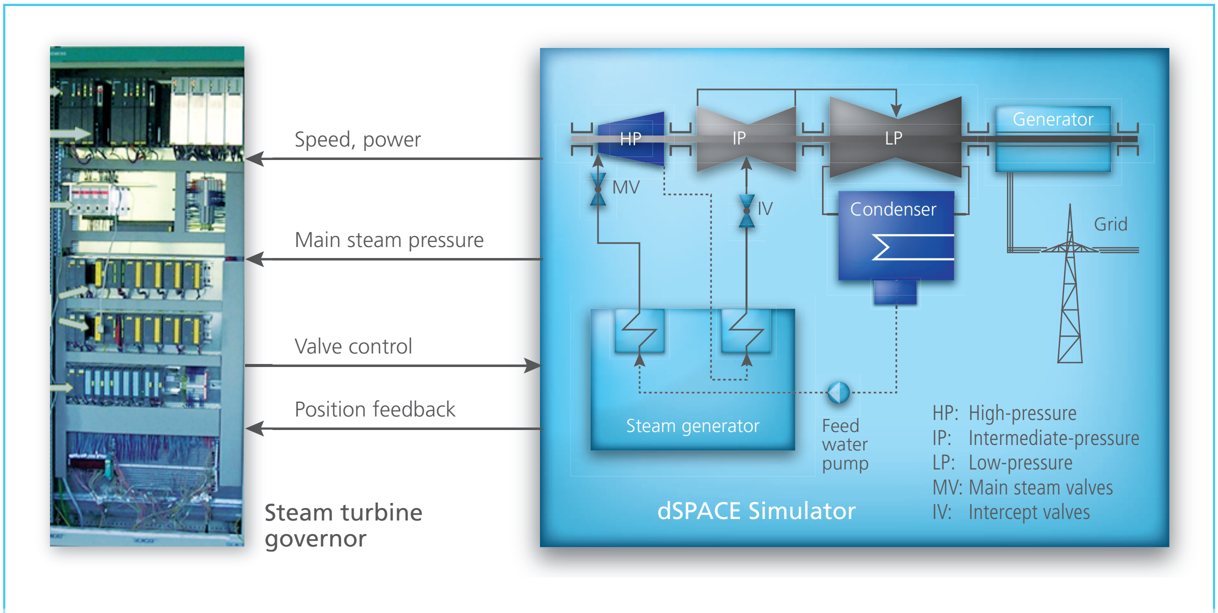


Figure 6: Test lab assembly with simulator in the laboratory.

over 50 state variables at the required step size of 1 ms. Two I/O boards for input and two for output, each with 32 analog channels, provide the numerous analog input and output signals necessary for connection to the turbine control system. Three I/O boards with digital channels supply the turbine's binary signals and rotary impulses. All the boards are installed in a dSPACE expansion box. Buffer amplifiers provide potential separation and adjustment of the analog signals. The digital signals also have electrical isolation and protection.

Working with the widely used MATLAB/Simulink software simplifies cooperation with other Siemens departments that are involved in the complex issue of steam turbine control. It also makes it easy to validate the models and parameters by means of measurements made on an operating plant.

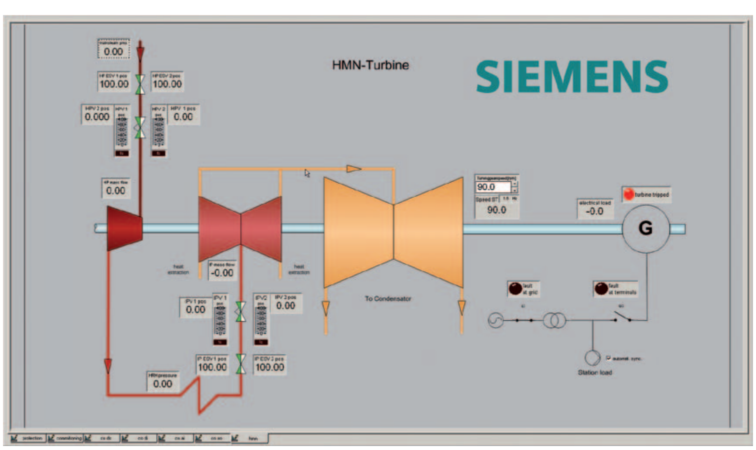
Human-Machine Interface

The simulator was given a dedicated graphical human-machine interface for each plant type, with a bilingual display to meet the requirements of the international power plant market. Turbine ramp-up to nominal speed, generator synchronization with the grid, and load operation are simulated with the aid of switches and inputs on the connected control system. Numerous other features provide comprehensive testing options, both in normal operation and in failure. All signals can be recorded and analyzed.

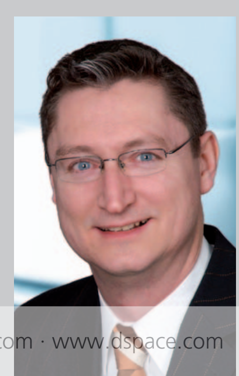
Passing the Test

A typical test begins by starting up the steam turbine to its rated speed, which is usually 3,000 rpm, corresponding to 50 Hz. When the volt-

Figure 7: All the relevant variables can be monitored with the human-machine interface of a simulator that simulates a turbine with HP, IP and LP sections and valves.



Martin Bennauer
Martin Bennauer coordinates the development of the simulator and is responsible for the steam turbine controller at Siemens AG in Mülheim an der Ruhr, Germany.



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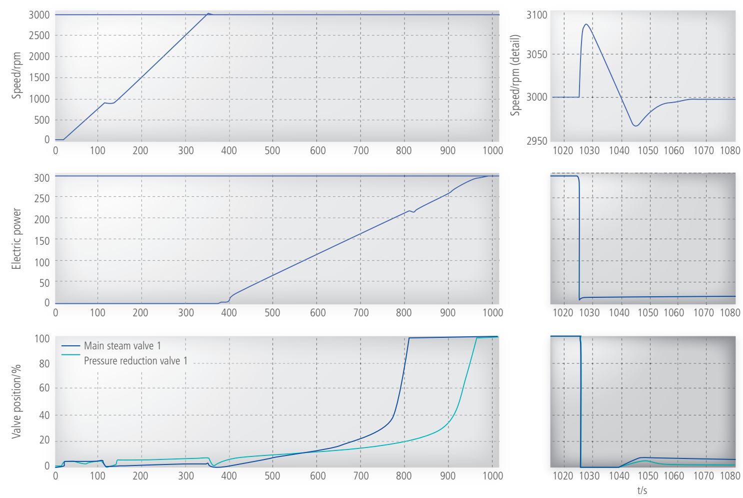

Figure 8: Only slight valve openings are needed to drive the turbine up to its rated speed. The intercept valves are initially closed and open after the main steam valves. After synchronization to the electrical grid, the turbine is loaded to full power (left). When the power plant is disconnected from the electrical grid, the electrical power drops sharply to the low house load (right). Because the valves close quickly, the speed rises to the uncritical value of approx. 103 % before it reaches a steady state with good damping.

age, speed and phase position are correct, the generator can be connected to the electrical grid and the turbine can be loaded to full power. If the steam turboset is disconnected from the electrical grid due to a grid fault while running at full power, the pressure must be reduced to the power plant's house load. The main steam and intercept valves have to be closed fast to avoid impermissible overspeed. At first the quantity of steam within the turbines increases the speed. At the same time the house load of the power plant has to be provided. This depends on keeping the speed within the permitted range. If the valves closed too late, causing impermissible overspeed, protection systems would activate to prevent any threat to the turboset. However, the plant would then shut down and would no longer be able to supply its house load. ■

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Conclusion

The simulator is also ideal for customer acceptance tests and for training. The complex functions of the digital control system can be optimized and demonstrated even before commissioning. When a plant is modernized, the simulator is flexible enough for quick adjustment, and it helps develop and optimize control functions.
As the next step, the model will be extended by including further control loops. Engineers will also investigate whether testing can be further optimized by test automation.

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